PRIMES scenario analysis towards 2030 for Belgium

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Abstract

During the period 2006-2007, the Belgian energy future has been investigated by the government-appointed Commission Energy 2030 (CE2030). To establish the necessary insights, different scenarios have been defined, run and interpreted. The scenarios have been performed with the PRIMES model. In this paper, the philosophy and the results of the scenarios are explained. Three scenario types are discussed.

First, as usual, a **baseline** is considered. This baseline, which assumes all the legal boundary conditions (in terms of obligatory measures, rules etc), serves as the reference against which the other scenarios are measured. All alternative scenarios are based on one simple driver: obligatory reduction of CO_2 or GHG; no other measures were imposed exogenously. As a second scenario type then, only **domestic energy-related CO_2 reductions** for Belgium were imposed; no interaction with the outside world was permitted on a CO_2-trading level (i.e., no flexibility mechanisms could be used). Eight cases have been considered: 15% and 30% CO_2 reduction, each time with the nuclear phase out implemented or lifted, and with or without the availability of Carbon Capture and Storage (CCS). These simulations can be considered as transparent but unrealistic (while at the same time favouring better understanding). Domestic reductions are shown to be very challenging, turning to (unrealistic) extreme values in case nuclear power is not allowed and CCS is not available. Next, as a third group, a different "limiting case" has been considered: overall **European-wide GHG reduction** by 30% compared to 1990, with a cost-effective allocation of emission reductions amongst EU member states. This approach could also be considered as the result of an idealized and perfect flexible mechanism in place on European territory (translated through a common emission-allowance value). Viewed somewhat differently, these simulation results could be used to appreciate the consequences for individual member states if it were assumed that there would be an equal emission-reduction responsibility for all member states. Although equal responsibility could also be considered as an unrealistic assumption, it gives interesting insights nevertheless. CCS is assumed not to be available; and the Belgian nuclear

phase out is implemented in one case and lifted in another. These simulation results show that considerably less CO_2 emission reductions take place in Belgium in case of a nuclear phase out; this signifies that phasing out nuclear power has a large opportunity cost in terms of CO_2 emission reduction (certainly if equal responsibility is assumed).

Comparison with the now known EU Commission proposals for reduction of GHG by 2020, shows that the CE2030 scenarios give a good estimate of what is to be expected under those European requirements. These last ones can more or less be situated in between the two types of alternative scenarios considered by the CE2030: a generalized Emission Trading Scheme (for the major industries, including the power sector) without burden sharing, and full auctioning by 2020, and still challenging GHG reductions (15% for Belgium compared to 2005) for the non-ETS sectors, basically to be established domestically. The reader is allowed to draw his own conclusions, but it is clear that the future energy provision in Belgium needs a clear long-term vision and will in any case be very challenging.

1. Introduction

The Commission ENERGY 2030 (CE2030) of Belgium was formally set up by the Royal Decree of December 06 2005. Its main objective was to "*provide the scientific and economic analyses necessary to evaluate Belgium's options with regard to the energy policy up to 2030*". Furthermore, it is stated that the study will "*specifically focus on the economic, social and environmental aspects associated with the various options or scenarios for investment policy involving production, storage and transport while bearing in mind the different types and sources of renewable and non-renewable energy as well as examine the issues of security of supply, energy independence and technical feasibility*".

To be able to fulfill this objective, a set of energy scenarios with horizon 2030 were performed. The Commission ENERGY 2030 was not commissioned to perform own research work or modeling-development. The existing model PRIMES has been utilized to execute energy scenarios with plausible constraints and policy options.

In this paper we discuss the scenarios and the immediate interpretation. Although in the final report of the CE2030, also some post-scenario considerations have been offered and policy conclusions have been drawn, such less tangible aspects are beyond the scope of the present paper.

First, as usual, a *baseline* is considered. This baseline lets the energy system evolve based on existing legislation & measures and boundary conditions. In the baseline for Belgium, this means that no post-Kyoto limits are set and that the nuclear phase-out law is assumed to be fully enacted. A variety of other scenarios has then been considered, whereby two approaches have been taken.

- In a first approach, eight variants, with a *domestic* energy-related CO_2 emission reduction by 15% and 30% in 2030 compared to 1990, and with each time the nuclear phase out enacted or lifted, and with CO_2 capture and storage (CCS) assumed to be available or not, have been performed. In this case, Belgium is considered as an "island" without possibilities to enjoy flexible mechanisms of whatever sort.

- In a second approach, an *EU-wide reduction* by 30% of Greenhouse Gases (GHG) is imposed, with a cost-effective allocation of emission reductions amongst EU member states, whereby it is investigated then how the Belgian energy theater responds to such obligation. In this second approach, Belgium can be considered as being merely a "province" in Europe, with full flexibility to interact with other European regions to fulfill its part of the obligation to reduce 30% GHG in the EU. If in addition, it is assumed that Belgium has an equal reduction *responsibility* by 30% GHG compared to 1990, then besides domestic reductions of GHG, the balance of the required reduction can be compensated by emission reductions abroad, by purchasing emission allowances.

Because of space constraints, this paper only describes the main findings of the scenario analysis. A more complete description can be found in the final report of the CE2030, [CE2030, 2007], which can be consulted at:
http://www.ce2030.be/public/documents_publ/CE2030%20Report_FINAL.pdf

A detailed account of the scenario analysis is provided in the reports dealing with the PRIMES results under the responsibility of the Belgian Federal Planning Bureau [FPB, 2006 - Sept] and [FPB, 2007].

The Preliminary Report of the CE2030 has been reviewed by a set of Review Panels, reflecting a large cross section of the relevant societal actors of a national nature, and the Commission EU – DG TREN and the IEA as international review panels. The CE2030 has analyzed and evaluated the comments made and has taken into account the relevant and pertinent remarks for the final version of its Report.

In line with the Royal Decree, this Final Report has been submitted to the Minister of Energy on June 19 2007.

2. Current energy situation in Belgium in a nutshell

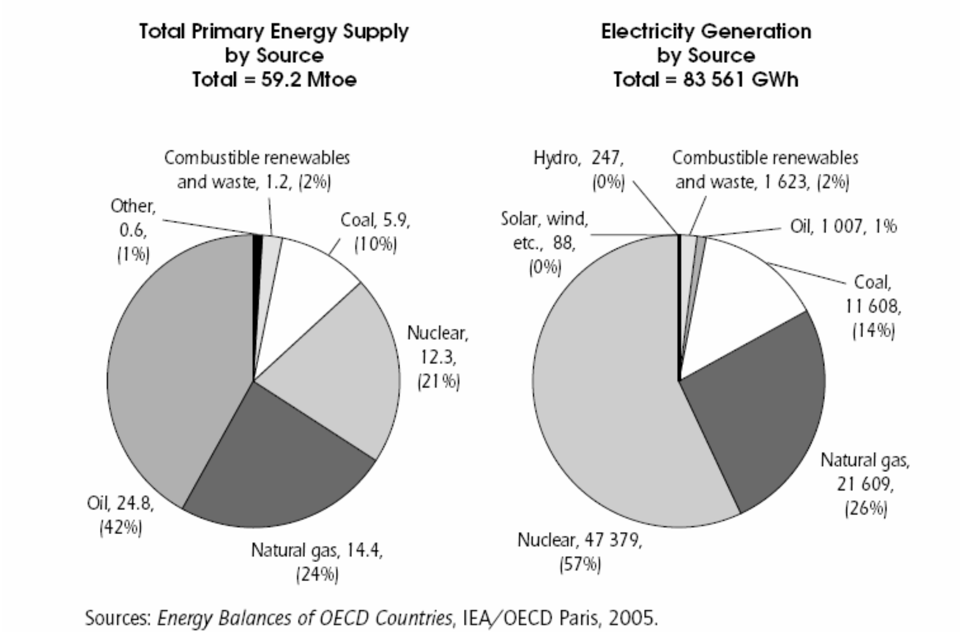
To better understand the results of the scenario analysis performed, some information on the current state of affairs in Belgium is helpful. For the sake of this paper, we limit ourselves to some general numbers and orders of magnitude to allow easy interpretation of the results of the scenarios. A comprehensive “summary” is available in the final report of the CE2030. [CE2030, 2007]

In addition, the IEA Review [IEA, 2006a] gives a quite accurate and complete picture of the state of affairs end 2005. Also, relevant information can be obtained from the website of the Ministry of Economic Affairs, DG Energy at http://mineco.fgov.be → Energy.

Additional interesting information on the current state of affairs in Belgium for electricity and gas, can be found in the Indicative Programs for Electricity Generation [CREG, 2005], the Indicative Plan for Supply of Gas [CREG, 2004 and the Development Plan 2005-2012 for electricity transmission [ELIA, 2005]. Also as general background documents, we mention the report of the AMPERE Commission [AMPERE, 2000] and the Fraunhofer study [Fraunhofer, 2003].

2.1. Primary energy mix

The decomposition of the Belgian primary energy mix is presented by a typical pie chart, as shown in Figure 1 (LHS). The exact percentages are shown in the figure; in orders of magnitude, we have for the primary energy mix: oil 40%; gas 25%; nuclear 20%; coal 10%, which points to a quite well-balanced mix, although the dominance of oil, and the negligible share of renewable sources are to be noticed.



Sources: *Energy Balances of OECD Countries*, IEA/OECD Paris, 2005.

Figure 1. *Primary fuel mix in Belgium (2005) in the overall energy provision (left) and in electricity generation (right). [IEA, 2006a] 1 toe = 41.868 GJ = 11.63 MWh.*

2.2. Fuel decomposition for electricity generation

Again, in orders of magnitude, the mix for *electricity* generation in 2005 was (See Figure 1 – RHS): nuclear 50-60%; gas 25%; coal 15%. Here, in contrast to the overall energy economy, the effective absence of oil is to be noticed. On the other hand (but as expected), the small share of renewables is in line with the LHS of the figure.

2.3. Greenhouse gas emissions

Under the framework Convention UNFCCC, each year, the Belgian state is required to submit a so-called national inventory report. Detailed information on the Belgian state of affairs can be found in those annual reports. See e.g., [NIR, 2007]. In what follows, some tendencies are summarized to give the reader an idea of the order of magnitudes involved for Belgium.

Figure 2 shows the evolution of GHG and CO_2 emissions in Belgium, referenced to 100% in 1990.[17] The Kyoto protocol (and the EU burden sharing agreement) requires that Belgium reduces its annual GHG emissions by 7.5% in the period 2008-2012 compared to 1990.

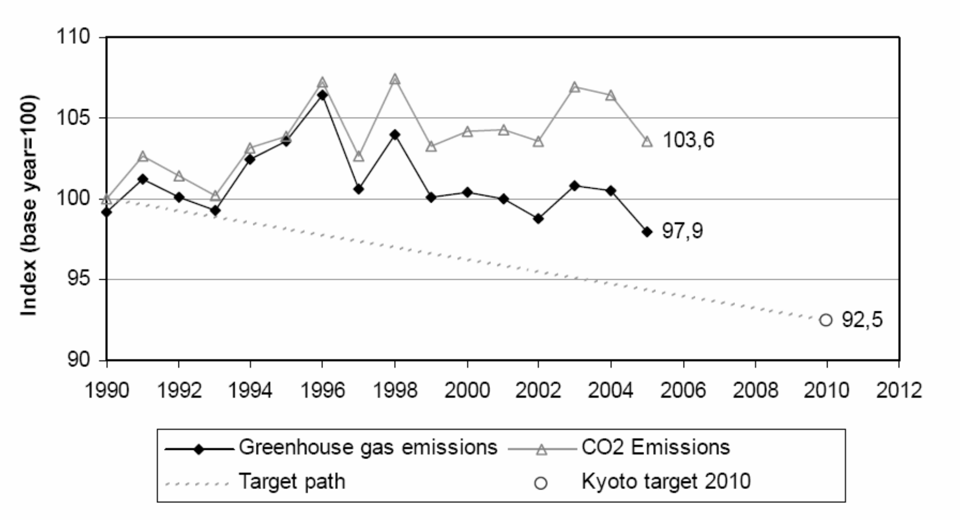


***Figure 2**. Evolution of CO_2 and GHG emissions in Belgium since 1990. [NIR, 2007]*

For consistency, we show the above information since that is the one that was available at the time of the finalization of the CE2030 report. In the mean time, the more recent submission of 2008 is available. (The 2008 submission is available at the same websites as [NIR, 2007], namely http://www.klimaat.be , http://www.climat.be.)

Because of the relative importance of the electricity sector in Belgium, especially because of the law on nuclear phase out by 2015, 2023 and 2025 (in three stages), it is instructive to show the evolution of CO_2 emissions of the electricity sector in Belgium, together with the additional emissions that would have taken place if nuclear power had been replaced by a mix of coal and gas in the same ratio already existing at that moment. This gives an idea of the avoided emissions, ceteris paribus. See Figure 3.

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[17] There is a slight deviation from the 100% reference in 1990 for the GHG because the reference year for some non-CO_2 GHG is 1995 and not 1990.

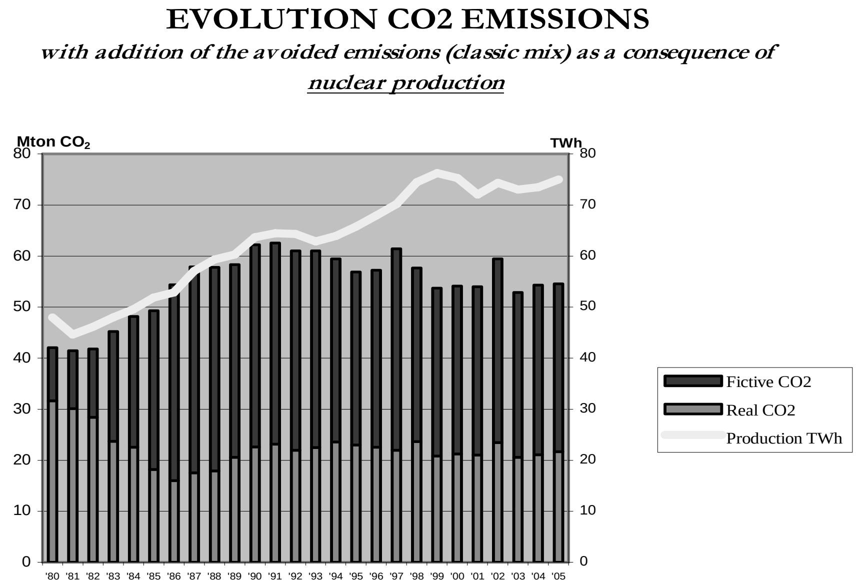

Figure 3. *Evolution of the electricity production and electricity-generation caused CO_2 emissions in Belgium. The dark bars show the CO_2 emissions that would have occurred if nuclear power had been absent and if electricity generation had been taken care of by a mix gas/coal proportional to the mix at that time.*

3. Definition of scenarios

3.1. Scenario model: PRIMES

For the underlying scenarios of the CE2030 study, the PRIMES model is used to quantitatively examine the energy outlook of Belgium in the period 2005-2030.

The PRIMES model[18] has been developed to make energy projections, evaluate scenarios and analyse the impact of energy-policy measures. It can be used to simulate trends in supply, demand, prices and emissions of pollutants for the various fuels, taking account of the fact that international energy prices and macroeconomic variables (GDP, disposable income,

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[18] See also Annex F of [FPB, 2006 - Sept].

inflation, interest rates and so forth) are incorporated exogenously. PRIMES is a partial equilibrium model because changes in the energy supply and prices and constraints on the emission of pollutants cannot in turn influence the economic sphere. PRIMES is a market-driven model which simultaneously simulates a balance between supply and demand both at a European level and for the 27 countries individually.

The PRIMES model is being developed and managed in the University of Athens (NTUA). More details about the PRIMES model can be found on the following web site: http://www.e3mlab.ntua.gr/downloads.php. Some elements on the date base are provided in [CE2030, 2007, FPB, 2006 – Sept]

It must be stressed that PRIMES only deals with the energy system and therefore only accounts for energy-related CO_2 emissions. (Other GHG are not considered by PRIMES.) Given the technical features and design of PRIMES, imposing a CO_2 constraint is equivalent to incorporating a variable which reflects the economic costs imposed by this constraint. This shadow variable is the marginal abatement cost (also referred to as *'carbon value'*) that is associated with the emission constraint. (For details, see [CEU, 2004; FPB, 2006 - Sept])

3.2. Goal of the scenario exercises

3.2.1. Philosophy of the baseline

The scenario analysis chosen in this paper starts from a baseline scenario, of the 'unchanged policy' type, that is set up to let the energy system evolve starting from the legally binding legislation and measures. In our analysis performed here, all regulations and existing trends up till 01.01.2005 have been taken into account.

This means that the baseline is not necessarily expected to reach the targets set by policy makers, such as e.g., x% of renewables or y% of CHP. Rather, this sort of baseline scenario can in principle evaluate whether the current regulation is sufficient to reach the set targets and objectives.

As already said above, the baseline is not designed to outline a desired future. On the contrary, the baseline will be shown to be unsustainable so that other scenario runs must be considered.

3.2.2. Philosophy behind the alternative scenarios

In contrast to the baseline scenario, the alternative scenarios considered for the purpose of the CE2030 evaluation impose desired targets or quota as constraints on the model, and it is then examined how the energy system tries to satisfy those constraints. Within the constraints imposed, the model will be guided by an economically optimal choice to satisfy the given demand for energy services[19]. From an analysis of the options chosen by the model, policy makers can then obtain inspiration as to which measures can be used to reach the desired objectives.

For the purpose of the CE2030 evaluation, it has been chosen to focus on the expected constraints that will be imposed to fight the Climate-Change challenge.

It must be noted that the CE2030 scenarios were defined in the course of 2006-2007, well before the CEU proposed its policy on January 23 2008.[20] The CEU proposals are mentioned later in this paper.[21]

In defining the alternative scenarios, we have been led by the "expected" post-Kyoto emission-reduction limits to be imposed by the EU. The CE2030 has focused on a 30% GHG/CO_2 reduction in 2030 compared to 1990 at the EU level.[22] As said before, to investigate what that means for Belgium, two approaches were considered:

(1) a domestic reduction of energy-related CO_2 emission, and the cost of such implementation;

(2) a European-wide reduction of GHG and identification of the in Belgium implemented reductions and the cost of such combined approach.

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[19] By "energy services" is meant the activities and applications we wish to enjoy: heat rooms to comfortable temperatures, keep food and drinks cool, drive kms, provide drive power and process heat in industry, etc. This concept here is different from the "services" provided by so-called "energy service companies (ESCOs)" or "audit bureaus".

[20] http://ec.europa.eu/environment/climat/climate_action.htm

[21] As a matter of fact, it will be observed that the CE2030 scenarios are not far off compared to the CEU proposals. Basically, it turns out to be well possible to evaluate the future Belgian situation based on the CE2030 scenario results.

[22] In this paper, the domestic scenarios are concentrating on energy-related CO_2 reductions only. The relationship with GHG reductions is considered in the CE2030 report. [CE2030, 2007]

In both cases, the influence of a nuclear phase out in Belgium is considered as an important factor; also the effects of the availability or not of carbon capture and storage (CCS) is investigated.

The first approach, with the constraint imposing energy-related CO_2 reductions on the Belgium territory, will demonstrate how difficult it is to obtain reductions beyond ~15% in the case of a nuclear phase out and if CCS is not available. In addition, running scenarios for an imposed reduction by 15% and 30%, next to the baseline in which effectively no post-Kyoto constraints are imposed, will allow to get an idea of the efforts required over the full range 0%-15%-30% if Belgium is faced with different reduction requirements (other than 0, 15 or 30) and if Belgium makes use of the flexible mechanisms foreseen under future post-Kyoto agreements.

In the second approach, which focuses on a 30% reduction of GHG on a European level, reductions of non-CO_2 GHG gases and CO_2 are first implemented in those countries where it is the cheapest according to the lowest marginal abatement cost. The distribution of the implemented reductions is determined by the principle of equal marginal abatement costs.

An important comment is in order concerning these alternative scenarios.

The first approach on domestic energy-related CO_2 reductions only, has the advantage of transparency, but it ignores non-CO_2 GHG and the efforts that Belgium could do abroad to satisfy its emission cut responsibility, unless this is taken into account in a separate reflective analysis. These domestic scenarios are therefore *transparent but unrealistic*, but they give a clear idea of the difficulty to perform domestic reductions.

The second EU-wide approach, on the other hand, seems to take into account everything (given that all details —especially the marginal abatement curves (MAC) for all GHG— of all EU countries are correctly represented in the model), but it may give the erroneous impression that the efforts by Belgium are moderate or even small compared to the other EU countries, in certain cases. These scenarios will indeed show that the emission reductions actually effectuated on the Belgian territory are small compared to the EU as a whole if nuclear power in Belgium is phased out and if CCS is not available. This is a consequence of a large MAC for Belgium in those cases, compared with the EU MAC for a given reduction percentage. This may not be interpreted that the economic effort by

Belgium would be small, since as said, the limited domestic reduction is merely a consequence of the high unit CO_2-cost reduction, and such reductions may still lead to a considerable total cost. If, in addition, however, one were to assume that Belgium should carry the same GHG-reduction *responsibility* of 30% (whereby the Belgian state must assure — somewhere somehow— a GHG reduction by 30% of its GHG emissions existing in 1990), then Belgium would have to complement domestic reductions with purchasing emission rights on the international market.[23]

3.3. Description of the scenarios implemented

3.3.1. The baseline — basic hypotheses

3.3.1.1. Belgian baseline as a part of the European baseline

The *Baseline* as defined for the CE2030 activities is in accordance with, and actually part of, the European Baseline developed for the EU Commission, DG TREN in November 2005 and published in May 2006, and developed with the PRIMES model. The European PRIMES Baseline treats the 25 EU countries[24], of which Belgium is one. The Belgian Baseline considered in the CE2030 activities, is a further detailed zooming in on the Belgian energy scene (as a part of the European system). Detailed information on the concept and the results of the European PRIMES series of Baselines is found in [CEU, 2003; 2004; 2006a]. The difference between the 2003/4 Baseline and the updated one of 2005/6 is to be found in higher fuel prices, and an update of the policy measures in many countries. In addition, the updated PRIMES version has as feature a (simplified) endogenous treatment of electricity and gas imports and exports, as well as trade in fuels between countries.

The same EU Baseline has also been utilized recently in the European studies EUSUSTEL [EUSUSTEL, 2007] and EURELECTRIC [EURELECTRIC, 2007].

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[23] The analysis of the Federal Planning Bureau [FPB, 2007] reports on a cost-effective physical allocation of emission reductions amongst EU member states, based on equal marginal abatement costs; it did not assume equal emission responsibility amongst EU members. However, the results available in [FPB, 2007] permit the evaluation of the extra cost if such emission responsibility is assumed, as has been computed in [CE2030, 2007].

[24] Sometimes extended to 28 or 30 countries.

In practical terms, the Belgian Baseline incorporates the nuclear phase out as specified in the law of January 2003,[25] and takes into account the *measures* that should lead towards satisfying the Kyoto protocol, without, however, imposing the 7.5% GHG-emission reduction as such. In any case, no post-Kyoto reduction limits are being imposed.[26]

Other typical features of the PRIMES Baseline, can be found in the references given above, especially [FPB, 2006 - Sept].

3.3.1.2. Economic activity and demand for energy services

A 'plausible' evolution for the Belgian demography and economic activity has been assumed. The relevant numbers for the different sectors can be found in [CE2030, 2007; FPB, 2006 - Sept]. These projections were based on EU forecasts, and long-term projections with the European general equilibrium (macroeconomic) model GEM-E3. [CEU, 2006a]. Figure 4 shows the assumed evolution of the GDP (which is the same in the alternative scenarios).

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[25] Belgian Official Journal (BS/MB Feb 28 pp 9879-9880).

[26] The Baseline does assume a flat carbon emission permit price of 5 €'00/ton CO_2 to reflect somewhat the European emission trading scheme for the sectors affected, and to include a variety of measures not easily explicitly translated into the model.

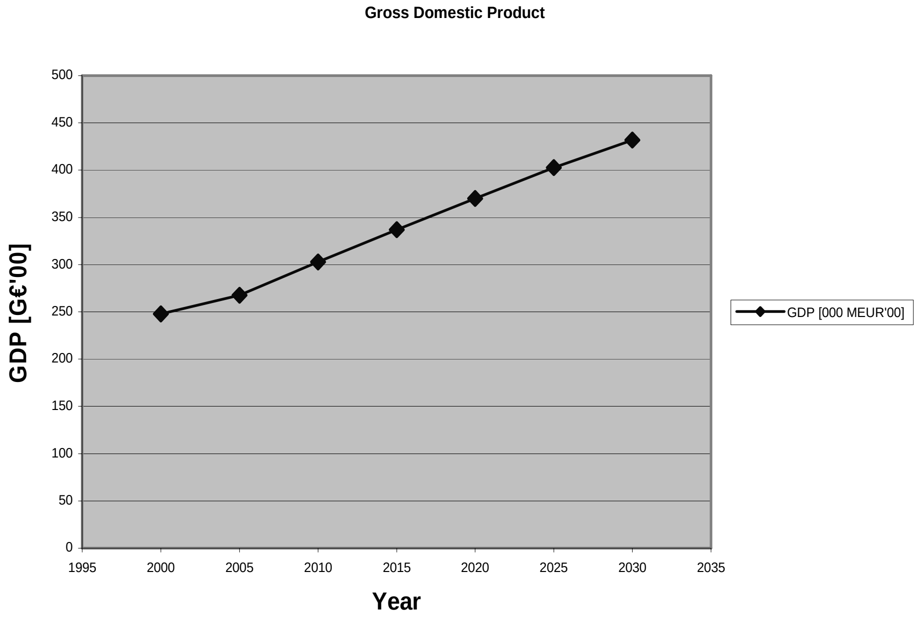

***Figure 4**. Assumed evolution of the Belgian GDP.*

The input assumptions for the transportation-sector evolution are expressed in passenger-km and ton-km and come from the EU SCENES transport network model. [SCENES, web] This model accounts for the capacity of existing networks and for infrastructure projects described in the TEN-T (Trans-European Transport Networks). [TEN, web] The input data can be found in [CE2030, 2007].

Those data have been considered as given in the CE2030 scenarios to follow.

A lower transportation activity would lower primary energy use and lower the cost of climate policy. However, most sources expect a strong increase of freight-transport needs and a more limited increase of passenger transport (except air transport). An increase in road transport will result from an increase of activities during off-peak periods. As a result, no further investments are needed. With different assumptions (level of transport activity or modal allocation), PRIMES would evaluate a different impact on energy consumption and emissions. An imposed "modal shift" in transport has not been analyzed in the PRIMES runs for the CE2030 study.[27]

From these assumptions, the PRIMES model derives the need for energy services in the different sectors, after which the market dynamics then assign the appropriate energy technologies on the demand and the supply side. The demand for energy services is affected by energy prices (including the cost for carbon emissions in case of carbon constraints, in PRIMES represented by a 'carbon value') through estimated price elasticities. Price elasticities are estimated on the basis of econometric analyses which reflect sensitivity (or consumption behavior) of economic agents to changes in energy prices. E.g., in the CO_2 constrained alternative scenarios to be discussed below, the 'carbon value' makes the model change the level of transport activity in reaction to higher energy costs. In other words, the transport activity in the CO_2 constrained cases is not the same as in the baseline, and this affects energy consumption and emissions of the transport sector.

3.3.1.3. Fuel price assumptions

Mainly to reflect the tendency of high(er) fuel prices, the PRIMES baseline of 2003/4 has been revised. (See also [FPB, 2006 - Sept].) It is not the goal of this fuel-price evolution to consider this as a 'forecast' of energy prices. History has shown that forecasting oil prices is effectively impossible, especially the fluctuations. The important point on these fuel-price assumptions is that 'given this evolution of fuel prices', the Baseline will react accordingly.

The price evolution assumed for the Baseline is as shown in Figure 5. [FPB, 2006 - Sept].

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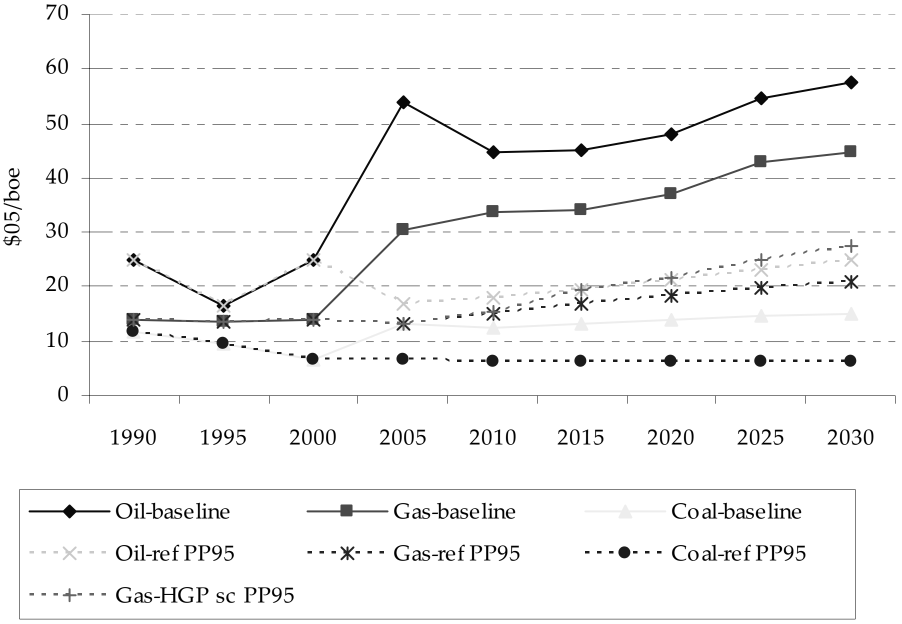
[27] A comprehensive study of a "modal" shift for transportation goes beyond the energy issue and should be undertaken in the realm of a full rethinking of the overall *mobility* issue (including logistics aspects of the economy, major infrastructure rethinking and investments, other approaches for residential and office, service & commercial building implantation and construction, and work-organization philosophies, etc) and this is well beyond the mandate of the CE2030. Also, a full European-wide approach should be considered as transit-type transportation is not negligible for a country like Belgium.



Source: NTUA (2005), PP95
refPP95: reference scenario in the PP95
HGP sc PP95: High Gas Price scenario in the PP95

Figure 5. *Comparison of international energy prices present baseline vs. scenarios in the PP95, 1990-2030 ($05/boe) [FPB, 2006 - Sept] boe =bbl oil equivalent*

The price evolution for the Baseline is shown in solid line, for oil, gas and coal. To see the difference with the previous EU baseline referred to above, and the earlier scenario work of the FPB (the so called PP95 study), these earlier prices have been shown in dashed line. [FPB, 2006 - Sept] Three important points are to be noticed.

(i) All prices are considerably higher than in earlier projections.
(ii) It is assumed that the oil prices will decrease till 2010, to start climb again (gradually) after that towards about 60$/boe (in constant $ of 2005).
(iii) The gas prices are supposed to partially follow the evolution of the oil prices.

Nuclear fuel prices include also the back-end costs. The overall simulation results are quite insensitive to the nuclear fuel cost.

In a variant to the Baseline, a situation with monotonously increasing prices is considered. This is discussed below.

3.3.1.4. Maximum assumed potentials

To reflect part of the Belgian reality into the scenarios, maximum 'technical realizable potentials', based on engineering judgment, have been imposed on the PRIMES model. These potentials apply to the Baseline and to all other scenarios run afterwards.

The CE2030 decided not to impose too many and too strict constraints of all kinds and sorts on the model, but to allow PRIMES to fill in what it believes should be made as investments. To reflect the reality that the first projects are usually the most attractive, a gradually increasing supply-cost function has been applied. Limitations due to e.g., required grid extensions have not been imposed explicitly; but the grid extensions are taken into account to some extent through shifts in the supply-cost curves. Similarly, we have not imposed exogenous growth-rate limitations, although such might certainly be justified. Indeed, for renewables, such as wind turbines and PV systems, it is likely that the manufacturers will not be able to deliver at a rate that the model sometimes predicts. The same applies to the observed strain on coal-fired plants construction because of a loss of manufacturing capability in Europe, together with an expected increasing demand for new coal-fired units.

The following maximum potentials were taken: [De Ruyck, 2006]

– wind onshore:	max 2,026 MW
– wind offshore:	max 3,800 MW
– PV:	max 10,000 MW
– biomass:	no constraint; but electric capacity limited by a "cost supply curve".

The limitations for onshore <u>wind</u> are based on detailed and recently updated studies. In the case of offshore, a total potential of some 13 GW_e has been identified on the very long term. For 2030, a limitation up to 3800 MW_e has however been taken, owing to the given concessions, growth limitations in terms of installing this capacity and the consequent grid penetration, and limitations in terms of overcapacity.

For PV systems it has been assumed that in principle 100 km² might be feasible to be covered with PV cells on roofs, highways, etc.

At these limits, the grid penetration rate of intermittent power production is getting so high that overcapacity starts to occur under low demand and high wind/sun conditions, and further penetration is unlikely without major electric storage capacity before 2030.

Having said this, it cannot be expected that the integration of these intermittent sources can occur without any major investment for back up and balancing. Installing more than about 900 MW offshore wind would, for example, require investment in the high-voltage grid. For massive PV installation, a similar reasoning applies to costs for the distribution grid. However, since these numbers are based on less tangible expert-judgment estimates, these sorts of limitations have not been imposed on PRIMES.

In the report CE2030 [CE2030, 2007], the scenario results have been qualified against the reality of these major investments, which have to be interpreted as major cost 'challenges' to be overcome if one wants to fill in the full 'technical' potential. But this analysis goes beyond the scope of this scenario-based paper; the reader is referred to [CE2030, 2007] for further details.

The domestic biomass potential from arable and forest lands is limited by the available surface areas in Belgium, which amount to 14,000 and 7,000 km², respectively. The amount of biomass energy which can be produced in both cases varies between 1 and 5 GWh_{th} per km², which sets an average limit of 60 TWh_{th} if the entire available surface is used for energy purposes. According to [LIBIOFUELS, 2005], up to 10% of the arable land is acceptable for energy production, leading to 1,400 km² and some 4.2 TWh_{th}. The availability of forest residues should be higher and is assumed here to be 30% of the total forest area, leading to 2,100 km² and 6.3 TWh_{th}. The availability of the domestic biomass cultivation is therefore estimated at some 10.5 TWh_{th}, possibly extendable by higher acceptable surface shares and increasing yields beyond 2030.

According to the Ampere report [AMPERE, 2000], biomass energy from dry biomass residues (other than forest) is in the range of 9 TWh_{th}/a, originating to a large extent from municipal waste. Energy from wet biomass residues leading to biogas can be estimated at 3 TWh_{th}/a, coming mainly from sludge and manure.

In summary, 22.5 TWh_{th} or 80 PJ_{th} energy should be obtainable from domestic sources, to be converted into either heat, electric power, or biofuel suitable for transport.

Further biomass penetration calls for massive import. Import of biomass is virtually unlimited because of the small size of Belgium. The reality of a high biomass-demanding Europe or even World, however, leads to considerable increase of the cost. In practice, it has therefore been proposed to limit the imports to 180 TWh_{th}, or some 30% of the primary energy consumption, subject to a growth limitation of 11% per year. This should be compared with a more conservative European limit of 15% primary energy from domestic biomass and less import than that. Such limitations have, however, not been imposed to PRIMES, where a cost supply curve has rather been assumed.

It should be mentioned that within the present limitations our import dependency in 2030 for biomass is already high, and that higher impact on the conclusions would mean enormous amounts of biomass import and high pressure on a (soaring?) biomass cost. We should also not forget the pressure on the environment caused elsewhere by massive use of biomass for energy.

It should finally be stressed that the repartition of biomass over electricity, CHP, heat and transport is controlled by PRIMES through its optimization process. There are no imposed quota in the considered scenarios, and biomass finds its way as well in electricity, CHP and heat production.

3.3.2. Baseline-like with soaring fuel prices

Before launching into a set of alternative scenarios, it is interesting to first consider a fuel-price-adjusted baseline. Therefore, it is examined how the results of the Baseline change if higher fuel prices had been chosen from the outset. These higher, often referred to as 'soaring', fuel prices are shown in Figure 6. The fuel prices of the Baseline proper have been shown in dashed lines for comparison. The 'soaring price' for oil is about 100 $'05 per barrel of oil equivalent in 2030. In this exercise, all other parameters, besides the fuel prices, have been kept the same as in the Baseline.

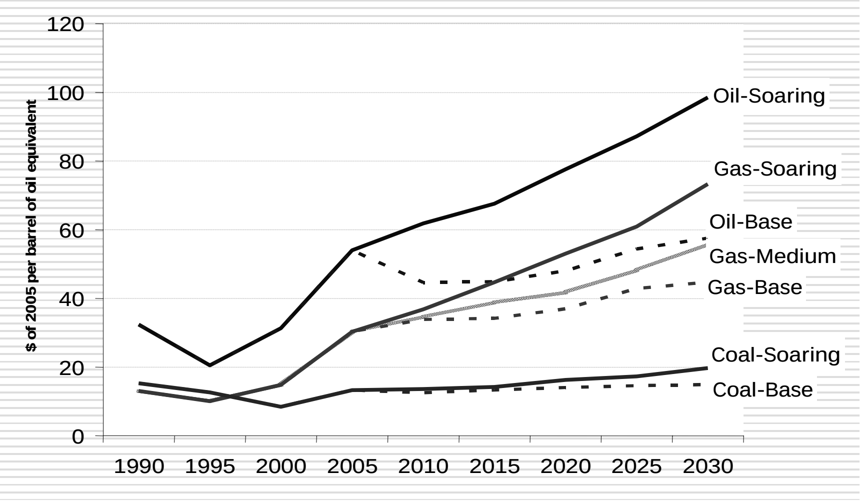


***Figure 6**. Assumed 'soaring fuel prices' compared to Baseline prices (1990-2030) [FPB, 2006 - Sept]*

As a matter of fact, this so-called sensitivity-analysis scenario with soaring fuel prices also can be viewed to encompass a particular policy decision. The results obtained by PRIMES would be the same if this scenario had been considered as a 'security of supply' scenario, in which an import tax (on a European-wide level) had been imposed on oil and gas. In both cases there will be a downward pressure on the use of oil and gas, forcing even more energy savings and domestic renewable energy, and improving the security of supply. The difference between the soaring fuel prices (in the literal sense) and the import tax, is that money is exported to the oil & gas producing countries, in the first case, while it remains here in our country in the case of a tax.

3.3.3. The concrete scenarios considered

In the alternative scenarios, substantial CO_2 or GHG reductions are taken as the main driver. The scenario results will allow interpreting the difference between a certain requirement of obligatory domestic emission reductions, versus a EU-wide approach with a cost-effective physical allocation of emission reductions amongst EU member states. In addition, in the EU-wide context, it will be possible to estimate the cost if Belgium would have to accept a same reduction *responsibility* as the EU-imposed level. To see what all that means for Belgium, we consider a variety of alternative scenarios.

3.3.3.1. Domestic reduction of energy-related CO_2

To demonstrate in a transparent way how difficult it is to reduce energy-related CO_2 emissions domestically, a first set of scenarios that impose an energy-related CO_2-emissions cut by 15% and by 30% in 2030 compared to 1990 (without having the possibility to "profit" from flexible mechanisms) has been run. The emission cuts are to take place in all sectors of the energy system, and all sectors will be influenced, but the emission cuts will first take place there where it is the cheapest to do so.

Although only representing about 16-17% of the final energy-use,[28] the electricity sector will be shown to be of paramount importance for satisfying the GHG constraint. Indeed, two electricity-generation related 'switches' exist for alleviating (or complicating) the reduction of GHG, and especially energy-related CO_2. These 'switches' are nuclear electricity generation and Carbon Capture and Storage (CCS). Hence, eight CO_2-reduction scenarios have been considered: -15% and -30%, each of them with and without the nuclear power option and with and without the availability of CCS.

Together with the Baseline, this gives a spectrum of results ranging from a domestic post-Kyoto emission reduction of 0% over 15% to 30%, for the latter cases each time with and without nuclear and CCS. This will in fact show that very deep domestic CO_2 reductions, in the absence of nuclear power and CCS, are extremely challenging by 2030. This "proof ex absurdo" will advise which domestic cuts seem reasonable and how we should make use of the flexible mechanisms.

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[28] These numbers apply to the period 2000-2005.

In summary, the following alternative domestic scenarios are considered.

Post-Kyoto -15% CO_2 in Belgium by 2030 compared to 1990

- nuclear phase out; no CCS available
- nuclear phase out; with CCS available
- no nuclear phase out; no CCS available
- no nuclear phase out; with CCS available

Post-Kyoto -30% CO_2 in Belgium by 2030 compared to 1990

- nuclear phase out; no CCS available
- nuclear phase out; with CCS available
- no nuclear phase out; no CCS available
- no nuclear phase out; with CCS available

3.3.3.2. European-wide reduction of GHG based on equi-marginal abatement cost

Led by the wisdom of the previous exercise that drastic domestic CO_2 reductions will be very difficult in Belgium (and certainly so without nuclear power or CCS), it is interesting to see how the GHG-reduction efforts can be reduced in the EU by using the flexible mechanisms. The CE2030 has been able to benefit from a post-scenario comparative analysis carried out by the Federal Planning Bureau [FPB, 2007], based on its earlier scenario work in 2006. [FPB, 2006 - July; FPB, 2006 - Sept] In that approach, one GHG-reduction limit is imposed on the entire EU, which is then considered as one region, in which CO_2-emission reductions take place according to equimarginal abatement cost. From that exercise it can be found where the actual emission reductions should take place. Assuming, in addition, a national emission reduction cut similar in % terms as the EU, but in terms of *responsibility*, it can in principle be figured out how a nuclear phase out influences the domestic reduction cuts, as well as the cost for relying on emission trading.[29]

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[29] The same comment as footnote 23 applies.

Summarizing, the following scenarios have been considered:

- Post-Kyoto -30% GHG in the EU by 2030 compared to 1990
- No CCS assumed to be available
- With and without implementing the nuclear phase out in Belgium.

Each of these alternative scenarios will then be compared with the Baseline, both for domestic reduction of CO_2 and the whole set of GHG.

3.3.3.3. The nuclear option

To find out the effects of the nuclear phase out on the ease or difficulty of satisfying the GHG constraints, it is considered in this ‘thought exercise’ to lift the phase-out obligation as follows. All existing units are allowed to prolong their operation after the age of 40 year, given the condition that they keep satisfying all safety requirements for ‘proper’ operation[30].

In that regard, based on expert judgment, the following reasonable assumptions have been made for the existing units:

(i) the four youngest units (Doel 3&4, and Tihange 2&3) can have an extended operation time of in total 60 years, without extra costs compared to the usual 10-year overhauls;

(ii) the three oldest units (Doel 1&2, and Tihange 1) can have an extended operation time of in total 60 years, but on the condition that extra investments take place. Taking into account the design, and previous overhauls, it is estimated that Tihange 1 might need an extra 1/4 refurbishment investment compared to the cost of a new unit. For Doel 1&2, an extra investment of 30% has been taken.

In addition, to allow the existing units having a prolonged operation time, the possibility is left to the model to invest in one extra new nuclear unit of 1700 MW after 2020. It will do so if the investment is cost efficient.

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[30] To be evaluated by the competent safety authorities.

3.3.3.4. Carbon capture and sequestration as a switching variable

From some literature, [IEA, 2004d[31], 2006b, 2006d, 2006e; IPCC, 2005], it might be assumed that the CO_2-'mitigation' technology of capturing and storing CO_2, could be available as a commercially viable option after 2020 - 2030. However, it is by no means certain that this technology will be 'up and running' at full speed.[32] For Belgium, especially the storage part seems to be uncertain to questionable by that time [Van Tongeren, et al., 2004; Pamplona & Mathieu, 2002; Piessens et al., 2007], also if safety issues on accidental release of CO_2 are taken into account and consideration is taken of timely construction and operation permits.

Because of the uncertainty surrounding CCS, it has been decided to consider a 'switch' in the post-Kyoto and nuclear versus non-nuclear scenarios: once with CCS available and once with CCS assumed not available. The European scenarios are without CCS present.

3.3.3.5. Schematic summary of scenarios

In summary, the whole range of scenarios can be presented as follows[33]:

Summary of scenarios

Baseline:

Bpk00: base scenario in which no post-Kyoto reduction limit is imposed in Belgium and where a decommissioning of nuclear plants takes place. Fuel prices are those of the 'standard'-baseline prices in Figure 5.7

Bpk00-h: baseline-type scenario in which no post-Kyoto reduction limit is imposed in Belgium and where a decommissioning of nuclear plants takes place. Fuel prices are those of the 'soaring' type as shown in Figure 5.8

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[31] Some numbers in this IEA report may be somewhat outdated, but it gives a good overview of the issues. The most recent numbers can be found in [IEA, 2006e].

[32] This is actually confirmed by the recent IEA publication on that matter [IEA, 2008].

[33] Adapted from [FPB, 2006 - Sept] and [FPB, 2007].

Domestic energy-related CO_2-reduction scenarios

Bpk15: scenario in which Belgium reduces its energy CO_2 emissions by 15% in 2030 compared to the 1990 level and where a decommissioning of nuclear plants takes place
Bpk15n: scenario in which Belgium reduces its energy CO_2 emissions by 15% in 2030 compared to the 1990 level, lifetime extension of existing nuclear plants + possibility of having 1 new nuclear unit of 1700 MW after 2020
Bpk15s: scenario in which Belgium reduces its energy CO_2 emissions by 15% in 2030 compared to the 1990 level, decommissioning of nuclear plants and CCS is not available in the period 2020-2030
Bpk15ns: scenario in which Belgium reduces its energy CO_2 emissions by 15% in 2030 compared to the 1990 level, lifetime extension of existing nuclear plants + possibility of having 1 new nuclear unit of 1700 MW after 2020 and CCS is not available in the period 2020-2030

Bpk30: scenario in which Belgium reduces its energy CO_2 emissions by 30% in 2030 compared to the 1990 level and decommissioning of nuclear plants
Bpk30n: scenario in which Belgium reduces its energy CO_2 emissions by 30% in 2030 compared to the 1990 level, lifetime extension of existing nuclear plants + possibility of having 1 new nuclear unit of 1700 MW after 2020
Bpk30s: scenario in which Belgium reduces its energy CO_2 emissions by 30% in 2030 compared to the 1990 level, decommissioning of nuclear plants and CCS is not available in the period 2020-2030
Bpk30ns: scenario in which Belgium reduces its energy CO_2 emissions by 30% in 2030 compared to the 1990 level, lifetime extension of existing nuclear plants + possibility of having 1 new nuclear unit of 1700 MW after 2020 and CCS is not available in the period 2020-2030

European-wide GHG-reduction scenarios

EUpkGHG30s: scenario in which the EU reduces its GHG emissions by 30% in 2030 compared to the 1990 level, decommissioning of nuclear plants in Belgium and CCS is not available in the period 2020-2030 in the EU

EUpkGHG30ns: scenario in which the EU reduces its GHG emissions by 30% in 2030 compared to the 1990 level, lifetime extension of existing Belgian nuclear plants + possibility of having 1 new nuclear unit of 1700 MW after 2020 in Belgium; CCS is not available in the period 2020-2030 in the EU

The following conventions have been applied:

B: *stands for Belgium*
pk: *stands for post Kyoto*
00, 15 or 30: *stand for the imposed Post-Kyoto reduction*
n: *means nuclear option open*
s: *means no CCS allowed (abbreviation of the French "sans")*
h: *high fuel prices*

4. Results of the scenarios

The FBP reports [FPB, 2006 - Sept], [FPB, 2007] and the CE2030 final report [CE2030, 2007] contain a systematic analysis of the PRIMES results which serve as input for the presentation of the scenario results. Only a very limited number of results have been extracted and discussed for this paper.

4.1. PRIMES baseline scenario; Belgian results

4.1.1. Final energy demand in the baseline

Figure 7a presents an overview of the evolution of the total final-energy demand and subdivided *per sector*. The final-energy demand seems to rise appreciably until 2015 after which it roughly 'saturates' (and even somewhat declines). This means that, given the assumed increase in GDP, the corresponding energy-demand *intensity*, as shown in Figure 7b, reduces considerably.

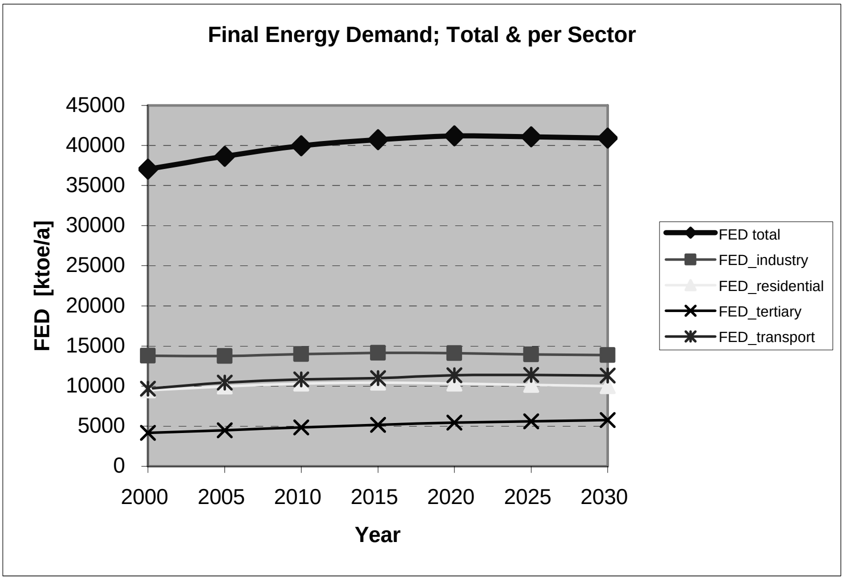


Figure 7a. *Baseline. Final energy demand; total and subdivided per sector (1 toe = 41.868 GJ = 11.63 MWh) [Primes, Nov 2005]*

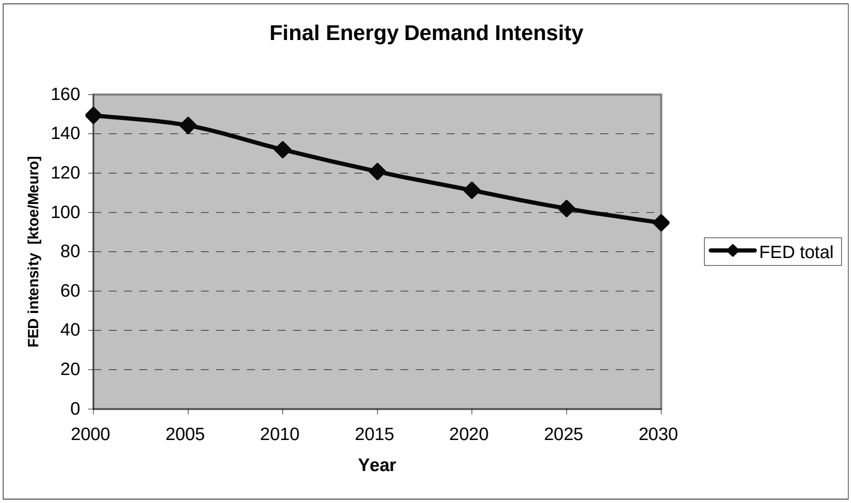


Figure 7b. *Baseline. Total final energy-demand* ***intensity****. (1 toe = 41.868 GJ = 11.63 MWh) [Primes, Nov 2005]*

4.1.2. CO_2 emissions in the baseline

Figure 8 shows the evolution of CO_2 emissions in the Baseline (in which, it is recalled, there is no post-Kyoto limit imposed). An obvious increase is observed from 2020 to 2030, due to a replacement of nuclear-generated electricity by coal-fired plants.

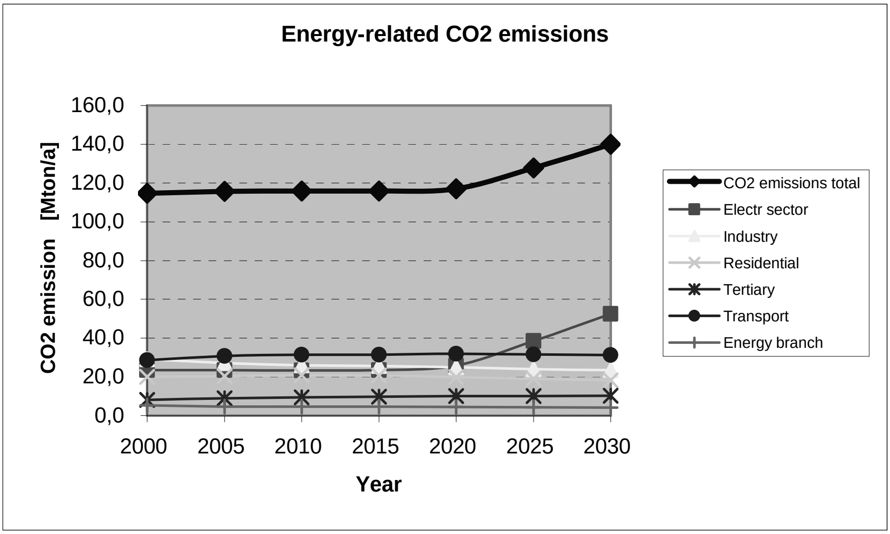
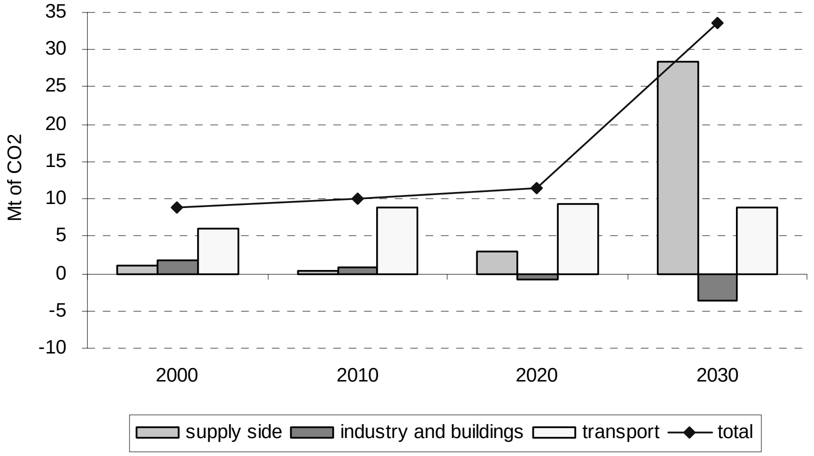


Figure 8. *Baseline. Evolution of the energy-related CO_2 emissions. [PRIMES, Nov 2005]*

Compared to 1990 levels (the Kyoto-reference year), the increase until 2030 is shown in the following graph (Figure 9) [FPB, 2006 - Sept].



Source: PRIMES
Supply side = power and steam sector + other energy transformation sectors

Figure 9. *Baseline. Changes in energy-related CO_2 emissions compared to 1990 levels. [FPB, 2006 - Sept]*

4.1.3. Baseline; closure

The present baseline scenario is clearly not 'sustainable' because the CO_2 emissions increase quite considerably, especially after 2020.

Recall that no CO_2-reduction targets were set for this baseline. As a matter of fact, in the baseline, no targets whatsoever have been set. Only the decided policies and measures up till 01.01.2005 have been taken into account.

Sustainability calls for alternative scenarios, where a substantial post-Kyoto constraint is the major driver because Climate Change is considered as the major challenge to tackle.

A more in-depth analysis of the baseline can be found in [FPB, 2006 - Sept] and [CE2030, 2007].

4.2. Soaring fuel prices-affected baseline-type scenario — results

As explained before, the 'soaring' fuel-prices scenario is a variant in which the oil and gas prices (the latter being linked to the former) go up to about 100 $'05/bbl in 2030. As to the reaction of the energy system, the effect is the same as if there would be an energy import tax levied on oil and gas (perhaps as part of a European energy tax) with the intention to improve security of supply and to force the system to decrease consumption and/or to utilize other (less expensive, more secure as regards supply and better storable) primary energy sources.

The differences in Primary Energy Consumption (or Gross Inland Consumption, GIC) and Final Energy Demand (FED) with the Baseline are shown in Figure 10.

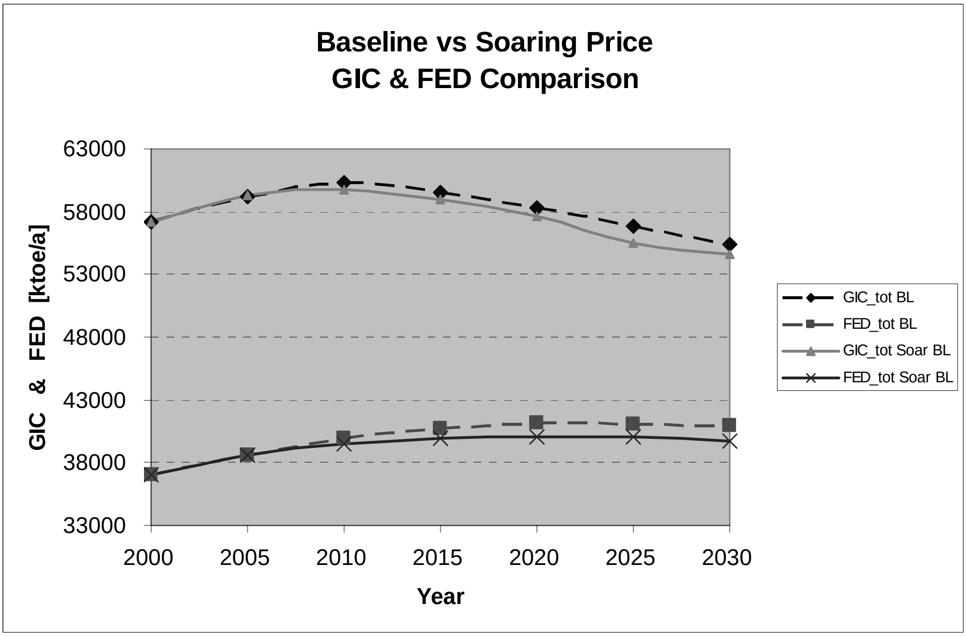


***Figure 10**. Comparison GIC and FED of the Baseline and the scenario with 'soaring' fuel prices.*
(1 toe = 41.868 GJ = 11.63 MWh) [PRIMES, Nov 2005]

Clearly, the higher fuel prices lead to a decrease in final energy demand, at a rate shown in Figure 10 as compared to the Baseline. The higher fuel prices have a mitigating effect on growth of final energy demand.

The energy-related CO_2 emissions evolve as shown in Figure 11. The fact that the CO_2 emission is effectively the same in 2030, is a consequence of the decrease in final energy demand being overshadowed by the fuel switch to coal as a consequence of the nuclear phase out (as was already the case in the baseline) and the more expensive gas prices, from 2020 on.

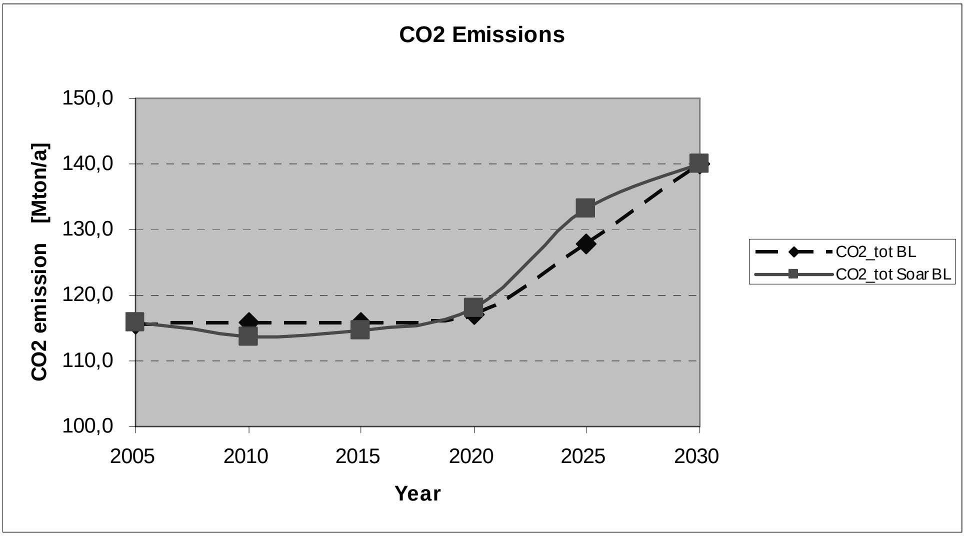


***Figure 11**. Comparison of the energy-related CO_2 emissions between the Baseline and the scenario with 'soaring' fuel prices. [PRIMES, Nov 2005]*

More information on the 'soaring' fuel-price scenario, is available in [FPB, 2006 - Sept].

4.3. Alternative scenarios; results

4.3.1. Results of domestic energy-related CO_2 reduction scenarios

As will be recalled from the scenario definition (and in contrast to the baseline), now there is a particular target set that the Belgian energy system has to satisfy, namely a stringent reduction of energy-related CO_2 by 2030. No further or new measures (evidently besides those to implement the imposed CO_2 emission reductions) than those in the baseline are enforced. The CO_2 constraint will put pressure on the system to effectuate considerable energy savings and to lead to a breakthrough for renewable build up.

In these alternative scenarios, there are no imposed quota for renewable energies and energy savings; these technologies are put on the same level as other technologies to satisfy the expected and very stringent post-Kyoto reduction targets in the different scenarios. As will be seen from the results, the CO_2-reduction target strongly increases the contribution from renewables leading to roughly the same (and in this way justified) effect of imposing quota in real life.

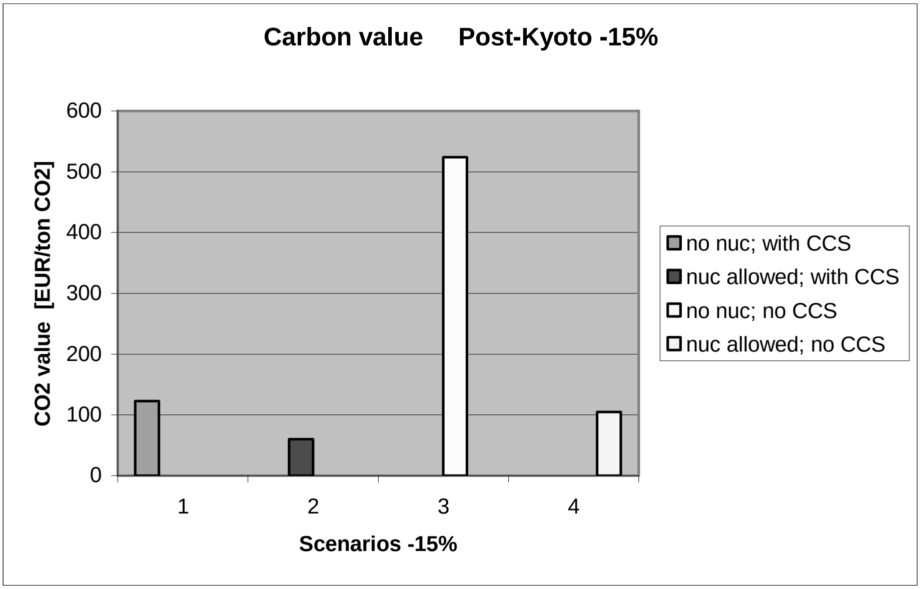
4.3.1.1. Abatement cost to reach post-Kyoto reductions

To reach a certain post-Kyoto reduction limit, PRIMES introduces a *'carbon value'*, being a measure for the marginal cost (cost of the last ton CO_2 reduced) to reduce CO_2 emissions.

This carbon value acts similarly to a CO_2 tax, in the sense that the energy system will reduce its emissions until the marginal abatement costs (which are increasing functions of increasing emission reduction and generally differ from sector to sector) are equal to the carbon value. The system searches for a particular carbon value, commensurate with the imposed CO_2 reduction. It is appropriate to consider it as the equilibrium market value of 'emission allowances' if such a system had been made obligatory for all sectors. This carbon-value parameter reflects the marginal cost of CO_2 emission reduction, and thus the degree of difficulty or ease of achieving a particular post-Kyoto constraint. The average cost per ton reduced is lower than the marginal cost, however.

Figures 12 and 13 show the carbon values for the post-Kyoto limits of -15% and -30%, respectively. Note that the vertical scale is different in both cases.

As a first remark, it must be noticed that the scenarios *no nuclear & no CCS* (represented by the "tall" bars in the figures; under numbers 3 and 7) turn out to be the extremely 'demanding' in terms of carbon value. The -15% case comes up with a carbon value[34] of roughly 520 €/ton CO_2 (in terms of barrel-of-oil cost, this would be comparable with an equivalent energy-price increase at the marginal unit of ~ 200 $/bbl), whereas the -30% case demands a carbon cost of more than 2100 €/ton CO_2 (comparable with an equivalent energy-price increase at the marginal unit of ~ 830 $/bbl).



1 = Bpk15; 2 = Bpk15n; 3 = Bpk15s; 4 = Bpk15ns

Figure 12*. Carbon values for the post-Kyoto -15% scenarios. Adapted from [FPB, 2006 - Sept]*

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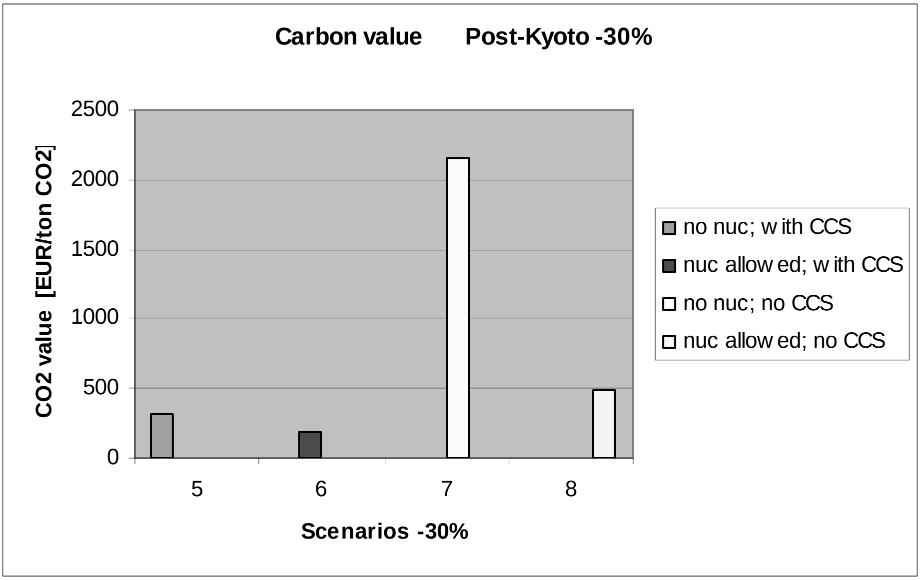
[34] This is thus the equal marginal abatement cost at which the system settles.



5 = Bpk30; 6 = Bpk30n; 7 = Bpk30s; 8 = Bpk30ns

Figure 13*. Carbon values for the post-Kyoto -15% scenarios. Adapted from [FPB, 2006 - Sept]*

As a second observation, the carbon values increase non linearly with the required reduction: a doubling of the reduction constraint from -15% to -30% leads to a 3 to 4 fold increase of the carbon value. This is in agreement with steeply increasing marginal abatement costs, with increasing reductions.

Third, relaxing the nuclear phase-out constraint, while still not relying on the CCS option (nrs 4 and 8 in Figures 12 and 13, respectively), would already substantially alleviate the pressure on the Belgian energy system. Carbon values would reduce by a factor 4 to 5, compared to the "no nuc & no CCS" cases.

As a final observation, we see that routine commercial CCS availability would help considerably to reduce CO_2 emission abatement costs. The combination of CCS with a nuclear continuation (nrs 2 and 6) would lead to moderate efforts for CO_2 abatement.

The above suggests also that the options in the electricity sector will largely influence the CO_2 abatement efforts in the other sectors.

The marginal abatement cost for CO_2 reduction, here called the carbon value, is an indication of the effort to reduce energy-related CO_2 emissions in Belgium. Some comments are in order though.

As will be recalled, our post-Kyoto limits refer to *domestic reduction of energy-related* CO_2 *emissions*. The non-CO_2 GHG have not been considered, nor have we allowed usage of ('international exchange') flexible mechanisms such as 'Joint Implementation', 'Clean Development Mechanism' or 'Emission Trading Schemes'. Clearly, as has just been shown, this will lead to extreme costs for domestic CO_2 abatement. This confirms the expected challenging nature of isolated domestic CO_2 reduction. In reality, such high abatement costs would certainly give rise to a refuge reaction via the use of flexible mechanisms, effectively meaning that Belgium would finance emission reductions abroad. (An EU-wide approach will be dealt with in the EU-based scenarios below.) It will then be part of the evaluation to check what is best for the country: cheap domestic reductions with domestic constraints such as a nuclear phase out relaxed, or paying for more expensive reductions abroad, if such domestic constraints are enforced. In any case, the scenarios here allow getting an idea as to what kind of effort domestic CO_2 reductions in the order of 15% and 30% require.

The burden on the Belgian economy might be alleviated if the carbon value were an effective tax, or if the (fictitious domestic) emission allowances would be auctioned.35 In this way, the government receives revenues, which it could then re-inject into the Belgian economy, e.g., by reducing social-security charges on labour. However, it must be stressed here that such economy-interaction effect with re-injection of the revenues is possible only if taxes or auctioning are implemented. Otherwise that is not the case. Furthermore, the issue is not as simple as it looks like.

The choice of instruments is a complex issue, because in an economy with other taxes, one needs to take into account the *interactions of the externality taxes (i.e.,* CO_2 *or GHG taxes or allowance revenues) with the remainder of the economic system.*

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35 In these domestic PRIMES scenarios, no *international* emission trading is taken into account; but the carbon value can be considered as the CO_2 allowance price for *domestic* emission trading.

This has three important implications:

(1) re-injecting the revenues into the economy is only relevant if there are important labor and other (distorting) taxes;

(2) but if there are important labor and other taxes (which is effectively the case), the cost to the economy of any environmental improvement is higher than presented in a partial-equilibrium model like PRIMES, even if the revenues are recycled;

(3) so it is risky to state that costs become lower because of re-injection of revenues, since this is only part of the story.

In summary, the recycling of external tax revenues may lead to an overall reduction of the cost for the whole economy. However, unless all distorting taxes in the economy are done away with, the cost to the overall economy will be higher than the energy system cost as projected by models like PRIMES. A more complete argumentation on this recycling issue can be found in the CE2030 report, Section 6.3.1.2. . [CE2030, 2007]

4.3.1.2. Final energy demand

As a first reaction to the post-Kyoto constraints, the final energy demand in the whole energy economy is expected to decrease. The evolution of the total energy demand and its intensity for the post-Kyoto limits of -15% and -30% are shown in Figures 14 & 15 and 16 & 17, respectively, and in each case compared to the Baseline and the 'soaring' fuel-price scenario.

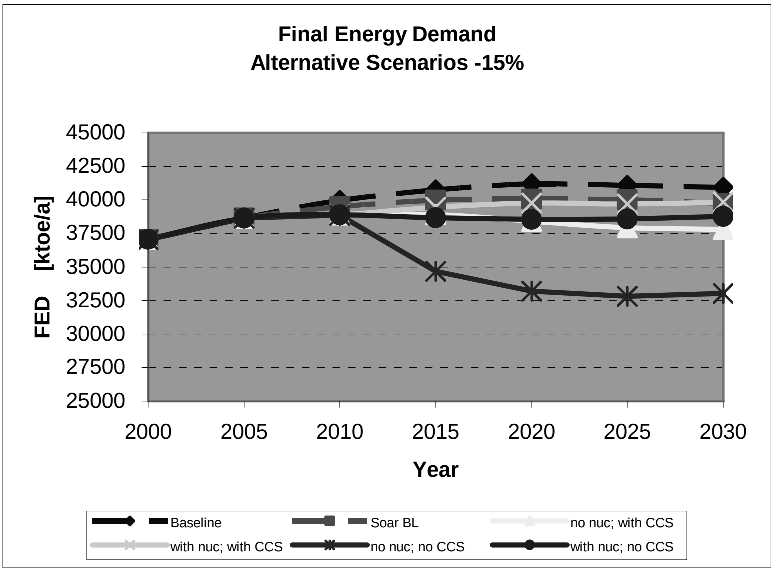

***Figure 14**. Final energy demand for the post-Kyoto -15% scenarios in comparison with the Baseline and the 'soaring' fuel prices. [FPB, 2006 – Sept; PRIMES, Nov 2005; PRIMES, July 2006]*

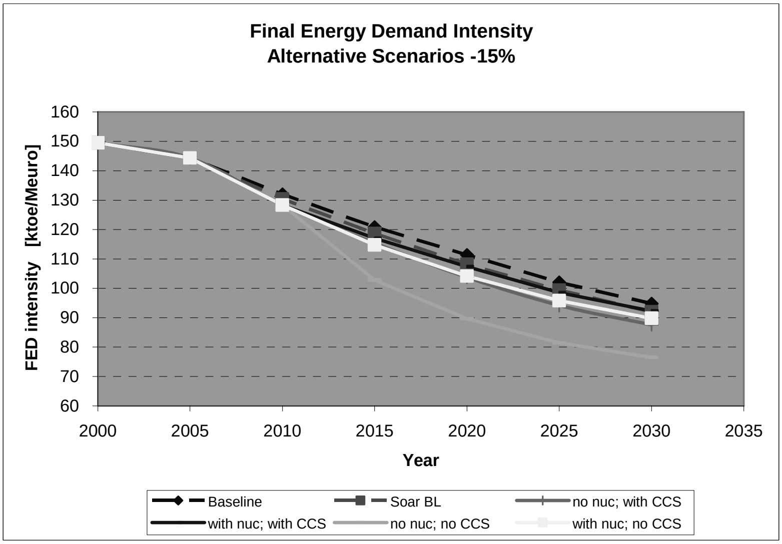

***Figure 15.** Final energy demand **intensity** for the post-Kyoto -15% scenarios in comparison with the Baseline and the 'soaring' fuel prices. [FPB, 2006 – Sept; PRIMES, Nov 2005; PRIMES, July 2006]*

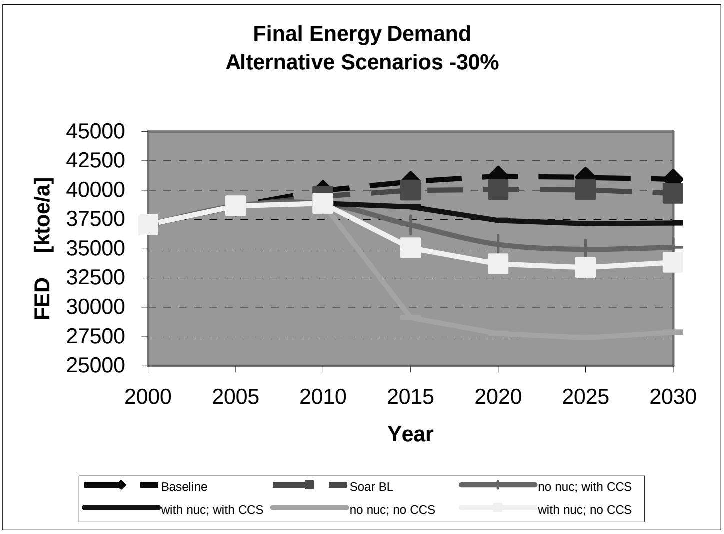

Figure 16. *Final energy demand for the post-Kyoto -30% scenarios in comparison with the Baseline and the 'soaring' fuel prices. [FPB, 2006 – Sept; PRIMES, Nov 2005; PRIMES, July 2006]*

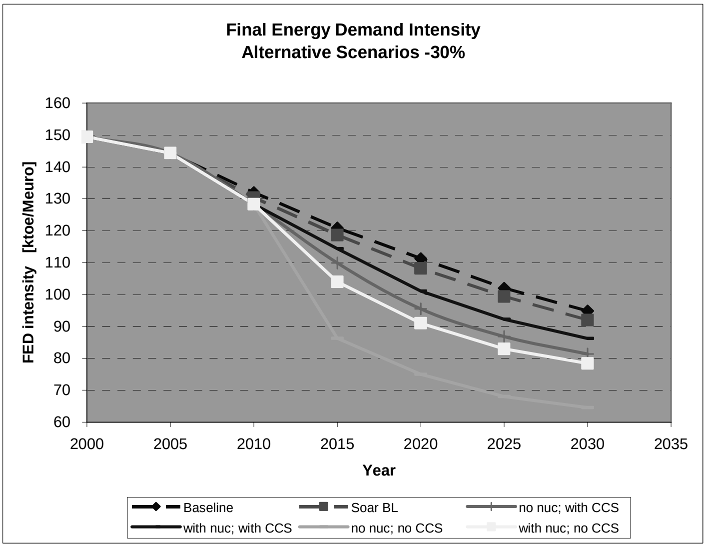

Figure 17. *Final energy demand* ***intensity*** *for the post-Kyoto -30% scenarios in comparison with the Baseline and the 'soaring' fuel prices. [FPB, 2006 – Sept; PRIMES, Nov 2005; PRIMES, July 2006]*

As expected, the very high carbon values in the '*no nuc & no CCS'* scenarios, force effectively all sectors (see Figures 12 and 13) to decrease their final energy demand substantially.

4.3.1.3. Price and cost considerations

The scenario results show indeed that domestically effectuated CO_2 cuts up to 30% are not really affordable for Belgium if nuclear power is phased out and if carbon capture & storage (CCS) turns out to be unavailable. This is a proof 'ex absurdo'.

As said before, without nuclear power and without CCS, marginal CO_2 abatement costs (or market price for CO_2 permits, here called 'Carbon Value', or CV) of up to 500 to 2000 €/ton CO_2 for the -15% and -30% scenario, respectively, are reported. These very high carbon values force a drastic final-energy demand reduction, well beyond those demand reductions doable at reasonable cost, and thereby imposing a high cost on our economy.

With such pressure on the energy system, final energy demand for the 15%-reduction case diminishes by 20%, and the energy-related cost per unit on energy in 2030 compared to the year 2000, increases by 150% in industry, 150% in the tertiary sector and by 170%, in the residential sector, compared to 24%, 31% and 63%, respectively, in the baseline.36

For the 30% CO_2 reduction case, these numbers are much more dramatic. The final energy reduces by somewhat more than 30%, while the energy-related cost per unit of energy in 2030 increases by an astounding 440%, 510% and 420%, for industry, tertiary and residential sector, respectively, again compared to 24%, 31% and 63% in the baseline.37

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36 Expressed in €2000/toe.
37 Expressed in €2000/toe.

Energy- related costs per unit of energy per sector

Values for 2030	Industry [€2000/toe]	Tertiary [€2000/toe]	Residential [€2000/toe]
	In 2000: 540	In 2000: 820	In 2000: 960
Baseline	660 (24%)	1100 (31%)	1600 (63%)
-15% no nuc / no CCS	1300 (150%)	2100 (150%)	2600 (170%)
-30% no nuc / no CCS	2900 (440%)	5000 (510%)	5000 (420%)

(% change between 2000 and 2030); 1 toe = 41.868 J = 11.63 MWh

Table 1. *Energy-related costs per unit energy per sector for the no nuc & no CCS cases. Constructed from [FPB, 2006 - Sept]*

After having utilized the other 'solution paths', such as energy savings and renewable energy, to a maximum reasonable extent according to PRIMES, substantial relief of this extremely challenging task to reduce domestic CO_2 emissions can be further obtained if *carbon capture and storage (CCS) would be available* or if *nuclear power were allowed* to continue operation beyond 2015 and 2025.

For the 15% CO_2-reduction cases, marginal abatement costs (CVs) of about 50 to 100 €/ton result, whereas the -30% case still leads to CVs of the order of 200 to 500 €/ton. Still a 'respectable' end-energy demand reduction occurs, albeit at a lower cost.

To go from 2000 to 2030, the projected energy-system costs for the end-use sectors are as follows. For the -15% case, the cost is 'slightly' higher than the cost in the baseline (although still up to 50% higher for industry) if nuclear power were allowed, whereby the no-CCS case is yet somewhat more costly; the case without nuclear power but with CCS, has a system cost that is 2 to 4 times more expensive than the baseline.

For the 30%-reduction case, costs with nuclear power allowed range from about 2 to 4 times the cost of the baseline (compared to a factor 15 to 20 without nuclear power and without CCS), with the case with both nuclear and CCS available, being the cheapest.

Energy-related costs per unit of energy per sector

Values for 2030	Industry [€2000/toe]	Tertiary [€2000/toe]	Residential [€2000/toe]
	In 2000: 540	In 2000: 820	In 2000: 960
-15% with nuc / with CCS CCCS CCS	730 (37%)	1100 (36%)	1600 (71%)
-15% with nuc / no CCS	790 (47%)	1200 (43%)	1700 (79%)
-15% no nuc / with CCS	970 (81%)	1500 (83%)	2000 (110%)
-30% with nuc / with CCS	930 (73%)	1400 (73%)	2000 (100%)
-30% with nuc / no CCS	1200 (120%)	1800 (120%)	2400 (150%)
-30% no nuc / with CCS	1300 (130%)	2000 (140%)	2500 (160%)

(% change between 2000 and 2030); 1 toe = 41.868 J = 11.63 MWh

Table 2. *Energy-related costs per unit energy per sector for the cases where nuclear power is allowed or CCS is available (or both). Constructed from [FPB, 2006 - Sept]*

The above numbers have been summarized in Tables 1 and 2; further details on the cost & price considerations are available in the report [CE2030, 2007].

In all these cases, it is important to recognize though that the *total* energy-related cost is lower than the energy-related cost *per unit of energy*, since energy demand has been reduced considerably in these more stringent cases.

4.3.1.4. Energy mix and CO_2 reduction in different sectors

A detailed overview of the energy basket, distributed over primary fuels and sectors is available in [CE2030, 2007], Tables 6.7 and 6.8. Also, the penetration of renewables, and the CO_2 reduction efforts in the different sectors are available via a multitude of results in the subsections of § 6.3.1 of [CE2030, 2007] and the references given therein. Furthermore, a post-scenario analysis of the "reasonableness" of these results, beyond what has been computed by PRIMES, and related to grid extensions, renewable growth rates, security of supply, and the required subsidies, is offered in § 6.3.2. of [CE2030, 2007].

4.3.1.5. Wrap up of simulation results of the alternative scenarios for domestic CO_2 reduction

Under these domestic CO_2-eduction scenarios, in both the -15% and the -30% cases, renewable energies cover a considerable share of the energy mix, with a very large contribution from solar PV in the absence of nuclear and CCS. Also, the energy savings in these CO_2-reduction scenarios are substantial both in energy-intensity terms as in absolute final-energy consumption.

An important conclusion regarding these domestic CO_2-reduction scenarios is that CO_2 abatement is a strong driver both for renewable-energy expansion and for energy savings, regardless of the assumptions about nuclear or CCS.

From the scenario numbers shown, it is clear that domestic energy-related CO_2 reductions up to 15% by 2030 compared to 1990 may be feasible, but it already becomes very expensive in the absence of nuclear and CCS. A domestic reduction of energy-related CO_2 by 30%, may be doable if nuclear and CCS are available; it would be very expensive if nuclear or CCS would be available; it would indeed be extremely challenging if nuclear and CCS are not available.

4.3.2. Post-Kyoto reduction scenarios in a European context

In this Section, we consider what we call the European approach of GHG emission reduction.

4.3.2.1. Influence of EU GHG constraints on the Belgian energy situation

To perform this set of "European" simulations, with a cost-effective allocation of emission reductions amongst EU member states is sought for. In fact such result can be obtained by assuming an idealized generalized emission trading scheme existing within the whole EU territory. As before, the value of such a (virtual) emission permit is called the Carbon Value (CV) and it gives the equilibrium marginal abatement cost to reduce emissions to a certain level for the EU as a whole.

In this European approach, it is taken as a given that Europe commits to reduce its GHG by 30% by the year 2030 in comparison with 1990. It is assumed furthermore that these reductions must take place on European territory and that Flexible Mechanisms outside Europe cannot be invoked. Two major scenarios will be considered: a first one with nuclear phase out in Belgium effectuated by 2025; in a second scenario, the nuclear phase-out law is assumed to be lifted and one new nuclear unit of 1700 MW is allowed to be built in addition to the existing nuclear plants (if the PRIMES model chooses to do so). CCS has not been kept as an emission-reduction option in Europe and Belgium by 2030 in this analysis.

(a) Marginal abatement costs

For an imposed GHG emission reduction of 30% by 2030 at the level of the EU, and according to the existing legislation and policy up to 01.01.2005, the marginal abatement cost (or Carbon Value) are estimated to be about 200 €/ton CO2-eq in 2030. This value thus assumes a Belgian nuclear phase out after 40 years of operation of its nuclear plants. If Belgium were to lift its nuclear phase out and allows the construction of one extra nuclear power plant of 1700 MW, then the European CV would decrease to 190 €/ton CO2-eq. At first sight, this European CV is not very dependent on the Belgian nuclear framework: phase out, or not. This is because the total of Belgian GHG emissions amounts to a mere 4% of the European amount. This apparently small difference of "merely" about 5% could be considered as "negligible", and given the uncertainty on these carbon values, caution is needed when interpreting this.[38] However, it must be noted that this "small" increase of about 5% would apply to the whole of

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[38] Because of the uncertainties, the 5% result should not necessarily be taken at face value, but it must be clear that there will be a difference, which may be of the order of several percentages.

Europe. In other words, by raising the European CV, all EU member states would collectively pay for the Belgian phase out. This observation has also been confirmed by [Bettzüge, 2007] for Germany.[39]

(b) Reduction of GHG and energy-related CO_2 in Belgium

The consequences of a European approach to reduce GHG are shown in Figure 18. The reductions on Belgian territory, i.e., the "domestic" reductions, are compared with the situation in the EU and with the baseline. (The "baseline" is referred to as "Reference" in this Figure.)

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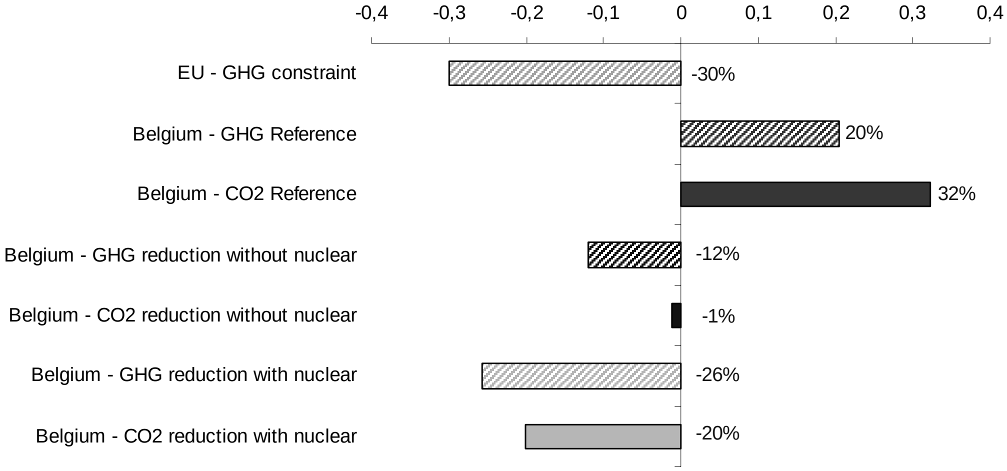
[39] A similar exercise has been made by [Bettzüge, 2007] of the Institute of Energy Economics in Cologne, for the German phase out, but now allowing Carbon Capture & Storage in Europe. According to their computations: "[the] nuclear phase out: 1) increases [the marginal cost of] CO_2 emissions in the German electricity sector by 3-7 €/tonne on the European level; 2) raises spot market prices by up to 7 €/MWh".



GHG = greenhouse gases
Hatched /////: GHG emission change
Full colour: CO_2 emission change

Figure 18. *GHG-emission reductions inside Belgium, for an imposed EU-wide reduction of 30% GHG by 2030 compared to 1990. The top bar shows the EU requirement to reduce GHG by 30%; the next two bars refer to the increase in GHG (hatched) and* CO_2 *(full) in Belgium according to the baseline. The 4-th and 5-th bars consider the domestic reductions in GHG (hatched) and* CO_2 *(full) in the case of no nuclear, whereas the last two bars consider the domestic reductions in GHG (hatched) and* CO_2 *(full) in the case with nuclear.*
Note that the baseline[40] *("Reference") is not sustainable.*
Ref. [FPB, 2007]

The top horizontal bar of Figure 18 shows the requirement (**hatched**) to reduce EU GHG emissions by 30%. The next two bars indicate the increase in both GHG emissions (hatched) and CO_2 emissions (solid fill) in Belgium for the baseline. Recall that no post-Kyoto constraints were imposed in this baseline. The last four bars, refer to the cases with the Belgian nuclear phase-out law implemented (without nuclear), or lifted (with nuclear), respectively. As before, the hatched bars refer to GHG; the "solid fill" bars refer to CO_2.

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[40] The word "reference" in the figure is synonym of "baseline".

In the case of a nuclear phase out, the domestic reductions of GHG in Belgium amount to a decrease by 12% in 2030 compared to the level of 1990. For energy-related CO_2 reductions on Belgian territory, there is only a decrease of merely 1% in 2030 compared to the 1990 level. Compared to the baseline, there is a respective reduction by 32%-pts or 27% of GHG, and a reduction by 33%-pts or 25% of the energy-related CO_2.

This small domestic reduction effort of both GHG and energy-related CO_2 within Belgium in the case of a nuclear phase out is a consequence of the very high abatement cost then applicable in Belgium. It is much cheaper to reduce emissions abroad than in Belgium.

If, however, the nuclear phase-out law would be revoked, with the additional possibility to construct a new nuclear plant of 1700 MW (the last two bars in Figure 18), then the emission reductions on Belgian territory would be 26% for GHG and 20% for energy-related CO_2. Compared to the baseline, the domestic reductions are dramatic: 46%-pts or 38% of GHG, and 52%-pts or 40% for energy-related CO_2.

Although electricity only represents about 16-17% of the final energy consumption in Belgium[41], the nuclear issue has a major impact on the domestic CO_2 reductions.

From the results of Figure 18 it can be deduced, that although a Belgian change in nuclear attitude results in a "minor" decrease of the EU-wide CV (from 200€/ton to 190€/ton), the domestic abatement cost inside Belgium is considerably lower with nuclear power allowed to continue operation compared to when it is phased out. The consequences of this are now addressed.

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[41] These numbers apply to the period 2000-2005.

4.3.2.2. Consequences for Belgium of EU-wide GHG reduction

(c) Import dependency and security of supply

(4) Electricity-generation basket

To get a good grasp of the energy mix and thus the import basket of Belgium, it is important to first focus a bit more on the electricity sector, since that sector will determine to a large extent the dependence on natural gas. Also, the electricity sector is important for short-time security of supply, since at any time supply has to satisfy demand.

Therefore, Figure 19 shows the relative importance of each primary source in the electricity mix.

The percentages are obvious from the figure. Especially the two bottom panels are to be compared, since they show the relative influence of nuclear power on especially gas dependence. The gas dependence reduces from about 70% to roughly 30%. Also, it is interesting to see that the renewable fraction in the “with nuclear” case is not much smaller than in the “no nuclear” case. It seems that renewables are not really pushed out by nuclear power.

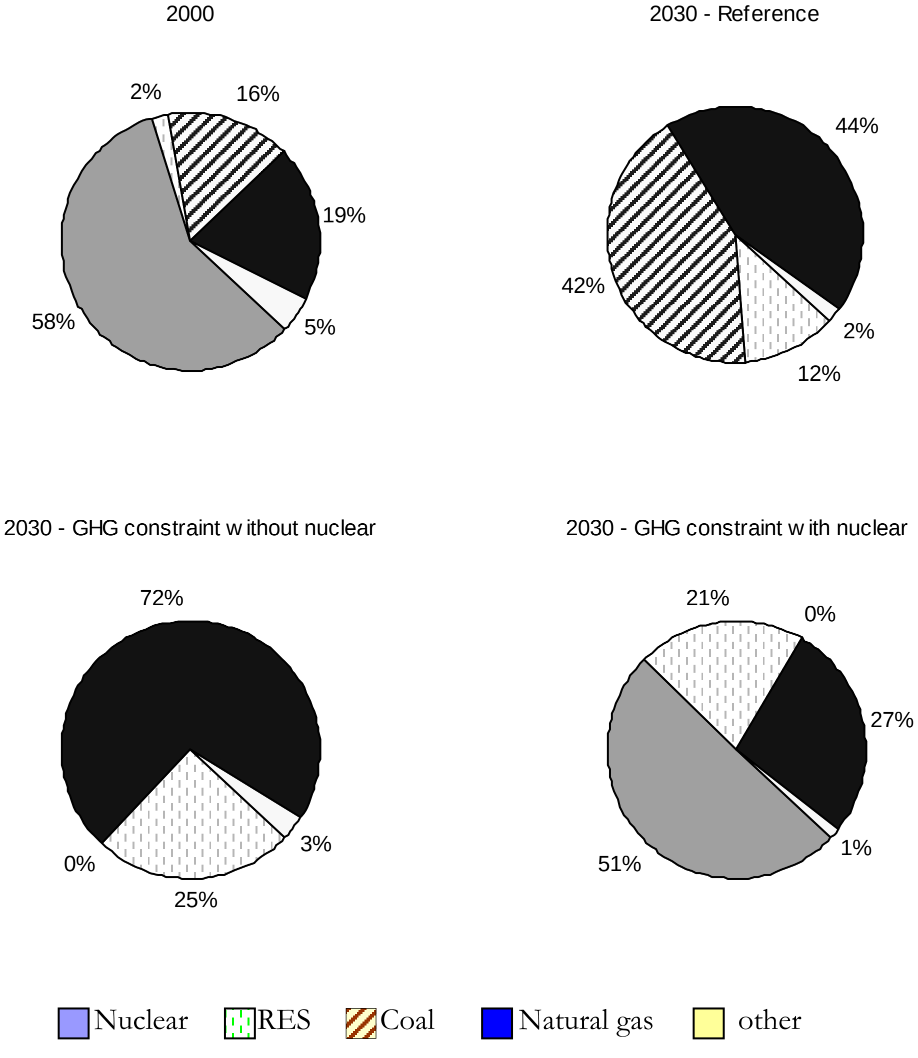
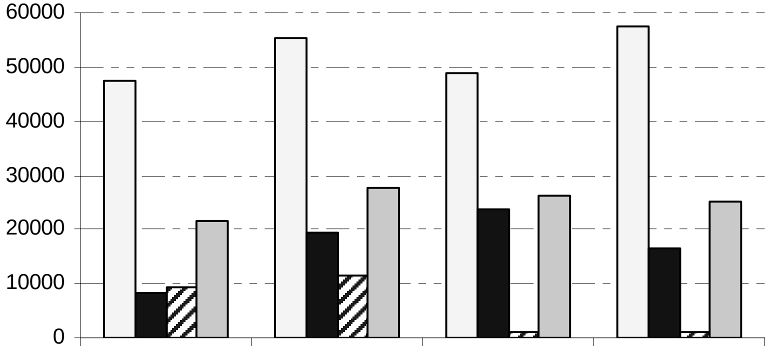


Figure 19*. Structure of the electric energy generated in Belgium in 2000 and 2030, according to the scenarios. [%]*
Ref. [FPB, 2007]

(5) Structure of the primary energy needs of Belgium

The changes within the alternative EU scenarios, regarding the final energy consumption and the electricity generation, also have their effect on the structure of the primary energy provision of Belgium. Since Belgium, with the exception of renewable sources (domestic generation of biomass, wind and solar), does not have any own energy sources (such as fossil and uranium) at its disposal, it is obliged to import them. This import concerns coal, natural gas and petroleum products, uranium in case nuclear power is utilized, and biomass when the demand exceeds domestic production.

Figure 20 displays the change in import dependency of primary energy sources, according to the different EU scenarios considered.



	1990	2030 - Reference	2030 - GHG constraint without nuclear	2030 - GHG constraint with nuclear
□ Total primary energy demand	47257	55429	48999	57466
■ Imports of natural gas	8217	19463	23566	16627
▨ Imports of coal	9492	11485	1255	1193
□ Imports of oil	21468	27780	26292	25134

Note: oil imports include the maritime bunkers that are not part of the primary energy demand (=ENERGY needs of the country)

Figure 20. *Change of the energy needs and energy import of Belgium, according to the scenarios* ***[ktoe].*** *Ref. [FPB, 2007]*

In the scenarios shown in Figure 20, the import basket remains dominated by oil. It should be noted, however, that although the level in 2030 in all cases is above the level of 1990, there is some stabilization (and even a slight decrease) of the import with respect to the year 2000 (not shown on the figure). From the projections, it follows more and more that oil is mainly used in the transport sector. This evolution is a consequence of two opposing trends: on the one hand, transport activity increases; on the other hand, the market share of oil decreases in the other sectors, and the energy efficiency of vehicles improves. The alternative scenarios lead to minor changes in the transport sector and therefore lead to little change in the oil import.

Regardless of the scenario, the gas import increases substantially by 2030, especially in the scenarios without nuclear power. Indeed, that gas import is especially needed for the electricity sector and some sectors for final energy consumption (i.e., heat production in industry and the residential sector).

The nuclear phase-out issue is an important factor for natural-gas dependence. In the scenarios without nuclear power, the demand for gas in the end-use sectors diminishes as a consequence of implementation of energy-saving measures, but in the electricity sector the market share of gas rises substantially. (See also Figure 19). In 2030, more than 50% of natural-gas import is designated for the electricity sector. Conversely, without nuclear power, and seen from the electricity sector, more than 70% of the energy mix in that sector originates from gas import on an annual basis. If considered on an instantaneous basis (taking into account the intermittent nature of especially wind) during some periods of time, this gas-import dependence can become close to ± 90% unless one chooses to import the lacking electricity.[42]

But also in the scenario with nuclear power, the overall energy system is more dependent on natural-gas import than in the past. The electricity sector, however, is less vulnerable now than in the non-nuclear scenario since the share of natural gas in that sector is now limited to 27% (see also Figure 19).

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[42] Note, however, that periods characterized by very low wind speeds, may simultaneously affect relatively large parts of Western-Europe. Hence, wind generation would then be low almost everywhere, such that neighbouring countries are faced with similar problems.

Finally, the imposed constraints for GHG reductions lead to an increase in renewable energy 'production' in Belgium. In energy terms, and on an annual basis, this domestic 'production' improves our primary energy-import basket. For our *energy* dependence (on an annual basis), this is a positive evolution, which is, however, to some extent offset by the intermittent character of some of these renewable sources, leading to an important electric-system challenge in terms of instantaneous electric-*power* delivery. In the scenarios considered here, the share of renewable energy sources (in terms of energy on an annual basis) as part of the total primary energy consumption, increases to about 7%-8%, compared to only 1.5% in 1990. This is shown in Figure 21.

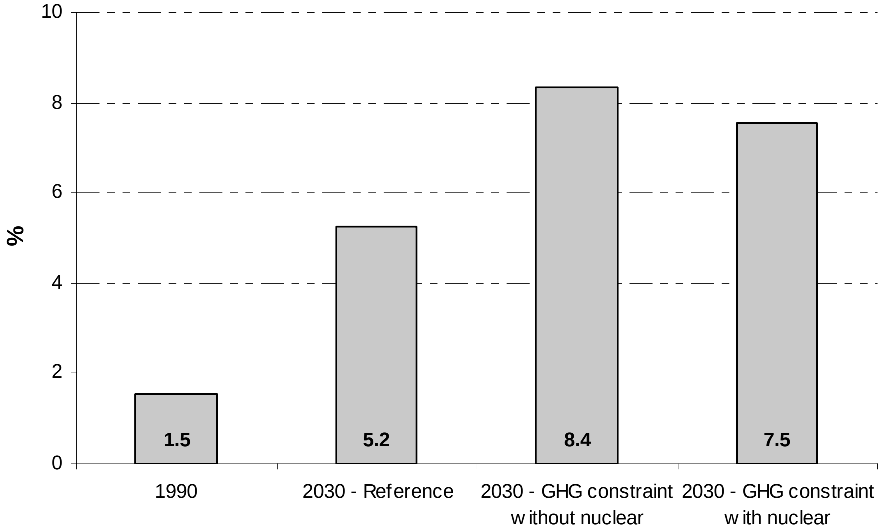

Figure 21. *Change of the share of renewable energy sources (on an annual energy basis) as part of the primary energy consumption in Belgium, according to the scenarios* ***[in %].*** *Ref. [FPB, 2007]*

(d) Cost consequences of the EU scenarios

Figure 18 has shown that domestic reductions of GHG and CO_2 on the Belgian territory are considerably smaller than the 30% GHG reduction limit prescribed on a European scale. This is a consequence of the fact that the marginal abatement cost (MAC) to reduce emissions domestically is (much) higher in Belgium then elsewhere. This would be especially the case when nuclear energy is phased out in Belgium.

As a consequence, and if one were to assume that Belgium has to fulfill the same reduction obligations (in % terms) as the EU as a whole, in terms of reduction *responsibility*, emissions that are not reduced domestically must be reduced abroad, e.g., via the purchasing of emission allowances. It is recalled that the scenarios represented in Figure 18 are all equivalent to the existence of a fully-fledged (virtual) emission trading scheme for the EU territory as a whole (without any actual exchange of money, evidently). This is also how PRIMES works for energetically-related CO_2 emissions.

In the following, we now assume that Belgium is bound by a 30% reduction-responsibility limit, and estimate the cost of purchasing emission certificates.

That means that besides the costs of domestic reductions, Belgium will have to buy a certain number of emission certificates (on the EU certificate market). The cost for emission reduction to be carried by Belgium is explained via Figure 22. The horizontal line represents the price of the emission permits (or allowances) in the EU. The segment OA is the (assumed) required emission-reduction responsibility for Belgium. Belgium will only reduce its domestic emissions up to point D instead of point A, thereby carrying a domestic cost represented by the area ODC. It will therefore avoid the domestic reduction cost DCBA, but it will have to purchase emission certificates for a cost of the area AEC'D' (equal to AECD), instead. The amount saved by using emission certificates is the triangular area CEB.

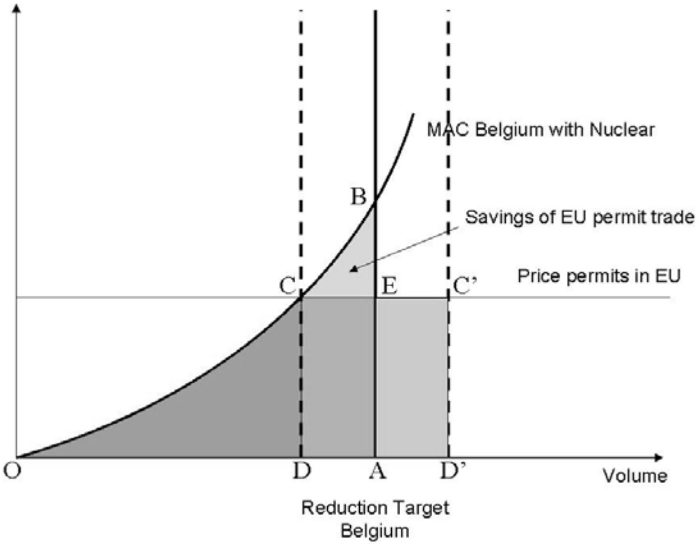

***Figure 22**. Explanation of the cost to reduce emissions by an amount OA ton GHG/a. (Note that on the abscissa, "volume" actually stands for tons of GHG to be reduced.) The ordinate is €/ton, and the curvilinear curve represents the marginal abatement cost. In this example, the MAC curve for a continued use of nuclear power is assumed to be given.*

In 1990, the amount of GHG emitted in Belgium was 144.3 Mton/a. According to Figure 18, a reduction of 26% would take place in the "with nuclear" case in 2030 (compared to 1990). This translates into a GHG-reduction amount of 37.5 Mton/a in 2030. In 2030, the price of the Carbon Value, or thus the emission certificated price is 200 €/ton CO_2-eq.[43] This value determines the point C in Figure 22. To find an order of magnitude of the domestic abatement cost, we roughly assume that ODC in Figure 22 is a triangular area. The cost for domestic reduction in 2030 is then approximately ~ 37.5 Mton/a * 200 €/ton / 2 = or 3.75 G€. Because of the overestimation, we take as a figure about ~ 3 G€. Compared to the GDP of Belgium of 2030, this would amount to about 0.7%.

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[43] For simplicity, we ignore that there is a small difference in the EU emission-allowance price between "with nuclear in Belgium (190 €/ton)" and "without nuclear in Belgium (200 €/ton)". We take as "averaged" figure 200 €/ton.

The cost for purchasing emission certificates in this non-nuclear phase-out case, is given by the area AEC'D', which is equal to AECD. Assuming a 30% reduction responsibility for Belgium, this means that for 4% of 144.3 Mton must be bought abroad. The cost of this would be about ~ 5.8 Mton * 200 €/ton or 1.2 G€, or rounded roughly 1 G€.

The total cost of GHG abatement in the year 2030 with nuclear power allowed would then be of the order of ~ 4 G€, or roughly 1% of the GDP. This total cost is represented by the total area OCEADO of Figure 22.

To find out what the extra cost of a nuclear phase out means, we consider Figure 23. Now, an extra MAC curve has been added, portraying an increase due to the nuclear phase out[44], since a cheap CO_2-reduction means is given up. As shown in detail in the final report CE2030 (Figure 6.70), the extra cost in 2030 is given by the triangular area OGE. [CE2030, 2007] From Figure 18, the difference in domestic reduction, reflecting the amount HD, equals 14 %-pts, or about 20 Mton/a. Again with a cost of a CV of 200 €/ton, the extra cost is about ~ 20 Mton/a * 200 €/ton / 2 or 2 G€/a in 2030. The extra cost due to a nuclear phase out adds about 0.5% of GDP. Also in this case, the cost can be assumed to be constant over the period 2025-2030. The given figure is therefore a good order of magnitude of the average annual cost in that five-year period.

Integrated over these 5 years, this amounts to about 10 G€. Before that period, especially because the nuclear phase out would occur stepwise from 2015, 2023 and 2025, the extra costs would be smaller. As a rough estimate, for the period 2015-2025, the total integrated cost over that 10-year period will be of the order of 5 to 10 G€.

In summary (and subject to the assumptions given earlier), *the extra cost due to the nuclear phase out is estimated at 15 to 20 G€ over the period 2015-2030*, which amounts to roughly 5-7% of the average GDP of one year of that period. On an annual basis, an extra cost of 0.5% seems a reasonable estimate.

As to a possible re-injection of GHG-related revenues, the issue has been discussed in an earlier Section. The bottom line there was that the overall cost to society will be larger anyway than what the PRIMES simulations show. Furthermore, it must be recognized that all emission permits

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[44] In reality, a shift of the MAC curve to the left should be added.

purchased on the international certificate market do not lead to revenues for the Belgian economy.

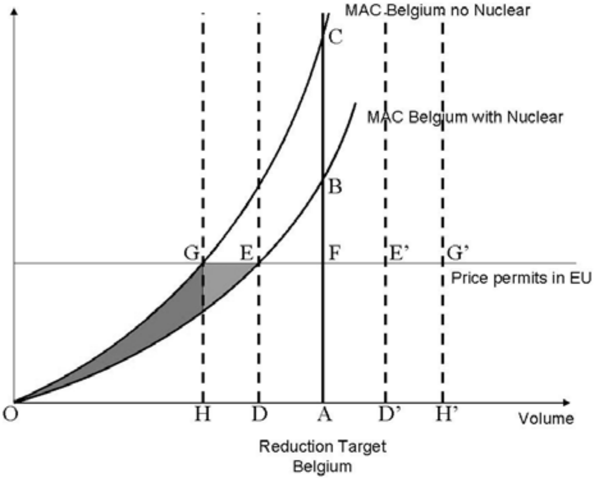

Figure 23*. Explanation of the extra cost due to a nuclear phase out if Belgium were to be responsible for a reduction of the emissions by an amount OA ton GHG/a. (Note that on the abscissa, "volume" actually stands for tons of GHG to be reduced.) The ordinate is €/ton, and the curvilinear curves represent the marginal abatement cost for the cases with and without nuclear power. The EU permit price is given by the horizontal line.*

5. Liberalized markets and the PRIMES scenarios

The version of PRIMES utilized for the CE2030 scenarios incorporates some elements of liberalized markets in Europe. Import and export of energy carriers (fuels and electricity) is accounted for based on price signals in neighboring countries and the available transmission & transport capacity. [FPB, 2006 – Sept, footnote 12]. The behavior is based on a fully competitive and transparent European market. Electric transmission capacity is represented by the equivalent DC-load capacity. [Ref. P. Capros, 2006, private communication]. Electricity prices are computed via the *Ramsey-Boiteux* principle [FPB, 2006 – Sept, footnote 23], which is effectively a *cost-plus approach*.

These elements are to be kept in mind when interpreting the PRIMES results. To mention a few deviations from reality, we can list the following points of attention. In fully-competitive markets, prices are not determined on a cost-plus basis, but are set by the marginal generation unit. However, even this is only the case in fully-competitive markets, and in reality strategic behaviour of players should be taken into account, which makes it even more complicated. Also, cross-border transmission occurs through several parallel lines, and local congestion may lead to redistribution of power flows (a.o., loop flows). Instantaneous equalizing of imbalances through fluctuating flows is not taken into account. Finally, we mention that investment in liberalized markets is not ‘automatic’, and requires time ‘in the field’ between decision, obtaining of the necessary permits/licenses, construction and operation.

The mentioned items are not a criticism of models such as PRIMES, but serve as a blinking light to keep enough interpretative distance and not to lose oneself in the fine details of the PRIMES results. Some birds-eye view perspective is necessary, without clearly forgetting the physical-technical requirements.

6. Reaching post Kyoto in practice and comparison with the EU proposals

The PRIMES scenarios considered by the CE2030 had severe post-Kyoto limits imposed, i.e., *-15% and -30% of domestic energy-related CO_2 emissions by 2030 compared to 1990*, on the one hand, and *EU-wide GHG reductions by 30%*, on the other hand. One might wonder what the value of those scenarios is, since post-Kyoto constraints should perhaps have taken into account possible burden sharing and practical considerations on flexible mechanisms.

At the time of finalizing the CE2030 final report (spring 2007) it was known that the EU had expressed its *intention* to reduce GHG by as much as **30% by 2020**, and that that should be *part of a broad international agreement.* In any case, the EU announced that it wants to commit to a GHG-emission **reduction of 20% by 2020** even if there is no international agreement. This is effectively the reading of the EU Spring Council declaration of March 09, 2007.

Based on these EU official statements with regard to 2020, it did not seem unreasonable to assume that the *EU will commit to a decrease in GHG of the order of 30 to 40% by 2030 compared to 1990*. That is the reason why throughout the CE2030 report, we have taken as a working hypothesis that the EU might commit to a 30% GHG reduction by 2030 compared to 1990.

In the mean time, and more precisely on January 23, 2008, the European Commission has released its concrete proposals for climate and energy targets by 2020, through the so-called 20-20-20 targets. [CEU, 2008)]. In those proposals, the goals are expressed to

- reduce final energy consumption by 20% compared to a baseline;
- guarantee that 20% of final energy consumption must originate from renewable sources (with 10% of transport fuels coming from RES, i.e., mostly biofuels);
- assure a 20% greenhouse-gas emission reduction in the EU, with limited flexibility mechanisms outside of Europe if there is no global agreement on GHG reduction.

6.1. GHG reduction

More specifically for the sake of the CE2030 scenarios, it is interesting to focus on the new EU proposals for an extended *Emission Trading Scheme* (ETS). For the industries (obligatory) participating in the ETS, including the electric power sector, the following goals have been formulated:

- 21% CO_2 reduction compared to 2005, meaning that in 2020 only 79% of allowances of the emissions for that ETS-participating group will be made available compared to 2005 (this is about ~ 26% reduction compared to 1990)
- this reduction applies to all participating industries, irrespective of country, location or type (this means that there is no such thing as burden sharing or a Triptych approach for the ETS)
- all allowances are to be auctioned by 2020; in principle and as a general rule, there will be no free allocations.

For the other sectors, i.e., residential, commercial & service sectors, transport and agriculture (and others), there is some kind of burden sharing, with an imposed reduction target of 15% GHG in 2020 compared to 2005 for Belgium.

In conclusion on this GHG reduction proposals: when "extrapolated" to 2030, ***these EU targets are not substantially different from the CE2030 targets****: domestic CO_2 reductions of 15% and 30% compared to 1990, on the one hand, and a 30% GHG reduction on the EU level, with full access to a perfect emission trading scheme, on the other hand. The targets set by the EU are somewhere inbetween the results obtained by the CE2030.*

6.2. Renewables

Concerning the renewables objective set by the CEU for Belgium, i.e., 13% of the final energy consumption by 2020, it will be shown now that this target is very ambitious, certainly without RES flexibility mechanisms (i.e., kind of a European-wide green certificate system).

The domestic "potential" of renewables in Belgium clearly depends on the cost: how much is one willing to pay for it, and how much of de-facto subsidies (or through levies on the electricity tariffs) are the authorities willing to devote to obtaining those targets.

A good estimate of what is realistically achievable can be inferred from the CE2030 domestic scenarios, but looking at the intermediate results for 2020.[45] See e.g.,[FPB – Sept 2006], Annex D, http://www.ce2030.be/public/documents_publ/Final%20report%20BFP%20to%20CE2030-v3.pdf . The results given here are taken from similar tables that have not been published.

The results given here concern the most stringent scenarios, i.e., a 15% and 30% CO_2 domestic reduction with the nuclear phase out implemented and with CCS not available (we called this earlier the *transparent but unrealistic* scenarios). Recall that this is the scenario that led to carbon values > 500 and 2000 €/ton in 2030, respectively.

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[45] In the mean time, another PRIMES analysis has been undertaken, with different assumptions, RES targets and renewable value, to estimate these renewables potentials. [http://www.klimaat.be/climat_klimaat/pdfs/081201_Final_report_FPB.pdf] Nevertheless, the CE2030 results (based on its particular assumptions) remain instructive and still provide an interesting estimate of what is reasonably possible by 2030.

The following numbers apply to **2020**:

- for the Baseline:
    - 4.0% renewables of the primary energy supply
    - 3.4% of final energy consumption originating from renewables
    - 6.4% biofuels in transport fuels
    - 8.9% renewable energy produced in Belgium compared to the gross domestic electric-energy generation, and 8.5% of the Belgian electricity consumption;

- for the modified Baseline with higher fuel prices:
    - 4.7% renewables of the primary energy supply
    - 4.0% of final energy consumption originating from renewables
    - 7.6% biofuels in transport fuels
    - 10.2% renewable energy produced in Belgium compared to the gross domestic electric-energy generation, and 9.7% of the Belgian electricity consumption;

- for the -15% CO_2 case w/o nuclear and w/o CCS:
    - 7.1% renewables of the primary energy supply
    - 6.2% of final energy consumption originating from renewables
    - 6.3% biofuels in transport fuels
    - 20.6% renewable energy produced in Belgium compared to the gross domestic electric-energy generation, and 19.7% of the Belgian electricity consumption;

- for the -30% CO_2 case w/o nuclear and w/o CCS:
    - 8.9% renew of primary energy supply
    - 6.9% of final energy consumption originating from renewables
    - 6.3% biofuels in transport fuels
    - 16.5% renewable energy produced in Belgium compared to the gross domestic electric-energy generation, and 15.7% of the Belgian electricity consumption.

Here it is noted that the renewables fraction from biomass includes (non-renewable) waste combustion so that the real renewable contribution is lower than indicated here. On the other hand, our percentages for final renewable energy consist only of the end-energy carriers electricity and biofuels for transport. No biomass for heat supply (counted as a final energy carrier) has been included in these numbers.

These figures show that even with very high carbon values, the domestic renewables contribution (excluding heat applications) remains below 10%. Reaching 13% domestic production will therefore require measures that will lead to non-efficient electricity production from the standpoint of CO_2 reduction.

7. Summary & conclusions of the scenario analysis

The CE2030 has carefully studied the energy-provision issue for Belgium by means of different scenarios with the time horizon of 2030, obtained by the PRIMES energy model.

All sectors (industry, residential & commercial & service sector, transport sector, electricity sector) as well as all primary and final energy carriers (oil, gas, coal, renewables, uranium, electricity, heat) have been studied. Because of the circumstances, mainly induced by the climate-change threat, the electricity sector plays a crucial role, however, in that important switches (nuclear power and carbon capture & storage) are situated in that sector and because the gas supply for that sector is of utmost importance. Nevertheless, the interaction between all sectors and carriers is properly taken into account.

All scenarios considered assume a reasonable projection of future demand for energy services (related to GDP growth, demographics, etc), identical to the recent PRIMES scenarios published by the European Commission DG TREN in May 2006.

7.1. Baseline scenario

The ***baseline scenario*** implements all energy- and climate-related policy measures and instruments agreed upon until 01.01.2005. It assumes no extra policy measures and does not impose any post-Kyoto constraints on greenhouse gases (GHG). In this scenario, the nuclear phase out is assumed to be fully effectuated.

In the baseline projections, despite a considerable increase of energy-service demand, the final energy demand increases only moderately. This leads to a considerable decrease by 2030 in energy intensity by 30% compared to the value in 2005 for all sectors. In the baseline scenario, coal-based electricity generation basically replaces most of the nuclear capacity and increases fivefold between 2020 and 2030. Overall CO_2 emissions increase substantially from 116 Mton/a in 2005 to 140 Mton/a in 2030 (being an increase by 32% compared to 1990). In this baseline scenario, the higher oil & gas prices and the nuclear phase out put a certain pressure on the energy system, but the absence of a post-Kyoto limit allows a 'convenient' escape route through the massive installation of coal power plants for electricity generation. ***Clearly, the Baseline is not sustainable*** with regard to CO_2 emissions.

7.2. Alternative scenarios with post-Kyoto obligation

Two types of scenarios have been examined: only domestic reductions of energy-related CO_2 emissions on the Belgian territory and a European-wide Greenhouse-Gas reduction (GHG) obligation, with possibility of purchasing emission allowances abroad.

7.2.1. Domestic CO_2 reduction constraint

Two post-Kyoto targets of 15% and 30% of domestically energy-related CO_2 reductions in 2030 compared to 1990 have been investigated, with for each case the implementation of the nuclear phase-out law, and the possibility for Carbon Capture and Storage (CCS) as additional 'turn-on/switch-off' variables. Such scenarios have the advantage of being transparent and they show the degree of difficulty to meet the imposed constraints domestically.

The scenario results show indeed that domestically effectuated CO_2 cuts up to 30% would not be affordable for Belgium if nuclear power is phased out and if carbon capture & storage (CCS) turns out to be unavailable. This is a proof 'ex absurdo'.

Without nuclear power and without CCS, expected marginal CO_2 abatement costs (or market price for CO_2 permits, here called 'Carbon Value', or CV) of up to 500 to 2000 €/ton CO_2 for the -15% and -30% scenario, respectively, are reported. These very high carbon values would force a drastic final-energy demand reduction, well beyond those demand reductions doable at reasonable cost, and thereby imposing a high cost on our economy.

With such pressure on the energy system, final-energy demand for the 15%-reduction case would diminish by 20%, and the energy-related cost per unit energy in 2030 compared to the year 2000, would increase by 150% in industry, 150% in the tertiary sector and by 170%, in the residential sector, compared to 24%, 31% and 63%, respectively, in the baseline.[46]

For the 30% CO_2-reduction case, these numbers are much more dramatic. The final energy would reduce by somewhat more than 30%, while the energy-related cost per unit energy in 2030 would increase by an astounding 440%, 510% and 420%, for industry, tertiary and residential sector, respectively, again compared to 24%, 31% and 63% in the baseline.[47]

In both these cases, it is important to recognize though that the *total* energy-related cost would be lower than the energy-related cost *per unit of energy*, since energy demand would have been reduced considerably in these more stringent cases.

If a ***nuclear phase out*** is implemented**,** and given expected technological evolution, the scenario results show that domestic CO_2 reductions would be ***very expensive.*** The numbers, as produced by PRIMES under the given hypotheses, show that a domestic CO_2 reduction of up to 15% would be barely tolerable; but also the 'unreasonableness' of a domestic 30% CO_2 reduction scenario by 2030 (compared to 1990).

After having utilized the other 'solution paths', such as energy savings and renewable energy, to a maximum reasonable extent according to PRIMES, substantial relief of this extremely heavy task to reduce domestic CO_2 emissions can be further obtained if ***carbon capture and storage (CCS) would be available*** or if ***nuclear power were allowed*** to continue operation beyond 2015 and 2025.

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[46] Expressed in €2000/toe.
[47] Expressed in €2000/toe.

For the 15% CO_2-reduction cases, marginal abatement costs (CVs) of about 50 to 100 €/ton result, whereas the -30% case still leads to CVs of the order of 200 to 500 €/ton. Still a 'respectable' end-energy demand reduction occurs, albeit at a lower cost.

To go from 2000 to 2030, the projected energy-system costs for the end-use sectors are as follows. For the -15% case, the cost would be 'slightly' higher than the cost in the baseline (although still up to 50% higher for industry) if nuclear power were allowed, whereby the no CCS case is yet somewhat more costly; the case without nuclear power but with CCS, would have a system cost that is 2 to 4 times more expensive than the baseline.

For the 30%-reduction case, costs with nuclear power allowed would range from about 2 to 4 times the cost of the baseline (compared to a factor 15 to 20 without nuclear power and without CCS), with the case with both nuclear and CCS available, being the cheapest.

7.2.2. European GHG reduction constraint

In a second approach, an overall European GHG reduction target of 30% in 2030 compared to 1990 has been considered. After an estimate of the decline of the non-CO_2 GHG, taking into account the marginal abatement costs of all European countries, and by freely allowing European exchange of climate reduction efforts through flexible mechanisms, it is found how the domestic CO_2 reduction efforts are distributed over the countries. In all scenarios here, no CCS is considered to be available.

With the nuclear phase-out law implemented and without CCS, most reductions will take place abroad, with only a 12% reduction of GHG and a mere 1% reduction of CO_2 on the Belgian territory, compared to 1990.

With nuclear power allowed (and without CCS), the cost to reduce energy-related CO_2 in Belgium becomes much smaller, giving rise to a GHG reduction by 26% and a CO_2 reduction amount of 20% on the Belgian territory.

These results show that the nuclear phase-out law prevents cheap domestic CO_2 reductions, requiring Belgium to implement and finance reductions abroad. Under the hypothesis that Belgium will have to accept <u>a similar GHG-reduction obligation</u> equal to the EU <u>level of 30%</u>, the European approach means that GHG reductions can be obtained at lower costs than effectuated domestically. However, the emission reductions abroad must be paid for by Belgium via equivalent emission allowances, at a price of the equilibrium marginal abatement cost (MAC). This would lead to an extra cost for CO_2 abatement of about ~ 15,000 - 20,000 M€ over the period 2015-2030.[48]

For these GHG and CO_2 reductions on a EU level, it is assumed that no flexible mechanisms outside the EU are applied. The 30% reduction of GHG is assumed to be effectuated within the EU.

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