Final report

# Transition towards a low carbon society in 2050: Status of long term modelling in Belgium

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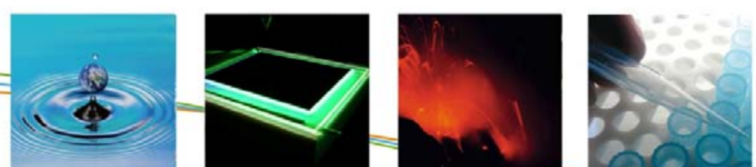

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# SUMMARY

The transition to a low carbon society, characterised by greenhouse gas emission reductions of 80 to 95 % in 2050 in comparison to 1990 requires significant changes to our energy system and the organisation of the economy. Adequate policies will have to be designed in order to achieve this target.

This study addresses the question "how can models support policy design in this context?" To this purpose, all the relevant model users/builders have been invited to a workshop held in Brussels. The objective of the workshop was to identify strengths and weaknesses of different modelling approaches related to various aspects of such a transition, to identify possible synergies between existing models, defining new needs and identifying ways to improve the models and to clarify conceptual differences of different modelling approaches.

**Types of models**

The workshop participants were asked to follow a template for the presentations – focussing on specific issues – and to provide recent model results relevant in the context of the transition to a low carbon economy. The types of models available today are the following ones.

***Accounting models (EPM, OPE$^2$RA, SAVER-LEAP, Anonymous model of FPB)***

The central modelling logic of this type of models is to guarantee consistency in energy accounting. Defining activity drivers and pathways for energy efficiency or carbon intensity improvements at the sectoral levels are the core elements of the methodology. Technologies are implicit and costs are often considered in an ex-post calculation. The particular strength of accounting models is their transparency and flexibility in presenting energy analysis concepts whilst guaranteeing consistency in energy accounting. They can be useful to explore possible pathways and provide more quantitative analysis on the required targets to be reached by the underlying hypothesis at sectoral levels and can be useful to explore the social acceptance of the transition as well as its contours by stakeholder consultation as they provide powerful reporting capabilities.

***Macro-economic models: General equilibrium macro-economic model (GEM-E3), econometric macro-economic models (HERMES, NEMESIS)***

Macro –economic models represent the whole economy and include feedback mechanisms from and to the energy system. These models are based on the same type of behavioural assumptions for the economic agents but they differ regarding the market equilibrium assumptions and the dynamic path modelling. Econometric models are more oriented towards the adjustment path in the short to medium term allowing market disequilibrium while general equilibrium model are medium to long term oriented evaluating the impact of a policy when the full effect are through. GEM-E3 is primarily a long-term analysis tool, but is not very suited as a projection tool, whereas HERMES and NEMESIS are more suited as projection tools.

***Partial equilibrium models of the energy system (TIMES and PRIMES)***

These models have a detailed representation of technologies in a consistent framework and are suited for the analysis of competitive energy efficiency technologies, process- and transformation technologies. PRIMES and TIMES differ in their mathematical formulations. PRIMES models the economic agent's behaviour (describing what would happen if) whereas TIMES is more normative from the point of view of the public authority (prescribing what optimally should happen), though it can also be used with private agent discount rates. Important differences relate to the pricing mechanism, the foresight assumption and the social discount factor.

***Partial equilibrium models for the transport sector (PLANET and TREMOVE)***
These models are designed to analyse a broad range of transport related issues: congestion problems, emission of air pollutants, accidents, energy and $CO_2$ related issues. Demand for transport is differentiated by purposes (work, school, non-working...), by localisation (rural or urban) and by timing (peak and non-peak). For personal transport, different car sizes and fuels technologies are considered. Choices for alternative transport modes are based on generalised costs, which include monetary cost and the time cost.

**Scenario analysis**

Thirteen scenarios developed with seven different models, covering the whole energy system and two scenarios covering the transport sector have been presented. The model results reflect differences in approach (back-casting versus simulation), assumptions on technological evolution, policy and growth assumptions, price assumptions, and geographical scope, but they have strong (although not identical) emissions reductions in common and all respect the phasing out of the nuclear installations. The most significant differences are observed for final energy consumption in the industry, (varying from -62% between 2005 and 2050 to + 8 %), in the transport sector (varying from -79 % to +65 %) and in consumption of electricity (from -30% to +41% in the same period).

The transition paths, resulting from different scenarios, are likely to induce other (desired or undesired) effects on the entire economy, more specifically on GDP and welfare. These have not been derived systematically and the comparison of derived effects is complicated by the different approaches and concepts used.

**Specific issues**

The remainder of the workshop was devoted to formulating answers on a how models are dealing with specific issues that were selected for being relevant in the context of a transition to a low carbon economy. The answers highlight the extent to which models are currently able to deal with those key issues. They also set the direction in which future research needs to be oriented in order to improve our ability to analyse the transition.

***Innovation -*** In NEMESIS technical change is endogenous via the variable “knowledge”, incorporated in the production functions. In GEM-E3 innovation and the impact of R&D are also endogenously modelled. The TIMES model allows to use learning curves (which to an extent makes technology improvements endogenous, but this functionality is not relevant when running an isolated Belgian TIMES model). In other models innovation is to a great extend exogenous. Finally, none of the models is currently able to include the impact of the level of investments on learning by doing[1].

***Behavioural and organisational change -*** Behavioural reactions on changing prices are reflected in macro-economic models and in partial equilibrium models but the approach is limited as it does not count for changes in the structure of preferences. The possibility of any non-price driven behavioural change is not implemented in these models. Accounting model can include such possible changes, but their introduction cannot be derived from the modelling exercise itself and has to rely on expert judgments.

[1] Jaeger et all (2011) provide a methodology for including endogenous learning by doing effects.

***Sensitivity to the international context -*** The macro-economic models are highly sensitive to the international context. In fact, these are the only type of models that also incorporate competitiveness – and hence activity -effects resulting from changes in international fuel prices (direct effect and feedback effect) or from changes in national export prices. These are however not able to model the impact of policies on the location of activities as these depend on a large number of factors.

***The discount factor -*** In macro-economic models, PRIMES and TIMES the discount factor determines the cost of capital but there is no homogenous view on quantifying discount rates. In TIMES a social discount rate of 2-4 % is implemented. Other models use private discount rates. Given that discount rates have a very strong impact on the results as far as social discount rates are concerned, they do implicitly reflect normative choices in terms of intergenerational equity. It is essential to always highlight their level.

***Expectations -*** Formalised types of expectations are implemented in PRIMES and TIMES. In PRIMES this is sector- specific, i.e. myopic expectations are implemented for consumers but the horizon of expectations is longer for industry and power production sectors. In TIMES the perfect foresight hypothesis is implemented. This means that the full projection horizon is considered.

***Endogenous growth -*** In most models growth is generated by exogenous assumptions on technical progress or on increase in resources (population, decrease in unemployment). In accounting models and partial equilibrium models growth is implemented exogenous (either in activity rates or in demand for energy services). NEMESIS and GEM-E3, include an endogenous technical change module based on "knowledge economics" where R&D stock (resulting from R&D expenditures) and spill over effects (between sectors) are considered and contribute also to the growth.

***Macro-economic and welfare impacts -*** In GEM-E3 a social welfare function is implemented. Welfare is derived from the consumer's utility function, which includes in a separable way the utility from the consumption of goods and leisure and the environmental utility/damage. Welfare aspect in PRIMES and TIMES are limited to the energy system. PRIMES reports on the costs from the perspective of final energy consumers, including disutility costs. In TIMES welfare cost is represented by the change in consumer and producer surplus. In TREMOVE and PLANET, welfare is presented as the change in consumer and producer surplus and also includes extra tax revenues for the government as well as the change in external costs. In the macro-econometric models, GDP or disposable income has to be used as a proxy for welfare.

***Income distribution and other social impacts -*** On this issue, it is recognised that the existing models are not sufficiently developed to study income distribution and other social impacts related to the transition to a low carbon economy. Only HERMES and NEMESIS have some very limited facilities.

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# CHAPTER 1 INTRODUCTION

The context of this study is the transition toward a low carbon economy characterised by EU-wide greenhouse gas emission reductions of 80 to 95% in 2050 with respect to 1990. In this context, the objective of the study is to:

- Identify the strengths and weaknesses of different modelling approaches related to the various aspects of such a transition to a low carbon economy, such as technical & infrastructure- macro & micro economic aspects - social aspects –education/information-policy instruments, etc …;
- Clarify the conceptual differences of the various approaches;
- Identify possible synergies between existing models;
- Defining new needs and identifying ways to improve the models, proposing solutions.

To this purpose all the relevant models users/builders in Belgium were invited to a workshop held in Brussels on March 22nd. This modus operandi was chosen because it allows direct interaction between the model builders. As model builders have basic knowledge on the different modelling methodologies, this method allowed skipping detailed presentations of model characteristics, leaving more time to discuss key issues that directly relate to the transition towards a low carbon economy.

The participants were asked to follow a given format and to provide answers on a number of critical questions (see annex 1). The questions focus on two fundamental issues.

- The first issue relates to the dynamics of the transition: what is the role of technological innovation, and what can we expect from behavioural changes?
- The second issue: does a transition to a low carbon economy necessarily involve welfare losses? One possibility to evaluate a transition path is to compare a reference scenario and a low carbon scenario. If the reference scenario is assumed to result from some optimization procedure, then "ceteris paribus" the transition to a low carbon economy involves additional constraints (or loss of freedom) and consequently additional costs (and welfare loss)[2]. The questions are: how much "ceteris paribus" is implemented in our models and whether all costs and benefits are included in the optimisation. In the *EU energy roadmap 2050 by the European commission,* for instance the fossil fuel energy prices are lower in the low-carbon scenarios compared to the prices in the reference scenario, generating some positive side effects. *Jaeger et all. (2011)* investigate the effects of investment on learning-by-doing and the effects of expectations on investment and conclude that a green growth path is feasible. Yet another issue is how to internalise the long term costs of climate change, which policy instruments to be used

[2] Under the assumption of no multiple equilibria.

The structure of the report is as follows. In chapter 2 we present the general characteristics of the models, which are based on the information provided by the participants of the workshop .The participants also made recent model-simulations available, which are relevant in the context of the transition towards a low carbon economy. In chapter 3, we present a selection of fifteen alternative scenarios, most of them having in common very significant emission reductions. These scenario are however different from each other as they rely on different methodologies, objectives (simulation versus back casting), different underlying assumptions regarding technological evolution, behavioural changes and policies and measures, and geographical and sectoral coverage. Finally, chapter 4 deals with specific issues in the different models. This analysis is mainly based on the answers provided by the participants and the discussions during the workshop.

Most models limited their analysis to the energy system and $CO_2$ emissions. However, the scenarios prepared with the BFP accounting model and with $OPE^2RA$ (by DECC and Climact) cover all greenhouse gases of the Kyoto Protocol ($CH_4$, $N_2O$, HFC's, PFC's, $SF_6$), the transport models also cover air pollutants (NOx, $SO_2$, PM)

# CHAPTER 2 GENERAL CHARACTERISTICS OF THE MODELS

The transition to a low carbon economy is likely to involve a major trend break from the current business as usual. The central question is how flexible is our economy to realise a major trend break and to adapt to new circumstances. Looking at models the relevant questions becomes what kind of flexibility and how it is represented (technological substitutions, technological progress, behavioural changes, spill over effects). In this chapter, we present an overview of different types of models from this perspective onwards.

## 2.1. ACCOUNTING –BACK CASTING- EXPERT JUDGEMENT

OPE$^2$RA [3] (model developed by the DECC UK[4] adapted by CLIMACT for the Walloon region)
SAVER – LEAP (applied by UA-STEM for Belgium)
EPM (applied by ECONOTEC for Walloon region)
Anonymous back-casting model applied by Federal Planning Bureau for Belgium

The central modelling logic of this type of models is to guarantee consistency in energy accounting. At the sectoral level, the development of a scenario starts by the choice of relevant activity drivers and defining activity paths. Typical activity drivers are square meter floor space per household, tons of steel production, passenger kilometres by private cars or by public transport, etc. The choice of the relevant drivers requires insights into the sectoral specificities. For instance, in the steel sector it is useful to differentiate between blast furnace steel and electro steel because of the different energy intensities involved in both processes and the increased recycling of steel. In the residential sector, it is worthwhile differentiating between single family and multi-family dwellings, as well as between new and existing dwellings. Behavioural changes can be accounted for by constraining certain activities, e.g. accepting less m² floor space in new dwellings or replacing car use by biking for homework mobility.

The second step is to develop pathways for energy efficiency or carbon intensity improvements. This requires also knowledge of the sectoral specificities as the energy efficiencies are the result of technological possibilities and choices. Ambitious objectives can be proposed, assuming that actors may opt for less energy intensive alternatives even if those are not always the least expensive ones in terms of private costs. This allows to avoid simply extrapolating current trends in energy efficiency, an approach which could only make sense for some sectors for a short or a medium period (residential sector, transport sector, 5-10 years) and is often too limited to test the possibility of more important changes.

The particular strength of accounting models is their transparency and flexibility in presenting energy analysis concepts whilst guaranteeing consistency in energy accounting. They can be useful to explore possible pathways and provide more quantitative analysis on the required targets to be reached by the underlying hypothesis at sectoral levels and can be useful to improve the social acceptance of the transition by stakeholder consultation as they provide built-in calculations

[3] Which stands for “Open Source Energy and Emissions Roadmap Analysis”
[4] Department of Energy and Climate Change in the UK

handling all of the "non controversial" energy and emissions accounting calculations, while at the same time providing powerful reporting capabilities and a rich graphical environment for visualizing data and results. However, accounting models should be used with care, as the underlying complexities of energy systems are not always amenable to expert judgment or stakeholder deliberation.

Accounting models may be used in a back-casting approach. According to Dreborg (1996), back casting is useful when:

- "the problem to be studied is complex, affecting many sectors and levels of society;
- there is a need for major change, i.e. when marginal changes within the prevailing order will not be sufficient;
- dominant trends are part of the problem-these trends are often the cornerstones of forecasts;
- the problem to a great extent is a matter of externalities, which the market cannot treat satisfactorily;
- the time horizon is long enough to allow considerable scope for deliberate choice.

The problem of how society could attain sustainability fits into this pattern."

## 2.2. MACRO-ECONOMIC (TOP-DOWN) MODELS

HERMES (applied by Federal Planning Bureau)
NEMESIS (applied by the Federal Planning Bureau)
GEM-E3 (applied by CES- KULeuven)

Macro –economic models represent the whole economy and include feedback mechanisms from and to the energy system. HERMES and NEMESIS are econometric models whereas GEM-E3 is a general equilibrium model. Both types of models are based on the same behavioural assumptions for the economic agents but differ on the market equilibrium assumptions and on the dynamic path modelling. Econometric models are more oriented towards the adjustment path in the short to medium term allowing market disequilibrium while general equilibrium model are medium to long term oriented evaluating the impact of a policy when the full effect are through.

| | HERMES | NEMESIS | GEM-E3 |
|---|---|---|---|
| Methodological approach | Econometric | Econometric | General equilibrium |
| Time horizon | 10 years | 30 years | Min 10 years |
| Sectoral resolution | 15 sectors | 30 sectors | 18 sectors |
| Consumption goods | 18 | 27 | 13 |
| Energy products | 8 | 5 | |
| International dimension | | 26 European countries | 25 European countries |

GEM-E3 is primarily a long-term policy analysis tool, but it is not very much suited as projection tool. The particular strengths are:
- its sound economic foundations and macro-economic consistency
- general equilibrium principle: impact of policy when all adjustments have occurred
- insight in distributional effects between countries and longer term structural mechanism
- -wide variety of policy instruments
- cost calculation and welfare analysis of policy

HERMES and NEMESIS are more suited as projection tools. They provide also macro-economic consistency and can be used to analyse a wide variety of policy instruments. In both models, the typical Neo-Keynesian approach is complemented with principles of neo-classical growth theory but in NEMESIS technical progress is endogenous whereas in HERMES this is exogenous. .

## 2.3. Partial Equilibrium models

### 2.3.1. Partial equilibrium model of the energy sector

PRIMES (applied by NTUA Greece)
TIMES (applied by VITO and CES-KULeuven)

These models are partial equilibrium models covering the energy sector. They have a detailed representation of technologies in a consistent framework and are suited for the analysis of competitive energy efficiency technologies, process- and transformation technologies. PRIMES and TIMES differ in their mathematical formulations. PRIMES models the economic agent's behaviour (describing what would happen if) whereas TIMES is more normative from the point of view of the public authority (prescribing what optimally should happen), though it can also be used with private agent discount rates. Important differences relate to the pricing mechanism, the foresight assumption and the social discount factor and some practical considerations.

**The pricing mechanism** - Prices and costs of fuels and technologies have significant impacts on the model results in both models. In electricity production, the choice of new technologies (capacity expansion) and the dispatching of existing and new technologies are determined simultaneously by cost optimisation in both models. However, the pricing of electricity is different. In TIMES the price of electricity is determined by the costs of the marginal production plant, i.e. the plant that produces the last unit of electricity, augmented by transmissions and distributions costs and other taxes. If it is a fossil fuel plant then a carbon price is reflected in the electricity price. In PRIMES the Ramsey Boiteux pricing principles are implemented. The price is based on the average production costs, including the cost of auctioned permits and augmented with transmission and distribution costs and other taxes. A mark-up for different types of users is determined inversely related to the demand elasticities in order to cover all production costs.

**The discount factor** - The social discount factor is consistently implemented in TIMES, i.e. to decide the most appropriate period to take action and to determine which technologies from a social/public point of view. The implementation of the social discount factor allows for a consistent evaluation of intergenerational aspects and put the different supply and demand sectors on the same level. In TIMES sector specific private discount rates can also be used. In PRIMES, sector specific private discount factors are used to evaluate the profitability of investments. No overall social discount rate is implemented.

**Myopic and perfect foresights** - TIMES uses the perfect foresight hypothesis, while PRIMES uses a complex foresights system with different horizons depending on the sector. [5]
On a theoretical basis, one could expect that the approach in TIMES is better to avoid a possible lock-in. For instance, deployment of CCS in the electricity sector could create a possible lock in, preventing massive deployment of renewable technologies. The approach in TIMES allows avoiding this by better to analysing the long-term potential of renewable technologies.

### 2.3.2. Partial equilibrium models of the Transport sector

PLANET (Applied by Federal Planning Bureau)
TREMOVE (Applied by Transport and Mobility –Leuven)

Transport models are designed to analyse a broad range of transport related issues: congestion problems, emission of air pollutants, accidents, energy and $CO_2$ related issues.

PLANET and TREMOVE use similar modelling principles. Demand for transport is differentiated by purposes (work, school, non-working...), by localisation (rural or urban) and by timing (peak and non-peak). For personal transport, different car sizes and fuels technologies are considered. The core of the model is a decision tree, in which each node represents a choice between two alternatives (for instance driving or not driving, peak transport or non-peak transport, public transport or private transport). A node is represented by a utility function (logit function) and the choice of the alternative based on the generalised costs. These include the monetary cots and the time cost. For road transport, the time cost is, among others, determined by the speed.

PLANET covers transport activity (freight and passengers) on the Belgian territory and TREMOVE has individual country models for all European countries, but these are not linked. This international dimension provides no additional value for analysing Belgian transport issues.

PLANET includes a transport generation module allowing making a projection of the demand for transport based on macro-economic and demographic assumptions. For TREMOVE a reference transport demand scenario has to be provided exogenously.

Modelling endogenous penetration of new technologies in the transport sector appears to be a difficult issue given the logit function calibration. So far, attempts have not provided the desired results.

## 2.4. Conclusion

None of the models described represents the full flexibility of an economy in an exhaustive way.

The GEM-E3 model represents responses of demand and supply in the most extensive way while at the same time respecting basic micro- and macro-economic foundations. Still, there is a limitation because GEM-E3 assumes that personal preferences are kept constant while changes in consumer preferences are likely to play a significant role (attaching less importance to large cars, large dwellings, long distance travel; preference for biking, lower meat consumption etc.). Another limitation of GEM-E3 is that the presentation of technological options is limited and does not allow investigating technological breakthrough.

Macro econometric models (HERMES, NEMESIS) are based on the same type of behavioural assumptions for the economic agents. They are best used to analyse adjustment paths in the short and medium terms.

Technologies are well represented in partial equilibrium models (TIMES,PRIMES,PLANET) TREMOVE) complement for the weak technological representation in GEM-E3, but also these models assume constant preferences and the model results are constrained by the prevailing economic paradigms implemented in these models. Changes in consumer preferences may result from increasing awareness and result in voluntary actions but none of the models provide a methodology for quantifying this flexibility.

Accounting models ($OPE^2RA$, SAVER-LEAP, EPM, FPB-model) can integrate such possible behavioural changes and can therefore be used to define scenarios, which include such changes. They however do not provide per se any justification for these changes.

# CHAPTER 3 DESCRIPTION OF A SELECTION OF SCENARIOS

## 3.1. INTRODUCTION

Several institutes recently developed scenarios based on different assumptions. In this chapter we present the scenarios that have been selected for our analysis. These scenarios are publicly available as they have been developed in the framework of scientific research projects or have been commissioned by public authorities. The Task force on sustainable development from the Federal Planning Bureau developed in 2006 two back-casting scenarios for a transition to a low carbon economy. Updates of these scenarios were completed in 2010, but have not yet been published. For practical reasons we limited the number of scenarios per model to two. If more scenarios where available we selected those we considered most relevant.

The scenarios were developed with the different models described in the previous chapter. Besides differences in models they also reflect differences in approach (back-casting versus simulation) assumptions on technological evolution, differences in policy and growth assumptions, differences in price assumptions, differences in geographical coverage (Walloon region, Belgium, Europe) and different objectives (evaluating current policies and measures versus back-casting) . From these points of view, these model results are not directly comparable.

However, most of these scenarios have in common that they were developed in the context of a transition towards a low carbon economy by 2050. Apart for the scenarios specifically developed by transport models strong (although not identical) $CO_2$ emission reductions are realised by 2050 (see Figure 1). This is a major trend break compared to the evolution of $CO_2$ emissions in the recent past. The scenarios also respect the phasing out of the nuclear installations in Belgium[6].

From this point of view, the results could be interpreted as expressions of different visions on how the strong reduction could be realised at the sectoral levels. To correct for differences in historical emissions we present all the results relative to 2005.[7], though this does not necessarily reflect the effort needed in the different scenarios because of the differences geographical scope.

We focus on the model results in 2020, 2030 and 2050, although EPM and FPB's studies based on PRIMES do not produce results for 2050. Blanks indicate that the figures are not available.

[6] The EU scenarios as well respect the closing of the nuclear installations in Belgium but this is less relevant at the European scale.

[7] The EPM scenario is relative to 2008.

| Scope | Abbreviation | Short description | Institute | Model | Family |
|---|---|---|---|---|---|
| Walloon region | Scenario 0HF | Closing of all hot steel production | ECONOTEC | EPM | Accounting |
| Walloon region | Scenario A | High demand- Low intermittent – CCS | Climact | $OPE^2RA$ | Accounting |
| Walloon region | Scenario E | Low demand – High intermittent – No-CCS | Climact | $OPE^2RA$ | Accounting |
| Belgium | B++T+ | B++T+: High behavioural - low technology contribution | UA-MTT: | LEAP | Accounting |
| Belgium | B0T++ | B0T++: Low behavioural- high technology contribution | UA-MTT: | LEAP | Accounting |
| Belgium | Pyramid | Strong international cooperation, high technology, low behavioural contribution | Federal Planning Bureau | BFP's AM | Accounting |
| Belgium | Mosaic | Low international cooperation, low technology, high behavioural contribution | Federal Planning Bureau | BFP's AM | Accounting |
| Belgium | Ref_30/20_flex | 30 % reduction by 2020 using flex mechanism | Federal Planning Bureau | PRIMES | Partial equilibrium model |
| Belgium | Ref_30/20_int | 30 % internal reduction by 2020 | Federal Planning Bureau | PRIMES | Partial equilibrium model |
| Belgium | No_Nuc Go_CCS | Closing of nuclear - allowing CCS | Vito-Kul | TIMES | Partial equilibrium model |
| Belgium | NoNuc-NoCCS | Closing of nuclear - not allowing CCS | Vito-Kul | TIMES | Partial equilibrium model |
| Europe 27 | EE | Energy efficiency scenario from energy roadmap | EC | PRIMES | Partial equilibrium model |
| Europe 27 | High res | High renewable scenario from energy roadmap | EC | PRIMES | Partial equilibrium model |
| Transport- Belgium | TREMOVE | Baseline EC DG MOVE | TM Leuven | TREMOVE | Partial equilibrium transport sector |
| Transport Belgium | PLANET | Reference scenario | Federal Planning Bureau | PLANET | Partial equilibrium transport sector |

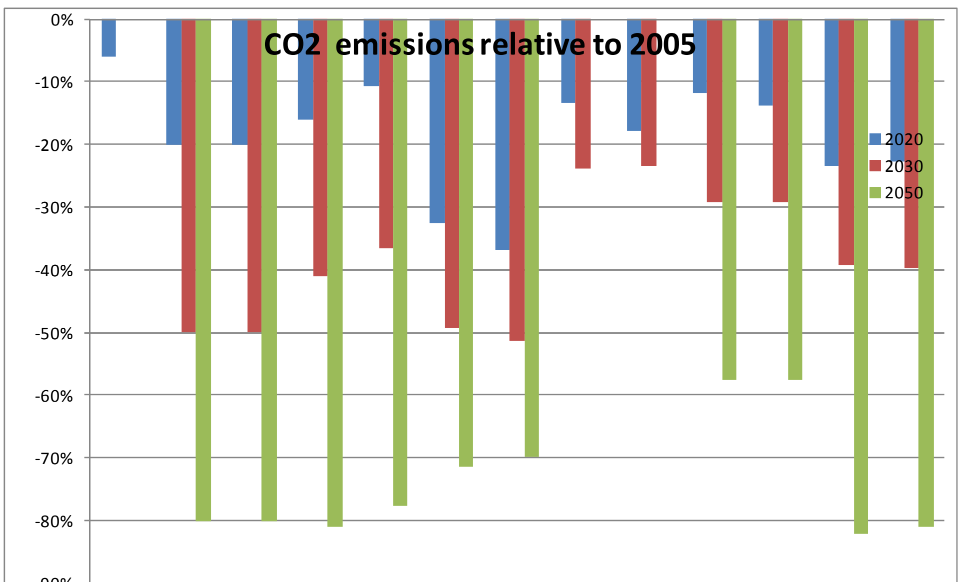
Table 1: selected scenarios for the quantitative analysis

## 3.2. IMPACT ON EMISSIONS AND THE ENERGY SYSTEM

### 3.2.1. TOTAL $CO_2$ EMISSIONS AND $CO_2$ PRICE

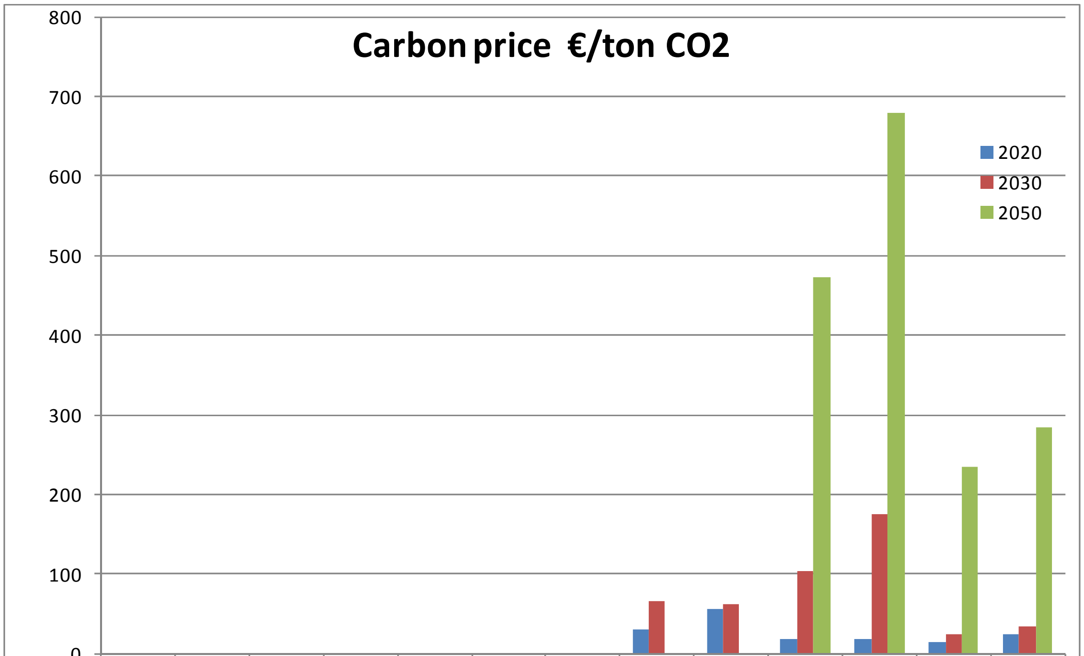
Most of the scenarios achieve very strong $CO_2$ reductions by 2050, of the order of 80 % (Figure 1). For the TIMES scenarios the $CO_2$ reduction is limited to 58 %. The latter figure results from a burden sharing analysis with the European TIMES model in which a minus 80 % was imposed at the European level. For 2030, higher $CO_2$ reductions are imposed by accounting models (from 36% to 50 %) compared to the partial equilibrium models for the Belgian territory (from 23 % to 29 %).

In partial equilibrium models, a carbon price is the result from the constraint on carbon emissions (Figure 2). It is by definition a marginal value. In other words, it corresponds to the cost of reducing the last ton of $CO_2$ to achieve the target. Interpreting these figures should be done with care as small deviations in activity assumptions or reduction potentials of technologies might result in significant changes in carbon prices, which is inherent to the methodology. The highest $CO_2$ prices are observed in the TIMES scenarios. In the NoNuc-NoCCS scenario, this might be explained by excluding the CCS option but a high $CO_2$ price is also observed for the NoNu-GoCCS scenario for which the technology assumptions are more in line with the assumptions of the Belgian and European PRIMES scenarios.




| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM- Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES -NoNuc _GoCCS | TIMES- No-Nuc -No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | -6% | -20% | -20% | -16% | -11% | -33% | -37% | -13% | -18% | -12% | -14% | -23% | -23% |
| 2030 | | -50% | -50% | -41% | -36% | -49% | -51% | -24% | -23% | -29% | -29% | -39% | -40% |
| 2050 | | -80% | -80% | -81% | -78% | -71% | -70% | | | -58% | -58% | -82% | -81% |

Figure 1: $CO_2$ emissions: % change relative to 2005



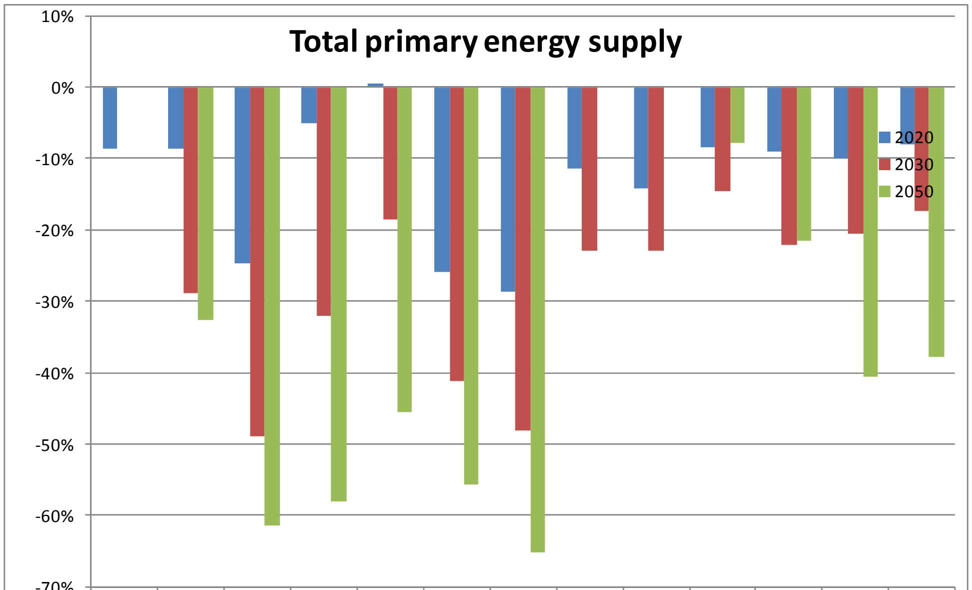

| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | | | | | | | 30 | 55 | 19 | 19 | 15 | 25 |
| 2030 | | | | | | | | 66 | 62 | 103 | 175 | 25 | 35 |
| 2050 | | | | | | | | | | 472 | 680 | 234 | 285 |

Figure 2: Carbon price in €/ton $CO_2$

### 3.2.2. CONTRIBUTION OF THE STATIONARY SECTORS IN ENERGY SAVINGS

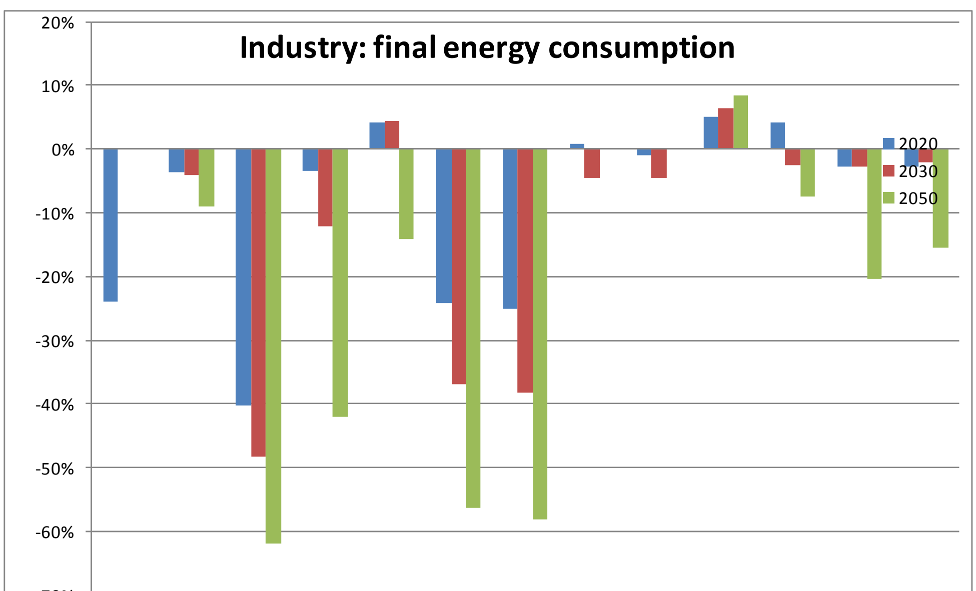
In 2030, reductions in total primary energy consumption are quite similar except for the SEPIA-LEAP B++T+ scenario and the BFP Pyramide and Mosaïq scenarios. Contrary in 2050 we observe large discrepancies (between 8 % and 58 %). The lower savings in the NoNuc-GoCCS scenario result from massive energy intensive CCS deployment.

Differences that are even more significant are observed when looking at sectoral level. For the industry the conjunction of strongly varying industry production trajectories and varying levels of energy savings lead to potentially very strong reductions in energy use in accounting models compared to the results obtained with TIMES and PRIMES at the Belgian or European level. The OPE$^2$RA scenario A has higher energy consumption as it reflects trajectories with an increase in industry production.




| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES -NoNuc_GoCCS | TIMES-No-Nuc-NoCCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | -9% | -9% | -25% | -5% | 1% | -26% | -29% | -11% | -14% | -8% | -9% | -10% | -8% |
| 2030 | | -29% | -49% | -32% | -18% | -41% | -48% | -23% | -23% | -15% | -22% | -20% | -17% |
| 2050 | | -33% | -61% | -58% | -46% | -56% | -65% | | | -8% | -21% | -41% | -38% |

Figure 3: Total primary energy supply, percentage change to 2005

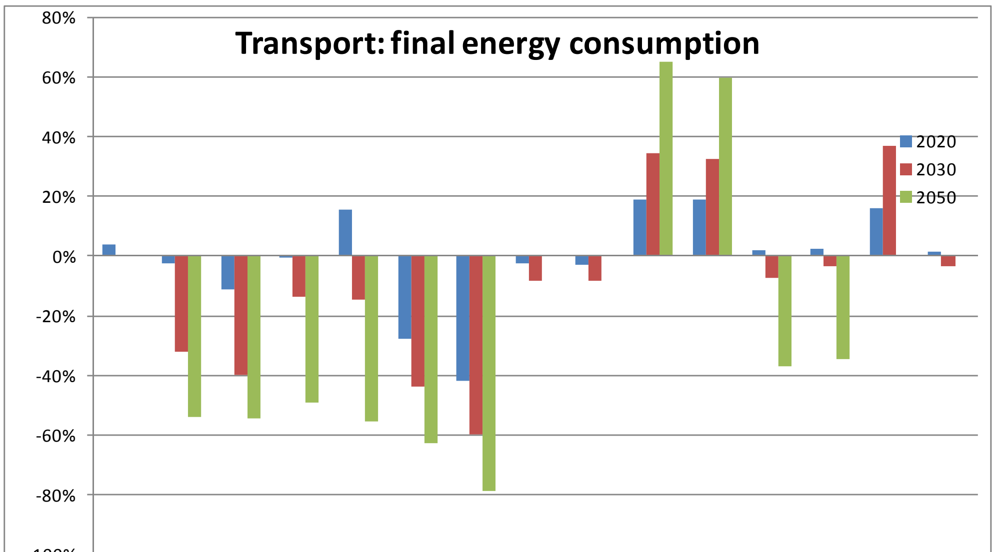



| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-NoCCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | -24% | -4% | -40% | -3% | 4% | -24% | -25% | 1% | -1% | 5% | 4% | -3% | -3% |
| 2030 | | -4% | -48% | -12% | 4% | -37% | -38% | -5% | -5% | 6% | -2% | -3% | -2% |
| 2050 | | -9% | -62% | -42% | -14% | -56% | -58% | | | 8% | -7% | -20% | -15% |

Figure 4: Final energy consumption in the industry sector, percentage change compared to 2005

### 3.2.3. DIFFERENT VIEWS ON THE TRANSPORT SECTOR

Significant differences are also observed for the transport sector. In 2030 final energy demand of the transport sector is between – 60 % to + 37% compared to 2005 levels, and for 2050 between - 79 % and + 65 %. Closer examination of these figures reveals that these differences are only partially explained by different views on evolution of the transport activity. For instance the increase in the TIMES results corresponds with the highest assumptions regarding the transport activity (see annex B). However, a detailed comparison is complicated because the activity assumptions (tonkm for goods transport and vkm for persons transport) are not reported consequently for all models[8].




| | EPM - Scenario 0HF | OPERA - Scenario A | OPERA -Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES -NoNuc_GoCCS | TIMES -No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES | Planet | TREMOVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 4% | -3% | -11% | 0% | 15% | -28% | -42% | -2% | -3% | 19% | 19% | 2% | 2% | 16% | 1% |
| 2030 | | -32% | -40% | -13% | -14% | -44% | -60% | -8% | -8% | 35% | 32% | -7% | -4% | 37% | -4% |
| 2050 | | -54% | -54% | -49% | -55% | -63% | -79% | | | 65% | 60% | -37% | -34% | | |

Figure 5: Final energy consumption of the transport sector, percentage change compared to 2005[9].

### 3.2.4. VIEWS ON THE ELECTRICITY SECTOR

Electricity demand increases significantly in those scenarios, which do not rely on strong behavioural changes. The increase is explained by the electrification of the transport sector, the use of heat pumps for space heating and the continuous growth of electrical appliances. The decrease in OPE²RA scenario E and SEPIA LEAP scenario B++T+, is primarily in the industry (-63 %

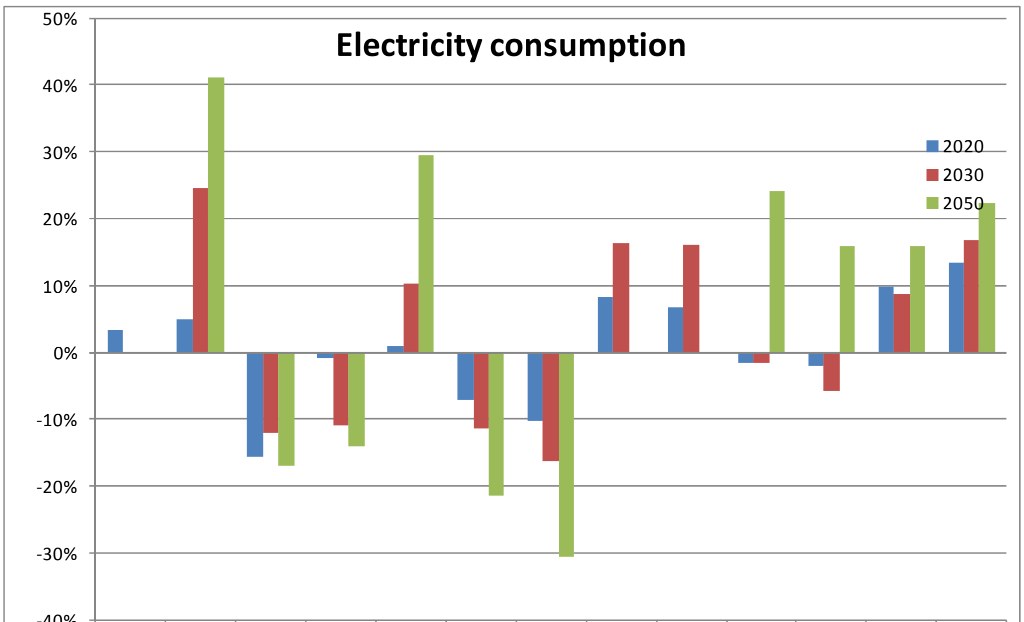
[8] Comparison of results for the transport sector is complicated by the fact that the coverage is different in particular for transport of goods. Often Belgian transport is defined as tonkm on the Belgian territory, including transits. Other definitions exclude transits. For GHG reporting it is based on fuel sales.

[9] Figures for Planet have been estimated on the basis of $CO_2$ emissions and shares of bio-fuels.

and -42 % respectively). In the BFP's AM Piramide and Mosaïc scenarios, the decrease is also likely to be explained by the assumptions concerning industrial activity.

On the production side there is more consistency. Nuclear is phased out in all scenarios. The share of renewable energy in electricity production is between 44 % and 88% in 2050 and natural gas plays an important role in 2030 but loses market share in 2050. However, on coal we observe different views. In most scenarios, including the European scenarios[10], coal disappears or becomes marginal. In OPE$^2$RA Scenario A and NoNUC-GoCCS, CCS is used in coal plants and takes a share of 31 % and 41 % respectively.

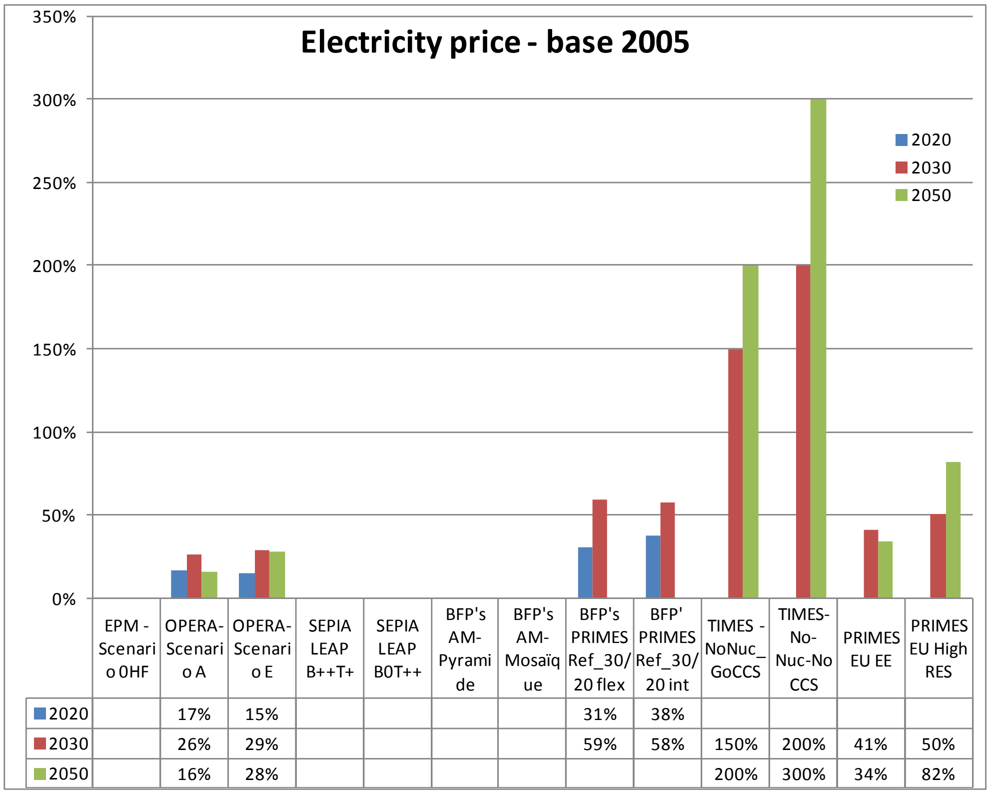
For the electricity price, we observe very high differences which are to a large extent explained by differences in the methodology. In OPE$^2$RA scenario A and E average production cost figures have been considered without including any price for $CO_2$. In PRIMES the cost of electricity is based on average production costs, including the cost of the purchase of $CO_2$ allowances. For TIMES the price reflects the marginal costs of electricity production, which are higher than the average production costs.




| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 3% | 5% | -16% | -1% | 1% | -7% | -10% | 8% | 7% | -2% | -2% | 10% | 13% |
| 2030 | | 25% | -12% | -11% | 10% | -11% | -16% | 16% | 16% | -2% | -6% | 9% | 17% |
| 2050 | | 41% | -17% | -14% | 30% | -21% | -30% | | | 24% | 16% | 16% | 22% |

Figure 6: Electricity consumption: Percentage change compared to 2005

[10] In the EU energy roadmap the share of coal is significantly higher in the Diversified supply technologies scenario and in the Low nuclear scenario.




| | EPM - Scenario 0HF | OPERA- Scenario A | OPERA- Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 17% | 15% | | | | | 31% | 38% | | | | |
| 2030 | | 26% | 29% | | | | | 59% | 58% | 150% | 200% | 41% | 50% |
| 2050 | | 16% | 28% | | | | | | | 200% | 300% | 34% | 82% |

Figure 7: Electricity price percentage change compared to 2005

### 3.3. Economic analysis

The transition paths, resulting from different scenarios, are likely to induce other (desired or undesired) effects on the entire economy, more specifically on GDP and welfare. The type of analysis presented depends on the models used. For instance, effects on GDP can only be quantified when using a macro-economic model, but partial equilibrium models can also compute welfare aspects, though at the level of the energy system. There are no standard procedures or guidelines for quantifying derived effects. The comparison of derived effects from different scenarios is complicated by the different approaches and concepts used.

The FPB analysed more deeply the economic effects of scenarios Ref_30/20_flex and Ref_30/20_int for the year 2020. This analysis concerns the impact on the direct energy system cost (i.e. energy related expenses and the disutility costs) and is complemented by an analysis of the macro-economic costs under different recycling regimes for the additional $CO_2$ tax revenues (lowering debt lowering social security contributions). The first impact is based on the PRIMES results whereas HERMES has been used for analysing derived effects on GDP and its components as well as on competiveness, public finances and employment.

This analysis demonstrates significant increases in the energy related expenses in all segments of the economy. Disutility[11] costs are an important fraction of direct costs. In some scenarios, the disutility costs do represent the whole costs of the energy system. GDP and employment effects largely depend on the use of additional government revenues for $CO_2$ auctioning. Lowering social

[11] The disutility cost is the loss in consumer and producer surplus

contributions results in modest GDP fall but increase in employment while reducing debt results in a more significant drop in GDP and employment.

In the EU low carbon roadmap by the European commission a macro-economic analysis on GDP and employment is based on GEM-E3 but only to 2030. The analysis considers four different cases depending on whether a $CO_2$ tax is considered in the NON-ETS sectors or not; and whether product prices account for opportunity costs originating from free allocated emissions rights or not. GDP is negatively affected (order of -1% in 2030) and even more without a $CO_2$ tax in the NON-ETS sectors (order -2% in 2030) but companies pricing policies do not demonstrate important effects. Employment increases relatively to GDP in all scenarios.

The EU energy roadmap provides an analysis of the average annual energy system costs. The system cost consists of capital expenses, energy costs, direct efficiency investment costs (often integrated in capital costs) and the disutility costs. Disutility costs typically account for 3% to 8 % of total system costs.

In TIMES (TUMATIM) the welfare analysis is reported in terms of change in consumer-producer surplus within the energy system.

### 3.4. CONCLUSIONS

The economic analysis of transition scenarios is not a trivial matter as the more detailed scenario models lack the macroeconomic components and information from these scenario models is not easily translated into the concepts used in macro-economic models.

Quantification of welfare aspects and effects on GDP is surrounded by uncertainty. For instance, the loss of consumer surplus for an energy service depends on the price elasticity for this energy service. The latter is not directly observable. Direct quantification by econometric methods is difficult due to lack of observations on energy service levels. Therefore the quantification of energy service elasticities is done indirectly.

# CHAPTER 4 SPECIFIC ISSUES

Modelling teams have been asked to elaborate on the extent to which a list of key specific issues are (or can be) addressed in their respective models. The answers highlight the extent to which models are currently able to deal with those key issues. They also set the direction in which future research needs to be oriented in order to improve our ability to analyse the transition.

## 4.1. INNOVATION

In accounting models the penetration of emerging technologies is decided by expert judgement. Here we observe two approaches: either what the experts judge as being realistic (simulation approach), or the need for innovation is based on realistic hypotheses to meet the desired objective(s) (back-casting approach).

In traditional macro-economic models innovation is to a great extent exogenous (or it is hidden in some trend coefficients expressing productivity increases, etc...), but more recently some successful attempts have been realised to endogenize technical change. In NEMESIS technical change is endogenous via the variable "knowledge", incorporated in the production functions. In GEM-E3 innovation and the impact of R&D are also endogenously modelled.

In the partial equilibrium models of the energy system (PRIMES and TIMES) the technical economic characteristics of technologies are assumed (exogenous) to change over time (as a result of R&D and economies of scale through mass production). In the PRIMES model, no endogenous learning by doing mechanism is implemented. The TIMES model allows to use learning curves (which to an extent makes technology improvements endogenous, but this functionality is not relevant when running an isolated Belgian TIMES model.

In transport models, emission factors and energy efficiency parameters take into account future technological evolutions in an exogenous manner. Technology choice in transport models is determined by technology cost and other parameters influencing the penetration rate. Breakthrough technology needs to be added explicitly to the model (i.e. change logit structure). The share of alternative vehicles until 2030 (hybrid, plug-in hybrid, electric) in the purchase of new cars is exogenously introduced. Attempts for endogenous technology uptake in the model so far have been unsuccessful (e.g. link between R&D expenditure & learning curves and consequent cost evolutions).

## 4.2. BEHAVIOURAL AND ORGANISATIONAL CHANGE

In this context, behavioural change reflects the ability to consume less energy by changing habits or taking normative private investment decisions and improving energy-efficiency discipline on a voluntary basis, as well as the related changes in the organization of society to allow for these changes to happen (e.g., adapting the timetables for schools and work to reduce transport peaks, or changing urban planning policies to multiply activity centres).

A typical way to implement behavioural changes is by modelling parameters as price elasticities or substitution elasticities. These elasticities have been quantified on historical data and it can be argued that the magnitude of price changes that can be expected in the future would fall outside the range where these equations could be safely used. However, this approach is also limited, as it does not count for changes in the structure of preferences, neither as an evolution in time nor as a result of policy nor driven by cultural changes. Hence, the possibility of any non-price driven behavioural change is not implemented in these models. Moreover, as energy related price elasticities are usually small, then, in the absence of high price increases, only a limited contribution is attributed to behavioural change.

Behavioural changes in accounting models are reflected as changes of the activity drivers, which however are (exogenous) outcomes of expert judgment or stakeholder deliberations, and are not directly related to price changes. Contributions of behavioural change are reflected in OPE$^2$RA scenario E, B++T+ , as well as in the back-casting analysis of the Federal Planning Bureau.

### 4.3. SENSITIVITY TO THE INTERNATIONAL CONTEXT

The macro-economic models are highly sensitive to the international context. In fact these are the only type of models that also incorporate competitiveness –and hence activity- effects resulting from changes in international fuel prices (direct effect and feedback effect) or from changes in national export prices.

In PRIMES and TIMES, the results are sensitive to changes in the international fuel prices but there is no feedback on the activity variables from the macro-system. In PRIMES and TIMES, the carbon price is introduced as an emissions tax or it results from an emissions constraint (shadow price of the constraint).

Accounting models are less sensitive to the international context. In fact international activity is implicitly represented in activity variables, availability of technologies and their techno-economic characteristics, constraints on energy imports (biomass and electricity), but these relationships are not established numerically.

In transport models sensitivity to the international context is limited to fuel prices. Although different 27 European countries are represented in TREMOVE it runs as independent models.

### 4.4. THE DISCOUNT FACTOR

The way the discount factor is implemented is closely related to the modelling of expectations (see section 4.5) in macro-economic models, PRIMES and TIMES the discount factor determines the cost of capital. Consequently the discount factor has an influence on the choice between capital intensive and energy and /or labour intensive technologies. In accounting models the discount factor is used to make an ex-post calculation of the cost of options but does not influence the choice of options.

There is no homogenous view on quantifying discount rates. PRIMES intends to simulate behaviour for different type of agents and therefore uses sector specific discount rates: 8% for large power utilities, 10-12% for heavy industry, 11-14% in service sector and 17% for households. TIMES uses generally the same discount rate for all sectors, of around 2-4%, following a more normative approach EPM uses 5 % for residential, 7,5 % for tertiary and 10 % for industry (real discount rates) for evaluating emission reduction cost curves.

## 4.5. EXPECTATIONS

The formulation of expectations in economic modelling is a critical element that can have significant impact on the outcome. Economic investment decisions are always based on expectations related to economic activity, evolution of prices, performance of technologies. The formulation of expectations is a challenging issue, which we can illustrate with the following example. Assume that it is expected that the price of a technology will go down in the future. Under these conditions it might be rational to postpone the purchase of this technology. If the cost of this technology follows a learning curve (i.e. that the price goes down with cumulative installed capacity) then the expected price drop might not happen.

In the models the following types of expectations have been formalised.

Expectations of stakeholders and experts - Accounting models are not dealing with any formalised type of expectations but obviously expectations of experts and stakeholders are reflected in visions and pathways. From this point of view, they are powerful tools to formalise and discuss expectations with experts and stakeholders in a very open manner. In a similar way exogenous variables in other models reflect expectations of the model user. Discussions with experts and stakeholders on exogenous variables can however be less transparent than those about visions.

Myopic expectations - Implicitly here it is assumed that the current situation will not change dramatically over the lifetime of the investment. Under these conditions, the evaluation of an investment is based on current prices, current activity. This type of expectations is implemented in PRIMES for some sectors and GEM-E3.

Perfect foresight expectations - This type of expectations is implemented in TIMES. All the conditions determining prices, efficiencies of technologies and activity variables are defined by the model user. Investment decisions consider the full endogenous determined horizon. A stochastic variant of TIMES allows to include the cost of uncertainty and to include real options theory.

Adaptive expectations - HERMES and NEMESIS do not consider expectations explicitly but some type of adaptive expectations is implemented in the ECM structure. The ECM (error correction mechanism) structure assumes that a long-term equilibrium conditions between economic variables exists (co-integration relationship) and that the real economy gradually tends to this long-term equilibrium. The more the actual situation deviates from the co-integrating relationship the more it tends to move towards this long-term relationship.
Although there is strong empirical evidence for the ECM structure, there is also a certain risk that this structure is not able to capture transition processes. For instance, if a long-term equation defines a relationship between energy consumption and economic activity, then long-term energy savings will not be possible. However if the long term equation defines a relationship between energy service and economic activity, then long term energy savings might be feasible.

Modelling expectations and discount rates - The discount factor determines the weight that is given to future cost and benefits in the decision making process. In Table 2 the corresponding weights for typical discount rates used in TIMES and PRIMES are presented. If the weights are small (like for households in PRIMES) then future costs and benefits will have no influence on the current decisions. This is consistent with the use of myopic expectations for households in PRIMES. For other sectors PRIMES uses a less myopic approach. The social discount rate of 4% in TIMES is consistent with the perfect foresight hypothesis.

| Model (sector) | Discount rate | Weight to future costs and benefits | | |
|---|---|---|---|---|
| PRIMES | | 10 years | 20 years | 30 years |
| -Households | 17% | 21% | 4% | 1% |
| -Services | 13% | 29% | 9% | 3% |
| -Large industry | 11% | 35% | 12% | 4% |
| -Power utilities | 8% | 46% | 21% | 10% |
| TIMES | 4% | 68% | 46% | 31% |

Table 2: The weights given to future costs and benefits for typical discount rates applied in PRIMES and TIMES

The transition to a low carbon economy involves choices on technologies with a lifespan extending to 30 or 40 years and even longer. Therefore choices made today interfere with new technological options that will become available in the future. For instance the choice for a new coal plant today will interfere with the penetration of renewable energy production in the future and the construction of new dwellings will have an impact on energy consumption over the full lifetime of the dwelling. In order to evaluate possible lock-in situations, sufficient weight should be given to future costs and benefits.

### 4.6. ENDOGENOUS GROWTH

Although it is generally recognised that economic growth is a key macro-economic variable, we observe a large discrepancy on how this variable is determined and how it is used. Two aspects merit some discussion: economic consistency and endogenous growth.

Economic growth is an exogenous variable in accounting models and partial equilibrium models. In some way economic growth determines the activity levels but there is no systematic methodology to guarantee consistency of activity levels and growth assumptions. This might become problematic when accounting models are not used appropriately for stakeholders consultation. By asking sector specialists for a reasonable low demand-activity scenario, one might get results, which make sense individually, but which cannot be aggregated without violating overall macro-economic growth assumptions. In order to be consistent, weak activity in one sector assumes higher growth in other sectors. Therefore it could be useful to complement energy accounting models with a macro-economic accounting model, which is the case for the BFP's accounting model[12].

National income or GDP are typical output variables in macro-economic models (HERMES, NEMESIS, GEM-E3) but it has to be emphasized that the mechanism behind economic growth are only partially expressed (represented).

[12] This is generally not a major issue, however, for the energy intensive steps in steel, cement, lime or glass production, as they only represent a small fraction of the total value added of industry.

In most macroeconomic models growth is generated by exogenous assumptions on technical progress or on increase in resources (population, decrease in unemployment, …). NEMESIS and GEM-E3, include an endogenous technical change module based on "knowledge economics" where R&D stock (resulting from R&D expenditures) and spill over effects (between sectors) are considered and contribute also to the growth.

It should be noted that many long-term scenarios reviewed with these models assume or imply strong GHG reduction (of the order of -80% between 1990 and 2050). It is reasonable to suppose that such a reduction would imply significant changes in the structure of societies (economic activity, consumer preferences, relative prices,...) similar or maybe even outreaching to some of the significant ones seen in the past 40 years (computers, internet, nano-technology, etc.).

Long-term forecast should thus be handled with great care. Indeed, many equations and parameters of current models are built based on observations from the past. Even the structure of the equations and the models are based on observed data, behaviours and technologies. There is thus no guarantee that future structural changes, trend breaks and current models based on current observations can capture future growth. They can, however, be used to show the magnitudes of the technological and behavioural changes needed to reach the long-term objectives (GHG emission reductions or others).

### 4.7. Macro-economic and welfare impacts

Welfare calculations are not considered in accounting models. For other models different approaches are observed.

In the macro-econometric models (HERMES, NEMESIS) utility functions are not implemented, but disposable income or GDP can be used as a proxy for welfare.

In GEM-E3 a social welfare function is implemented. Welfare is derived from the consumer's utility function, which includes in a separable way the utility from the consumption of goods and leisure and the environmental utility/damage.

The welfare aspects in PRIMES and TIMES are limited to the energy system (no feedbacks from/to macro-level). PRIMES reports on the costs from the perspective of final energy consumers. This includes capex, opex, fuel costs as well as disutility costs. In TIMES welfare cost is represented by the change in consumer and producers surplus in the energy system. It is the optimal welfare loss or gain, which can be obtained given the model constraints. External costs can be considered by introducing a tax on pollutants in both models.

TREMOVE and PLANET are using a similar welfare approach. The welfare change from policy measures is expressed as the gain/loss in consumer and producer surplus + extra tax revenues of government + changes in external costs (emissions to air, accidents, noise, infrastructure). Congestion costs are included automatically via generalised prices.

Macro-economic models are suitable for the development of consistent activity projections, for the analysis of macro-economic effects of policies and measures and for competitiveness analysis. Given the long-term perspective, NEMESIS is likely to be better suited than HERMES but HERMES could be used for analysis of medium term transition. The comparative advantage of NEMESIS is its ability to develop a reference scenario whereas the GEM-E3 model is particularly useful for welfare analysis and to evaluate the full impact of policies and not only the adjustment/transition path. Both models can be used for the evaluation of policy instruments. To support intellectual discussions among policy makers and to get more scientific insights it would be worthwhile using both models and comparing the results.

### 4.8. INCOME DISTRIBUTION AND OTHER SOCIAL ASPECTS

Except for HERMES and NEMESIS all models use the concept of the representative consumer and cannot be used to study social distributional impacts of the transition to a low carbon economy. The HERMES model makes a distinction between low-high wages and younger-older employees and in NEMESIS there is a difference between skilled and unskilled labour.

We conclude that the functionalities to explore social impacts of the transition to a low carbon economy are limited.

### 4.9. REMARK ON TRANSPORT SCENARIOS

Similar to other sectors the transition to a low carbon economy involves a technology and a behavioural component. The discrepancies between the scenarios relate to the technology component and even more to the activity component. The relevant question is whether a strong reduction of transport activities is compatible with economic growth. The huge differences feed the impression that the complex relationship between the transport sector and GDP so far has not been clarified sufficiently. Transport of goods is part of the production process (not only linked to) as it is a requirement to get the goods to the marketplace. Persons transport activities can be looked at from the different transport motives. Partially it should be allocated to the production process (working trips) and partially to consumption (leisure trips) but undoubtedly there are also trip categories that are difficult to allocate. An important challenge for the transport models is the development of long-term activity scenarios, which are consistent with other views on the transition to a low carbon economy.

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More model information:

http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The_PRIMES_MODEL_2010.pdf
http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/PRIMES_ENERGY_SYSTEM_MODEL.pdf
http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1569_2.pdf
http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/Peer_Review_Part_1_2_3.pdf
http://www.tremove.org
http://www.etsap.org
http://ipts.jrc.ec.europa.eu/activities/energy-and-transport/gem-e3/
http://www.e3mlab.ntua.gr/models.php?title=gem-e3

## ANNEX A : TEMPLATE FOR THE PRESENTATIONS

### Welfare in the transition to a low carbon economy

***How can models support policy***?

**Template for the presentations**

### General characteristics of the model

**General overview of the model (Max 2 slides**)

Methodology, sectoral coverage, size (detail), theoretical economic background, typical simulation horizon (and why), model specification

Input and output variables (1 slide input, 1 slide output)

Different models use different type of input and results. Please provide an overview of the direct input requirements (exogenous assumptions) in your model and the direct output variables (endogenous results)

For some key variables, we would like to know how these relate to all models. These variables might be part of the exogenous variables or endogenous results or they are used indirectly to build the scenario or some indicative value can be derived from the output variables. Please mention the following variables and how they relate to your model: GDP (growth), Energy prices, Carbon price

**Methodological issues related to the model parameters**

Different models use different type of parameters and rely on different methodologies for quantifying these parameters. (For instance econometric models often use historical data (time series and panel data to derive elasticities), but alternatively they can use literature figures as well)

Projection and/or policy analysis tool

Please clarify whether your model approach is appropriate for projection and/or policy analysis. A projection tool requires only a limited number of input variables (historical variables and a limited number of exogenous assumptions) and is able to produce in the most endogenous manner a reference scenario whereas in a policy analysis tool the focus is mainly on the deviation between a reference an a policy scenario.

### Specific issues

**Innovation**

New technologies emerge and performance of existing technologies improves but modelling innovation and progress is still a big intellectual challenge. Not all research programs are successful. In top-down models, using a low technological resolution, technological progress is often implicit represented is some parameter values. In bottom-up modelling it is even more critical. One approach is the use of learning curves, stating that the price of technologies is a decreasing function of cumulative worldwide installed capacity, expressed in the progress ratio. The empirical underpinning of this approach is rather weak and the practical application is limited by the geographical coverage. Another challenge is that when making projections over a very long horizon in bottom up models one has to make assumptions on new technologies that are still in the research phase or that have not yet been emerged in a preliminary phase.

However, despite difficulties in quantifying and modelling, technological progress is a one-directional non-stationary process that cannot be ignored when developing scenarios with a horizon up to 2050. Please illustrate how technological progress is handled in your model. What is the modelling approach, how has it been quantified?

**Welfare**

One obvious question for any economist is: how can we derive the appropriate pathway that realises the objective and optimises welfare. A first question is how welfare is identified and represented in the models. For instance, in an aggregated macro-economic model one could assume that welfare is represented by private consumption expenditure. But then as the transition to a low carbon economy requires huge investments in energy savings and renewable energy technologies, families will shift away their spending from consumption (fuel spending) to investment (energy saving investments) but the will enjoy a similar level of comfort.

Please clarify how welfare is represented in your model, explain how welfare relates to GDP, costs of mitigation policies, employment, consumption, disposable income ( if appropriate for your model), highlight pros and cons of this approach and explain how welfare aspects of policies can be evaluated. The answers can be different depending on the type of the model. For instance, sectoral models can deal with the wellness aspects attributed to the sector only.

Intergenerational aspects and the risk for lock in

The transition to a low carbon economy requires the construction of low carbon infrastructure and will invoke a shift from fuel spending (consumption) to capital spending (investment). At the macro-economic level, additional investment requires additional savings (I=S). In critical sectors, decisions today will have implications in 2050. Wrong decisions today, in particular related to infrastructure with a long life time, might create a lock-in and additional costs for the future generations. Please, explain how your model handles intergenerational aspects.

Income distribution and other social aspects

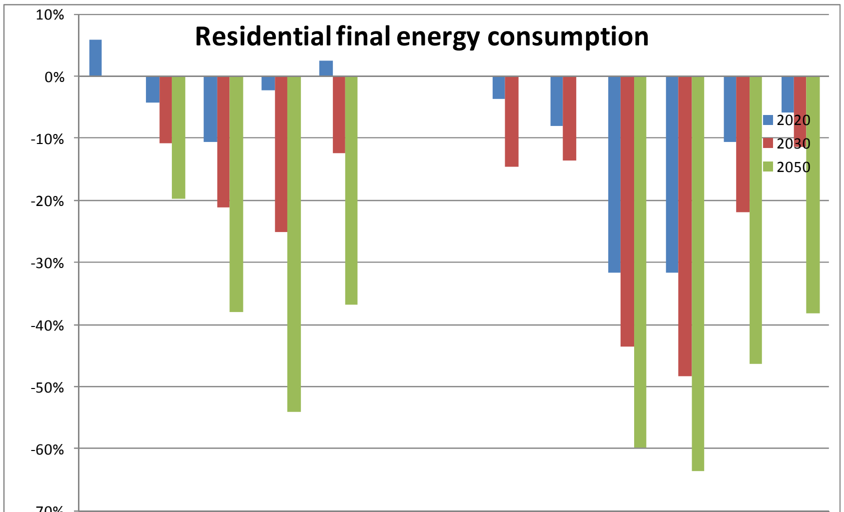
So far little attention has been given to the analysis of income redistribution and social aspects related to GHG policies, but recently the existing support system for solar panels has highlighted this issue. The transfer to a low carbon economy will involves a shift from variable costs to investment.

**Personal appreciation**

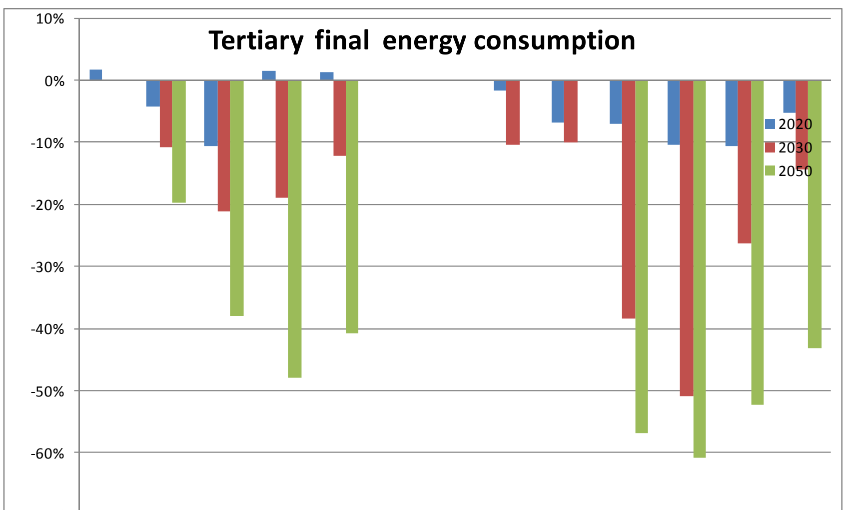
We don't need always complex models to answer simple questions (but we do need them to answer the more complicated questions and we should avoid too many simplifications)

What are the particular strengths of your model? Why is it better than other models? What kind of analysis is it suited for? Please illustrate with some real examples

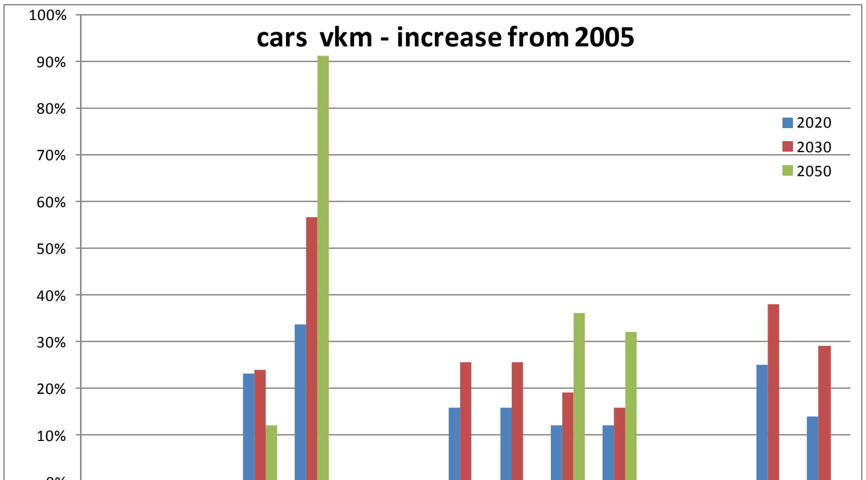
## Annex B : Additional model results




| | EPM - Scenario 0HF | OPERA- Scenario A | OPERA- Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM- Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES -NoNuc _GoCCS | TIMES-No-Nuc-NoCCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 6% | -4% | -11% | -2% | 2% | | | -4% | -8% | -32% | -32% | -11% | -6% |
| 2030 | | -11% | -21% | -25% | -12% | | | -15% | -14% | -44% | -48% | -22% | -11% |
| 2050 | | -20% | -38% | -54% | -37% | | | | | -60% | -64% | -46% | -38% |

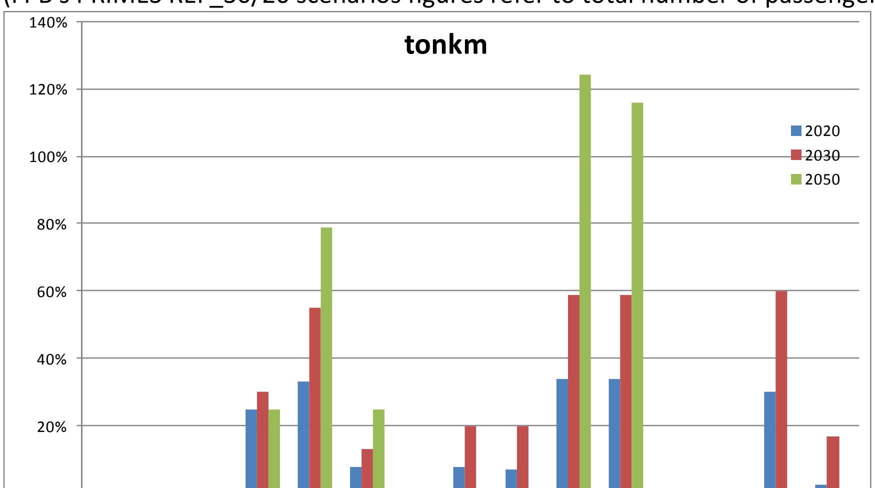



| | EPM - Scenario 0HF | OPERA- Scenario A | OPERA- Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM- Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES -NoNuc _GoCCS | TIMES-No-Nuc-NoCCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 2% | -4% | -11% | 1% | 1% | | | -2% | -7% | -7% | -10% | -11% | -5% |
| 2030 | | -11% | -21% | -19% | -12% | | | -10% | -10% | -38% | -51% | -26% | -14% |
| 2050 | | -20% | -38% | -48% | -41% | | | | | -57% | -61% | -52% | -43% |

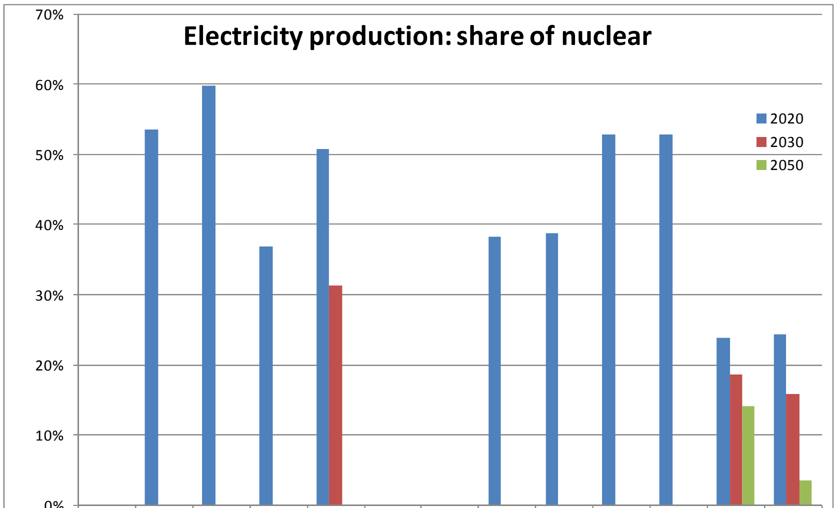



| | EPM - Scenario 0HF | OPERA - Scenario A | OPERA - Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES -No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES | Planet | TREMOVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | | | 23% | 34% | | | 16% | 16% | 12% | 12% | | | 25% | 14% |
| 2030 | | | | 24% | 57% | | | 26% | 26% | 19% | 16% | | | 38% | 29% |
| 2050 | | | | 12% | 91% | | | | | 36% | 32% | | | | |

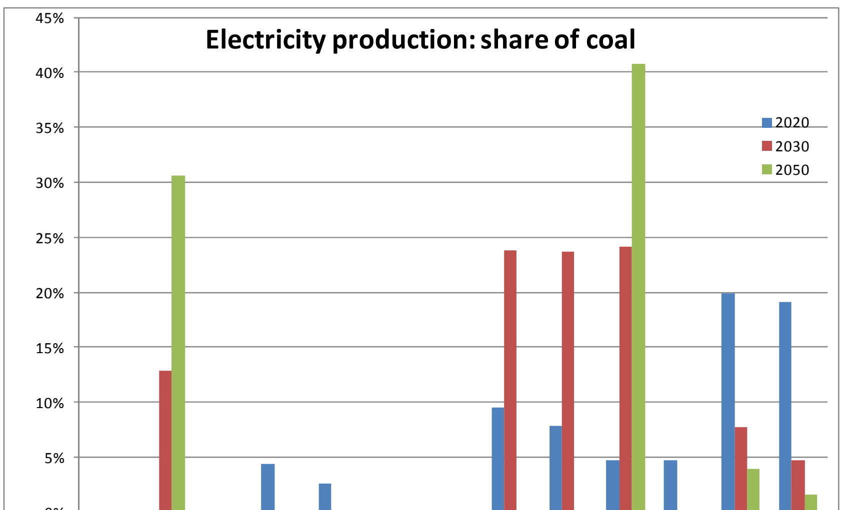
(FPB's PRIMES REF_30/20 scenarios figures refer to total number of passenger-kilometres)



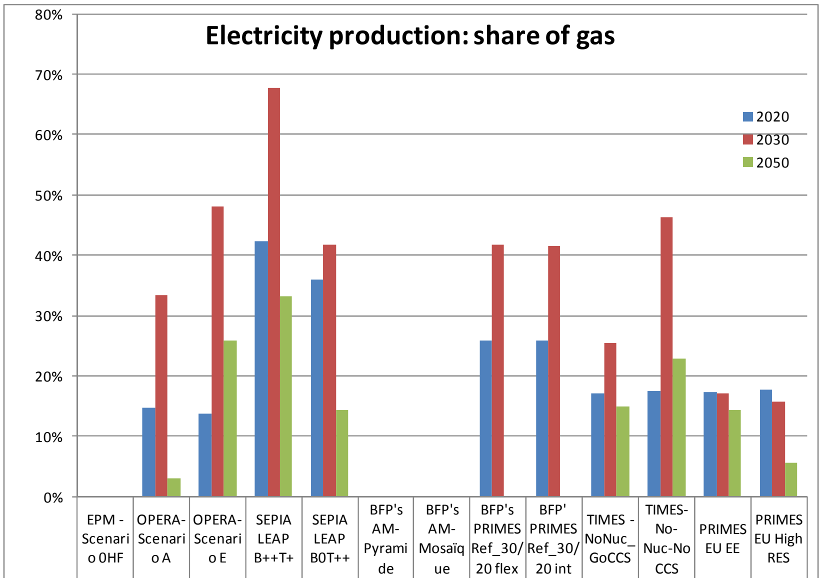

| | EPM - Scenario 0HF | OPERA - Scenario A | OPERA - Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES -No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES | Planet | TREMOVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | | | 25% | 33% | 8% | 0% | 8% | 7% | 34% | 34% | | | 30% | 3% |
| 2030 | | | | 30% | 55% | 13% | 0% | 20% | 20% | 59% | 59% | | | 60% | 17% |
| 2050 | | | | 25% | 79% | 25% | 0% | | | 124% | 116% | | | | |



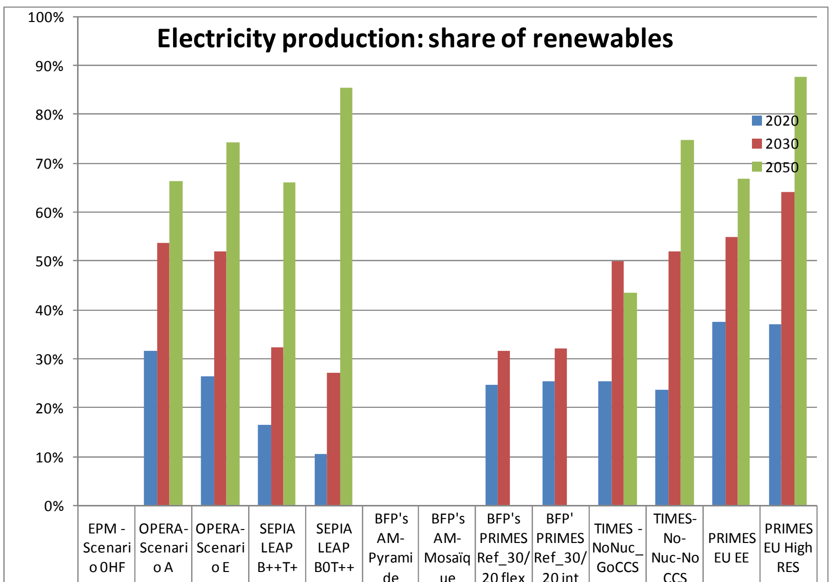

| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 54% | 60% | 37% | 51% | | | 38% | 39% | 53% | 53% | 24% | 24% |
| 2030 | | 0% | 0% | 0% | 31% | | | 0% | 0% | 0% | 0% | 19% | 16% |
| 2050 | | 0% | 0% | 0% | 0% | | | | | 0% | 0% | 14% | 3% |



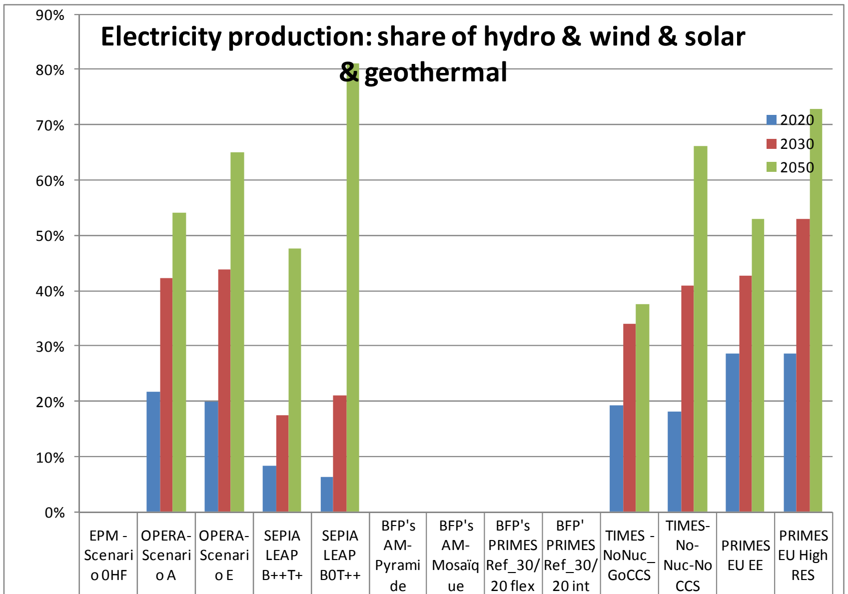

| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 0% | 0% | 4% | 3% | | | 10% | 8% | 5% | 5% | 20% | 19% |
| 2030 | | 13% | 0% | 0% | 0% | | | 24% | 24% | 24% | 0% | 8% | 5% |
| 2050 | | 31% | 0% | 0% | 0% | | | | | 41% | 0% | 4% | 2% |



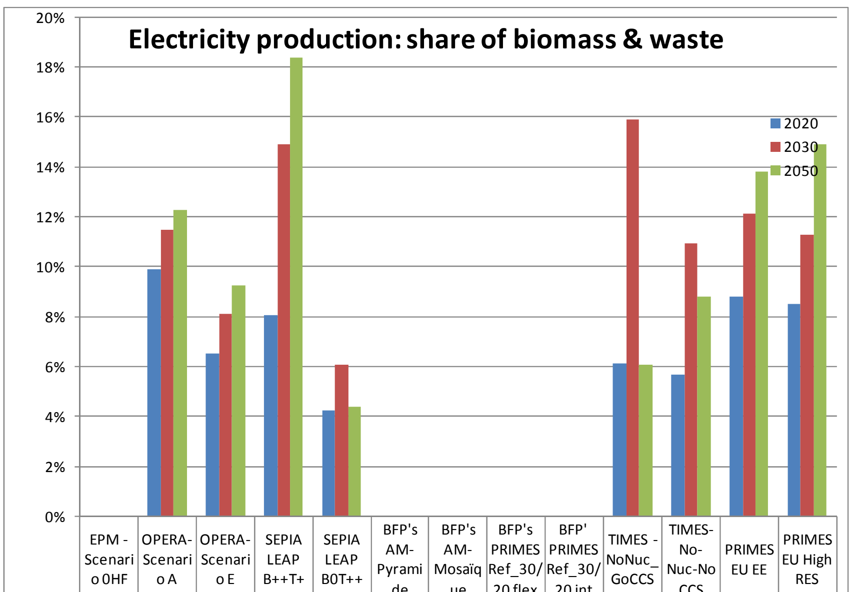

| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 15% | 14% | 42% | 36% | | | 26% | 26% | 17% | 17% | 17% | 18% |
| 2030 | | 33% | 48% | 68% | 42% | | | 42% | 42% | 25% | 46% | 17% | 16% |
| 2050 | | 3% | 26% | 33% | 14% | | | | | 15% | 23% | 14% | 6% |




| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 32% | 26% | 16% | 11% | | | 25% | 25% | 25% | 24% | 37% | 37% |
| 2030 | | 54% | 52% | 32% | 27% | | | 32% | 32% | 50% | 52% | 55% | 64% |
| 2050 | | 66% | 74% | 66% | 86% | | | | | 44% | 75% | 67% | 88% |




| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 22% | 20% | 8% | 6% | | | | | 19% | 18% | 29% | 29% |
| 2030 | | 42% | 44% | 17% | 21% | | | | | 34% | 41% | 43% | 53% |
| 2050 | | 54% | 65% | 48% | 81% | | | | | 38% | 66% | 53% | 73% |




| | EPM - Scenario 0HF | OPERA-Scenario A | OPERA-Scenario E | SEPIA LEAP B++T+ | SEPIA LEAP B0T++ | BFP's AM-Pyramide | BFP's AM-Mosaïque | BFP's PRIMES Ref_30/20 flex | BFP' PRIMES Ref_30/20 int | TIMES - NoNuc_GoCCS | TIMES-No-Nuc-No CCS | PRIMES EU EE | PRIMES EU High RES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | | 10% | 7% | 8% | 4% | | | | | 6% | 6% | 9% | 8% |
| 2030 | | 11% | 8% | 15% | 6% | | | | | 16% | 11% | 12% | 11% |
| 2050 | | 12% | 9% | 18% | 4% | | | | | 6% | 9% | 14% | 15% |