# Untangling the web : integrating energy and environmental policy instruments by assessing their interactions along power systems

Simões, S.

**Author**: Simões, Sofia
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# 5 Effects of exogenous assumptions in GHG emissions models - A 2020 scenario study for Portugal using the Times model*

* This chapter is submitted tp the Technological Forecasting and Social Change Journal for publication. Co-authors: Patrícia Fortes, Júlia Seixas and Gjalt Huppes.

## Abstract

Model outcomes are substantially based on assumptions. The challenge of this paper is to quantify the role of specific assumptions on policy relevant modelling outcomes. The development of greenhouse gases (GHG) emission scenarios, using energy-economy-environment models, is fundamental for climate policy. Scenario uncertainty depends to a substantial degree on the appropriateness of the assumptions implemented as exogenous parameters. Main causes for uncertainty relate to the different assumptions on exogenous parameters such as demographic and economic development, technology evolution and deployment, and the implementation and effectiveness of policy decisions. To assess the uncertainty it is a common practice to run different scenarios combining several assumptions. However, this makes it difficult to assess the role of individual assumptions in overall scenario's uncertainty. This paper assesses the individual contribution of different exogenous parameters for scenarios on the Portuguese energy system. The linear optimization technology model TIMES_PT is used to develop seven alternative GHG scenarios for 2020. The Baseline scenario includes a combination of assumptions on all exogenous parameters. The other six technical scenarios each vary in only one assumption. The comparison between them shows how the assumption influences outcomes quantitatively. The assumptions contributing most to overall uncertainty are the ones related to the socio-economic development, followed by the assumptions on technology deployment. Quite astonishingly, the availability of energy resources leads to minor variations on GHG emissions only, less than 2% of the Baseline scenario emissions in 2020.

## 5.1 Introduction

Energy-economic-environment models such as TIMES (Loulou *et al.*, 2005a and 2005b), but also PRIMES (Capros, n.d.) and POLES (Russ *et al.*, 2009), are frequently used to support policy makers in climate change policy decisions. They are used to develop greenhouse gas (GHG) emission scenarios, as conditional forecasts. Examples are the EU Energy Climate Policy Package (EU Commission COM(2008) 30) that relied on emission scenarios developed with the PRIMES model (Capros *et al.*, 2008); the French National Climate Change Plan[48] (NCCP) which used GHG scenarios for the electricity sector derived from POLES (DGEC, 2011); the Italian official energy and GHG emission scenarios built with the TIMES Italy model (ENEA, 2012); and the United Kingdom's 4$^{th}$ Carbon Budget of the country's Carbon Plan, using the MARKAL model (AEA, 2011). Such models require a set of exogenous assumptions, like as the rate of demographic and economic development, rate of energy-efficient technology evolution and deployment, the availability and price level of energy resources, and the pace of implementation and effectiveness of policy decisions.

Naturally, each of these assumptions has an associated uncertainty[49]. Therefore, the degree of uncertainty of each GHG forecast is affected by the assumptions on exogenous parameters (IEA, 2012; DECC, 2011). It is common practice to model sets of alternative scenarios representing different sets of assumptions combined, as interesting pathways. Each pathway combines two or more sets of exogenous assumptions, resulting in a range of emission scenarios. One of the most well-known examples of this approach is in the Special Report on Emission Scenarios (SRES) of the IPCC (IPCC, 2000). For example, the IPCC A1F1 emission scenario considers a pathway that describes a world with fast economic and population growth peaking in 2050, continued use of fossil fuels and moderate deployment of new and efficient technologies. In opposition the A2 scenario has continued population growth beyond 2050 but slower economic and technological change (IPCC, 2000). There is good reason to combine different pathways into feasible

48 The emission scenarios used in the French NCCP are also an input in other national policies, especially the National Energy Efficiency Action Plan.

49 In this paper we use the IPCC definition of the term (IPCC, 2012: p.564): "An expression of the degree to which a value or relationship is unknown". It can result from many reasons as "quantifiable errors in the data, ambiguously defined concepts or terminology, or uncertain projections of human behaviour" and thus can be represented both quantitatively and qualitatively.

scenarios. In that process, however, information on the role of the different assumptions is lost. It also is difficult and time-consuming to estimate the contribution of each individual assumption on overall uncertainty of scenario outcomes. This paper is set out to fill this gap in knowledge, highly relevant in interpreting modelling outcomes for policy purposes.

Which assumptions are the most relevant ones and which should be modelled and assessed in more detail? Typically, policy makers and modellers place special emphasis on assumptions on variations of socio-economic growth, on fossil fuel prices and on the availability of key energy technologies (e.g. variable renewable energy resources (RES) or nuclear). Assumptions on the pace of the implementation / decommissioning of planned electricity plants and detailed deployment of end-user energy efficient equipment (e.g. appliances or insulation) are not always perceived as equally relevant for uncertainty, possibly because these are areas that can be more easily controlled by national or regional policy making. Most national and EU GHG emissions scenarios do not explicitly address these two last exogenous assumptions (see next section) and to our knowledge individual variations to each of the exogenous assumptions was never performed with the TIMES family of models.

This paper addresses this issue by assessing the contribution of each of a set of exogenous parameters, using a scenario study on the Portuguese energy system as a case. We vary the penetration of end-use energy efficient equipment; socio-economic growth rates; rate of implementation of policy incentives & investments for promotion of renewable electricity; availability of water resources for hydropower; and primary fossil energy import prices. The linear optimization technology model TIMES_PT is used to develop seven alternative GHG scenarios for 2020. One of these is a Baseline scenario which includes a combination of assumptions on all exogenous parameters, while the others have variations in only one of them. The next section presents an overview of exogenous assumptions in GHG emission scenarios in several European countries, followed by a section on the methodology for scenario development in the TIMES_PT model, and finally there are the analysis of results and the conclusions.

## 5.2 Overview of exogenous assumptions in GHG emission scenarios across Europe

An overview of major exogenous assumptions in energy and GHG emission scenarios for eight European countries is found in Table 5.1. The scenarios typically cover the period to 2020 or 2030. We focused on scenarios which have been used to support national energy/climate change policy. This overview does not review all available emission projections as we aim here to set a context for the assessment of scenario studies for Portuguese policy development. In the reviewed studies no systematic quantitative uncertainty assessments have been performed, with limited exceptions in the studies for the United Kingdom, Spain and the Netherlands. All studies include a simplified analysis for varying one or more of selected exogenous assumptions. In none of the documents we found indication that a systematic series of variations in one or more of the assumptions was performed as part of the sensitivity analysis. Instead, very specific alternative cases were assessed, e.g. high oil prices relative to a specific oil price or no implementation at all of a specific policy measure (P&M). This selection of assessed assumptions probably reflects ideas on what is politically acceptable or relevant, regardless of effects on GHG emissions as modelled. This is the case for example in the revision of the German forecasts introducing a nuclear exit option following the Fukushima accident.

We have found that from these 8 studied cases only Portugal and Spain have used more than one macro-economic scenario. All forecasts, consider different degree of implementation of existing and planned P&M that can be broadly grouped with having effects on energy intensity via promotion of energy efficiency and on the deployment of renewable electricity (RES-e) power plants. The most common considered P&M are the National Energy Efficient Action Plans (NEEAP) and the National Renewable Energy Action Plans (NREAP). Not all of the forecasts are developed exclusively with the aim of deriving GHG emissions scenarios or projections, as they are in fact used for national energy planning. Therefore, probably some of the assumptions are relevant for energy policy making and not necessarily for GHG emission mitigation. Nonetheless, when it comes to energy production and consumption these two are closely related enough for considering them in our study.

**Table 5.1 – Examples of medium term GHG emission scenarios and projections from energy production and consumption and considered exogenous assumptions**

| **Study** | **Methods** | **Timeline** | **Major exogenous assumptions** [a] |
|---|---|---|---|
| **Dutch Reference projection energy and emissions 2010-2020** | 12 combined models including POWERS for wholesale Dutch electricity market and RESolve-E for renewable electricity (ECN/PBL, 2012) | 2020-2030 | Three scenarios with the following policy variants: adopted P&M, adopted plus proposed, and adopted plus "*Lente*" policy package. This entails differences in: level of effectiveness of buildings thermal regulations, deployment of more efficient technologies and installed fossil power capacity in 2020, level of financial incentives to RES power plants (and subsequent RES-E generation), biofuels and deployment of RES technologies for heating and cooling.<br>All scenarios have the same macro-economic assumptions (-0.3% GDP annual growth rate in 2010, 1.7% in 2011-2020), as well as energy and $CO_2$ prices (20 €/t in 2020). However, the uncertainties regarding some of the parameters' assumptions above were translated into uncertainty of energy use and emissions per sector by attributing ranges to energy and $CO_2$ prices. |
| **French NCCP** | POLES energy system simulation model (DGEC, 2011) | 2020-2030 | Two scenarios, with and without the P&M in the Grenelle policy package (Pre-Grenelle and Grenelle scenarios). This entails differences in: level of effectiveness of thermal regulations for buildings, EU ETS $CO_2$ prices for industry (18 or 25€/t in 2020), type of biofuels in road transport (1st and 2nd generation), deployment of new installed nuclear capacity in 2020 and level of cross border electricity trade.<br>Both scenarios rely on the same macro economic assumptions (1.5% GDP annual growth rate in 2010-2015, 2.2% in 2015-2020 and 1.6% in 2020-2030) and energy prices (oil price of 100 USD/bbl in 2020 and 115 USD/bbl in 2030). The scenarios mention a preliminary sensitivity analysis on nuclear power capacity. |
| **German Scenarios for an Energy Policy Concept** | DIME investment and dispatch optimisation model for electricity and CHP and LORELEI optimisation model for renewable electricity integration (PROGNOS/, EWI/ GWS, 2010 and 2011) | 2020 (2050) | Five scenarios: reference plus scenarios I - IV, where the reference scenario reflects the extrapolation of observable trends and no $CO_2$ cap. Scenarios I - IV have a 2020 $CO_2$ cap of 40% below 1990 levels, different extension times for existing nuclear power plants and rates for energy efficiency improvements. An update was made in 2011 following the Fukushima accident converging in an "Exit" and "Life Extension" scenarios regarding the nuclear plants.<br>Only one common macro-economic scenario with the following GDP annual growth rates: 0.35% in 2008-2015 and 0.66% in 2016-2020 with oil price of 98 USD/bbl in 2020 and 110 USD/bbl in 2030. The $CO_2$ prices are of 20 or 19-23 €$_{2008}$/t in 2020, respectively for the reference and I – V scenarios. No other explicit sensitivity analysis or variation in assumptions seems to have been made but for alternative retrofit costs for nuclear power plants in the scenarios I – V. |

| Study | Methods | Timeline | Major exogenous assumptions [a] |
|---|---|---|---|
| **Irish GHG emissions and energy forecasts** | HERMES macro-economic model for the energy sector and IDEM electricity dispatch model (SEAI, 2011) | 2020 | Three scenarios with different policy variants: Baseline (all P&M until end of 2010), NREAAP/NEEAP with the P&M in these two plans including +7% RES installed capacity in 2020 than Baseline, and the Exploratory scenarios with two variations: Exploratory Potential with higher RES deployment (+148% installed capacity in 2020 than Baseline) and Exploratory Risk with a more pessimistic view of energy efficiency and RES developments (-1% installed capacity in 2020 than Baseline).<br>All scenarios have the same macro-economic assumptions (3.0% GDP annual growth rate in 2011-2015, 3.3% in 2016-2020), as well as energy (oil price of 111 USD/bbl in 2020) and $CO_2$ prices (33 €/t in 2020). No variations in oil prices or in economic growth are quantified, although discussed. The variations in exogenous parameters are the ones in the scenarios described. |
| **Italian GHG emissions and energy scenarios** | TIMES Italy energy system optimisation (ENEA, 2012) | 2020-2030 | Three scenarios Reference (P&M in place as in 2009), Current Policies (considers effect of NEEAP and NREAP) and Roadmap (necessary additional P&M to comply with GHG target as in EU Road Map 2050).<br>All scenarios have the same macro-economic assumptions (1.0% GDP annual growth rate in 2011-2015, 1.5% in 2016-2020), as well as energy (oil price of 108 USD/bbl in 2020 and 129 USD/bbl in 2030) and $CO_2$ prices (32 €/t in 2020). The variations in exogenous parameters are only the ones in the described scenarios. |
| **Portuguese NCCP** | TIMES_PT energy system optimisation model (Seixas *et al.*, 2009) | 2020-2030 | Four scenarios combining two different macro-economic scenarios (Tendency and Change) with different level of implementation of P&M as planned in the previous version of the NCCP and NEEAP (from energy efficiency in buildings to deployment of RES power plants and biofuels in transport) and as in the energy policy targets to meet with the RES final energy national target: Business as Usual (only existing policies and RES plants), Tendency Kyoto and Change Kyoto (P&M and RES deployment as in the NCCP and NEEAP) and Road Map RES (high RES deployment).<br>The two macro-economic assumptions scenarios encompass the following GDP annual growth rates: 1.7 – 1.9% GDP in 2006-2010, 1.9 – 2.8% in 2011-2015 and 2.1 – 3.2% in 2016-2020). All consider the same energy prices including an oil price of 84 USD/bbl in 2020, 93 USD/bbl in 2030, and no $CO_2$ prices. Sensitivity analyses were performed for high primary energy import prices and for low and high hydro availability. |
| **Spanish GHG** | Non identified simulation tool (MINETUR, 2011, | 2020 | In MINETUR (2011) there are three scenarios: Central, High and Low considering a similar degree of implementation of P&M (NEEAP (E4), Spanish Strategy for Climate Change and Clean Energy, NREAP, Strategic Carbon reserve Plan and the Industry Policy Plan |

| Study | Methods | Timeline | Major exogenous assumptions [a] |
|---|---|---|---|
| **emissions and energy scenarios** | MAGRAMA, 2011) | | (PIN2020)) but different annual rates for the reduction of the final energy intensity in 2010-2020 (respectively 2%, 1.5% and 2.5%), resulting in differentiated final and primary energy consumption. In order to ensure the compliance with the common RES targets a differentiated RES deployment is considered in the Central and High scenarios (22% more RES installed capacity in 2020 in the High scenario).<br>The three macro-economic assumptions scenarios, Low, Central, and High, encompass the following respective GDP annual growth rates: 1.9, 2.2 and 2.9% in 2010-2015 and 1.8, 2.4 and 2.8% in 2016-2020. All consider the same energy prices including an oil price of 111 USD/bbl in 2020, and $CO_2$ prices of 25 €/t in 2020.<br>For the official GHG emission scenarios (MAGRAMA, 2011) a slightly different approach was considered as the three GHG emission scenarios assume different degree of implementation of the P&M above (WoM with only P&M until 2000, WM with the P&M until 2020 and WaM with P&M under discussion). It is developed an uncertainty analysis with subjective probability levels defined by experts to identify upper and lower ranges for economic evolution, energy and material efficiency, emission factors and general uncertainty within a 95% confidence interval. |
| **UK GHG emissions and energy projections** | DECC Energy and Emissions model (DECC, 2011) | 2020 | Due to the frequent update of the projections only one central scenario is presented, but factors affecting the emission estimates are mentioned when comparing with the previous projections (e.g. changes to savings estimates via implementation of policies, in power plant assumptions or changes to economic long term growth projections). The projection considers the implementation of all current climate change policies.<br>The projections rely on one macro-economic scenario with annual GDP growth rates of 2.5% in 2010-2015 and 2.8% in 2016-2020). The central scenario has an oil price of 118 USD/bbl in 2020 and 128 USD/bbl in 2030 plus a CO2 price of 24 - 27 €/t in 2020 respectively for industry and electricity generation. In addition there are low and high fossil fuel prices scenarios with corresponding CO2 prices. An uncertainty assessment was performed based on Monte Carlo simulation to capture the likely variations in the following key inputs to the projections: fuel prices, GDP, temperatures, policy impacts, power station capital costs, non-CO2 emissions. |

[a] Except if otherwise mentioned all oil prices are in USD 2010 and CO2 prices refer to ETS and are in Euros 2010.

## 5.3 Methods and model

To quantify the contribution of different exogenous assumptions on the uncertainty of GHG emission scenarios for Portugal, seven scenarios were generated for 2020 using the TIMES_PT model. TIMES_PT is a linear optimisation bottom-up technology model generated with the TIMES model generator from ETSAP[50] of the International Energy Agency. More information on TIMES can be found in Loulou e*t al.* (2005a and 2005b). It represents the Portuguese energy system from 2000 to 2030. The model considers both the supply and demand sides and includes the following seven sectors: primary energy supply; electricity generation; industry; residential; commercial; agriculture; and transport.

The model is supported by a detailed database, with the following exogenous inputs: (1) *end-use energy services and materials demand*, such as residential lighting, machine drive requirements or steel; (2) characteristics of the existing and future *energy related technologies*, such as efficiency, stock, availability, investment costs, operation and maintenance costs, or discount rate; (3) present and future *sources of primary energy supply* and their potentials; and (4) *policy constraints*, such as emission caps. The model finds the optimum combination of energy supply and demand technologies to satisfy the demand, i.e. it designs an energy system with the lowest possible total costs. More information on the details of the TIMES_PT model and its exogenous technology database can be found in Simoes *et al.* (2008). The other exogenous inputs are detailed in the following sections.

As a partial equilibrium model TIMES_PT does not model the economic interactions outside of the energy sector. Furthermore, it does not consider in detail demand curves and non-rational aspects that condition investment in new and more efficient technologies. In fact, the model unrealistically assumes that stakeholders are rational with perfect market foresight. Thus, some of the most important barriers for the uptake of new energy technologies in industry, and the residential and commercial sectors are inherently absent in TIMES_PT. These barriers are exogenously introduced,

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[50] Energy Technology Systems Analysis Programme.

as described in the section detailing the studied scenarios and in Simoes *et al.* (2009).

The seven scenarios are: Baseline (BASE), Efficiency (EFF); Demand (DEM), Low Renewable Electricity (low RES-e), Low Hydro (LowH), High Hydro (HighH) and High Oil Price (100$). The BASE scenario was developed considering a number of assumptions on exogenous model inputs, such as on demographic and economic evolution, technology deployment, energy resources availability and on the implementation and effectiveness of policy decisions. In each of the other six scenarios we made a variation in one of the exogenous assumptions. Besides this variation, which is explained in detail below, these scenarios are identical to BASE. None of the scenarios include a GHG cap or $CO_2$ tax. Thus, the EFF scenario is identical to BASE except for the higher level of penetration of renewable and end-use efficient equipment in the demand sectors, particularly in the industry, commercial and residential sectors. The DEM scenario considers a higher economic and demographic growth; whereas the low RES-e scenario has a lower implementation of the infrastructures and incentives for production of renewable electricity. The LowH and HighH scenarios are identical to BASE but have lower and higher water availability, respectively. Finally, the 100$ scenario considers higher primary energy import prices. In this section we explain the exogenous assumptions considered in each scenario.

### 5.3.1 Penetration of end-use efficient equipment in the demand sectors - EFF scenario

Regarding the promotion of end-use energy efficiency & renewable end-use equipment, all scenarios except EFF have the same limited penetration of new equipment for residential, commercial and industry, based on 2000-2005 trends and on the estimated evolution until 2015 (assumed to be maintained until 2020) as in the NEEAP (RCM 80/2008). The EFF scenario does not have any limits on the degree of penetration of end-use efficient & renewable equipment. Thus, it reflects the maximum gains obtained by the full realisation of the national demand-side technological potential. Therefore, this paper only addresses savings due to technological replacement and does not assess energy savings due to reduction of demand for energy services, such as reduction in thermal comfort requirements motivated by environmental awareness.

**Table 5.2. Differences between scenarios regarding the penetration of end-use efficient equipment**

| Measure/Scenario | Unit | 2010 | 2020 | |
|---|---|---|---|---|
| | | | BASE, DEM, low RES-e, LowH, HighH, 100$a | EFF |
| Maximum Insulation in existing buildings | % of households and of commercial building area | n.a. | 9% | 50% |
| Maximum double glazed windows in existing buildings | % of households and of commercial building area | n.a. | 18% | 50% |
| Maximum solar thermal water heating | % of households | n.a. | 8% | 100% |
| | % of commercial building area | n.a. | 1.2% | 100% |
| Maximum heat pumps and efficient biomass heating | % of households and of commercial building area | n.a. | 8% | 100% |
| Maximum efficient lighting (CFL) | % of efficient lamps in total lighting | 15% | 61% | 100% |
| Maximum efficient refrigeration (A+ and A++) | % efficient freezers and refrigerators | 1% freezers 8% refrigerators | 37% freezers 25% refrigerators | 100% |
| Maximum efficient dishwashers and cloth washing appliances (A+ and A++) | % efficient dishwashers and cloth washing | 1% | 25% | 100% |

n.a. – not available; [a] Portuguese NEEAP objectives for 2015, assumed identical for 2020

If no exogenous limits are imposed to the penetration rate of efficient & renewable equipment, a substitution of existing technologies will happen as this leads to cost savings. As previously mentioned, TIMES_PT is an optimisation model with the ultimate objective of cost reduction. Thus, barriers to the penetration of cost-saving new equipment such as resistance to change, imperfect information, and aesthetics or other subjective preferences are not considered by the model. In order to reflect these "realistic" constraints, exogenous inertia factors are considered in all scenarios. With the exception of EFF, all scenarios have embedded a delay in the penetration rate of new technologies and fuels in the residential, commercial and industry sectors. These factors were defined for the replacement of existing lighting and other electric appliances, for penetration of insulation, and for existing biomass, LPG and diesel technologies for cooking, space heating, and water heating by new more efficient alternatives, but using the same fuels. The main differences in the scenarios regarding end-use efficient equipment are presented in Table 5.2.

### 5.3.2 Socio-economic scenarios and energy and materials demand projections for 2020 – DEM scenario

Demand projections drive the whole energy system modelled in TIMES_PT and the effects of a demand variation were studied with the DEM scenario. Despite this variation, all seven scenarios share the same projection methodology used in all scenarios, as follows. The socio-economic scenarios and respective materials and energy services demand projections considered in this paper were generated within the study “PortugalClima2020 - Impact evaluation of the EU climate and energy policy package in Portugal” for the Portuguese Ministry of Environment (Seixas *et al.*, 2009). Under the framework of PortugalClima2020, two different socio-economic scenarios (and respective demand projections) were built: Tendency and Change. The first assumes a moderate economic and demographic growth, whereas the latter is more optimistic as it assumes a higher economic growth and an economic shift towards innovation and technology (Ribeiro *et al.*, 2008a). For the purpose of this paper, the Tendency scenario was considered in all scenarios except DEM which considers the higher growth of the “Change” socio-economic scenario, as summarised in Table 5.3 and in the Appendix.

**Table 5.3. Differences between scenarios regarding main macro-economic drivers until 2020**

| | | | | BASE, EFF, low RES-e, LowH, HighH, 100$ | | | DEM | | |
|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Unit** | **2000** | **2005** | **2010** | **2015** | **2020** | **2010** | **2015** | **2020** |
| GDP | Meuros (2000) | 122270 | 127490 | 138863 | 152436 | 168729 | 139935 | 160384 | 187933 |
| Private consumption | Meuros (2000) | 73702 | 79420 | 85600 | 93586 | 103327 | 85985 | 97759 | 113330 |
| Population | 1000 inhab. | 10226 | 10549 | 10596 | 10538 | 10420 | 10656 | 10725 | 10740 |
| **Annual average growth rate %** | | | **2001-2005** | **2006-2010** | **2011-2015** | **2016-2020** | **2006-2010** | **2011-2015** | **2016-2020** |
| GDP | | | 0.8% | 1.7% | 1.9% | 2.1% | 1.9% | 2.8% | 3.2% |
| Private consumption | | | 1.5% | 1.5% | 1.8% | 2.0% | 1.6% | 2.6% | 3.0% |
| Population | | | 0.6% | 0.1% | -0.1% | -0.2% | 0.2% | 0.1% | 0.0% |

### 5.3.3 Implementation of infrastructures and incentives for production of renewable electricity – low RES-e scenario

Regarding the promotion of renewable electricity, the major difference between low RES-e and all other scenarios is the degree of RES in electricity generation and in biofuels consumption in transports. All seven scenarios include: i) the *mandatory target set by the European Biofuels Directive* from 2003[51] of a biofuels consumption of 5.75 % of petrol and diesel use for transport in 2010, which is extended to 2020, and ii) *current and on-going investments* on renewable energy supply infrastructures to achieve the indicative target of 39% RES-e on gross electricity consumption by 2010, following the RES- e European Directive from 2001[52]. In addition, in all six scenarios, except the low RES-e, are considered: i) the more ambitious *national target of 10% biofuels* consumption of petrol and diesel use for transport in 2010 (extended to 2020), ii) the *expected but not yet implemented* investments on renewable energy supply infrastructures to achieve the indicative target of 45% RES-e for 2010 and to comply with the national Kyoto Protocol GHG emission target, according to national policy commitments (RCM 1/2008; INAG, DGEG and REN, 2007; MEI, 2007a; MEI, 2007b). This includes the installation of 900 MW of a coal power plant with $CO_2$ capture and storage (CCS) in 2020.

Because the TIMES_PT model deals exclusively with emissions from combustion and productive processes (approximately 81% of national emissions in 2005 (APA, 2008)) to verify compliance with GHG targets were also considered emissions not estimated in TIMES_PT[53] from Seixas *et al.* (2009).

51 Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport.

52 Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market.

53 GHG emissions from solvents use, non-combustion agricultural activities, waste management, and f-gases.

**Table 5.4. Differences between scenarios in terms of infrastructure and in incentives for RES-e production**

| Measure/Scenario | Unit | **2010** | **2020** | |
|---|---|---|---|---|
| | | | **BASE, DEM, EFF, LowH, HighH, 100$** | **low RES-e** |
| Biofuel consumption target | % consumption of petrol & diesel use for transport | Gasoline: 0.0% & Diesel: 0.08%[a] | 10% | 5.75% |
| RES-e installed capacity | GW | 9.41 | 13.43 | 10.42 |
| *Hydro* | *GW* | *4.84* | *6.86* | *5.58* |
| *Wind-onshore* | *GW* | *3.87* | *5.70* | *4.50* |
| *Biogas* | *GW* | *0.01* | *0.10* | *0.05* |
| *Solar* | *GW* | *0.13*[b] | *0.15* | *0.10* |
| *Waste* | *GW* | *0.09* | *0.12* | *0.12* |
| *Biomass (non-CHP)* | *GW* | *0.11*[b] | *0.25* | *0.05* |
| *Waves* | *GW* | *0.00* | *0.25* | *0.03* |
| New Gas CCGT (minimum CCGT activity % of capacity) | GW | 3.04 (34%) | 4.38 of which 3.2 new (37% minimum activity) | 4.38 of which 3.2 new (no minimum activity) |

[a] values for 2009; [b] for solar and biomass the on-going investments at the time the results were generated totalled 0.10 GW and 0.05 GW for 2020, respectively. These were the minimum capacities introduced in the model. However, the most recent official data for 2010 (made available in the end of 2011) show that the figure was exceeded already in that year.

The minimum installed capacity of RES-e technologies were implemented in the model as in Table 5.4. In the BASE, EFF, DEM, LowH, HighH and 100$ scenarios the minimum installed capacities were retrieved from the Ministry of Economy objectives for 2010 to 2020 (MEI, 2007a). In the low RES-e scenario conservative estimates were made for 2020 based in the 2007 installed capacity, on issued permits, and assuming a growth rate similar to the verified in 2000-2007 for the cases of non-CHP biomass, solar photovoltaic (PV) and biogas power plants. Due to the existing feed-in tariff mechanisms, considered to be maintained until 2020, it is assumed that all RES-E technologies function at its maximum technical capacity (considering technology specific availability factors that account for seasonal effects and technological specificities). Also reflecting the current energy policies, which include incentives for combined cycle gas turbines (CCGT), the authorised investments for new 3.2 GW of CCGT are included in all scenarios. Of these 1.6 GW were operating in 2010. In the BASE, EFF, DEM, LowH, HighH and 100$ scenarios, 1.6 GW of new CCGT are assumed to function at least at 37% of their capacity. This is the minimum threshold to justify investment in such plants, based on information supplied by the National Energy Directorate (DGEG). In the low RES-e scenario, the new CCGT are installed but are not forced to operate (Table 5.4).

### 5.3.4 Availability of hydro resources – LowH and HighH scenarios

Hydropower plays an important role in electricity generation in Portugal (26.8% of total generated electricity in 2000). However, its contribution depends on each year's hydrological characteristics, which have high annual oscillations (38% of generated electricity in 2003 and only 20% in 2002). For all scenarios, except for LowH and HighH, the available hydro resources considered in the TIMES_PT model replicate an average hydrological year. This means that from 2000 to 2030 all modelled years have identical annual hydro availability (with seasonal variations) which is similar to those available in the year 2000 (an average hydrological year according to DGEG, 2012).

In the LowH scenario the availability of hydro resources for power generation replicates 2005 values, a dry year (IPH of 0.336). In the HighH scenario the hydro availability replicates the values of 2003, a wet year (IPH of 1.090). All other five scenarios (BASE, EFF, DEM, low RES-e, 1004 bbl) have hydro availability corresponding to an IPH of 0.885 (as in 2000). The low and higher hydro availabilities of LowH and HighH were modelled in a simplified form by reducing or increasing the availability factors of each (existing and new) hydro power plant technologies. The reduction and increase of availability factors is roughly the same as the difference between average, dry and wet IPH. Thus, the availability factor of the LowH scenario is 62% lower than the BASE & other scenarios, and the AF of the HighH are 23% higher.

### 5.3.5 Primary energy import prices – 100$/bbl scenario

For all scenarios except for 100$ scenario the average primary energy imports prices projections (Table 5.5) were adopted from the Reference scenario of the PRIMES and GEM-E3 models used by the EU in the preparation of the energy-climate policy package (Russ *et al*, 2007). The oil prices vector are generated by the global POLES[54] model, considering scenarios of available oil, new oil reserves that might be discovered and the supply and demand laws. The corresponding real gas and coal prices were estimated by Seixas *et al.*, 2009 considering the annual relationship between oil and other fossil fuels assumed by the IEA in the Reference scenario of the World Energy Outlook 2007 (IEA, 2007).

For the 100$ scenario it was assumed the high oil prices scenario from the study on oil prices developed by the Department of Prospective and Planning and International Relations of the Portuguese Ministry of the Environment (Ribeiro *et al.*, 2008b). This national study was based on scenarios developed by IEA and US National Energy Agency and was validated by national energy experts. The corresponding real gas and coal prices were estimated by Seixas *et al.* (2009) considering the annual relationship between oil and other fossil fuels assumed by the IEA in the High Growth scenario of the WEO 2007 (IEA, 2007).

It should be noted that these prices does not consider the effects of extreme situations, such as oil price peaks due to political instability or natural catastrophes. Moreover, the most recent values from the IEA for Europe in 2020 (IEA, 2012) are substantially higher than the Base & Other scenarios (e.g. 97 to 118 $2010/bbl of oil) which might have a significant effect on absolute results. However, the (too) low price estimates still allow for a view on the role of *differences* in oil price levels. It should be noted that in the Energy Roadmap 2050 considers in 2020 89 $ 2010/bbl of oil for the reference scenario and 133.5 $2010/bbl for the high scenario (EU Commission COM(2011)885 final).

[54] http://www.enerdata.fr/enerdatauk/tools/Model_POLES.html

**Table 5.5. Major differences between scenarios regarding primary energy import prices**

| Year/Scenario | BASE, DEM, low RES-e, EFF, LowH, HighH | | | 100$ | | |
|---|---|---|---|---|---|---|
| | Oil ($2010/bbl) | Natural Gas ($2010/m3) | Coal ($2010/ton) | Oil ($2010/bbl) | Natural Gas ($2010/m3) | Coal ($2010/ton) |
| 2000 | 37.63 | 0.22 | 37.01 | 37.63 | 0.22 | 37.01 |
| 2005 | 60.01 | 0.28 | 69.11 | 60.01 | 0.28 | 69.11 |
| 2010 | 56.21 | 0.23 | 53.39 | 97.94 | 0.41 | 89.29 |
| 2015 | 58.88 | 0.25 | 58.46 | 101.99 | 0.43 | 90.32 |
| 2020 | 61.69 | 0.26 | 61.12 | 106.21 | 0.45 | 91.36 |

## 5.3.6 Summary of the studied scenarios

The seven studied scenarios were designed to integrate in varying degrees the major exogenous assumptions considered in the development of GHG emission scenarios: penetration of end-use energy efficient equipment; socio-economic growth rates; rate of implementation of policy incentives & investments for promotion of RES-E; availability of water resources for hydropower; and primary fossil energy import prices. The scenarios are summarised in Table 5.2.

**Table 5.2. Synthesis of the modelled scenarios**

| Assumption/Scenario | BASE | EFF | DEM | low RES-e | Low H | High H | 100$ |
|---|---|---|---|---|---|---|---|
| **Penetration of end-use energy efficient equipment** | Following NEEAP targets | High | Following NEEAP targets | | | | |
| **Socio-economic growth** | Tendency | | Change (high growth) | Tendency | | | |
| **Implementation of policy incentives & investments for promotion of RES-E** | Extra investments for 45% RES-e & 10% biofuels | | | Only current & on-going investments & 5.75% biofuels | Extra investments for 45% RES-e & 10% biofuels | | |
| **Availability of water resources for hydropower** | Average hydrological year | | | | Dry year | Wet year | Average hydrological year |
| **Primary fossil energy import prices** | Reference | | | | | | High |

Finally, in all seven scenarios the following assumptions are made reflecting the most relevant Portuguese energy policies in place:

1. A ban on nuclear power due to the political unacceptability of this option in the modelled time horizon;
2. New coal power plants will only be available from 2015 onwards following energy sources diversification policy and support to the use of natural gas. It is assumed that "conventional" coal power plants without sequestration will not be implemented from 2015 onwards, following expected GHG control policies;
3. The 2005 tax on oil products, differentiated according to the energy carriers, was included and extended until 2020;
4. To emulate developments in electricity imports and exports - affected by interconnection capacity with Spain - increasing maximum limits were set from 2000 to 2030, up to a maximum import and export of 46 and 20 PJ in 2020, respectively, and of 60 and 30 PJ in 2030. These are rough estimates since there are no good forecasts at the moment, although they are in line with the national transmission operator studies (REN, 2008). This corresponds to a growth of imports with 255% and of exports with 121%. Thus, trade uncertainty under the liberalised Iberian electricity market is not considered.

# 5.4 Results and discussion

This section presents the comparison between the six studied scenarios and the Base case in terms of GHG emissions and renewable energy consumption and their compliance with the energy-climate policy package. In Table Table 5.7 we present the variation in GHG emissions in 2020 for the studied scenarios as well as an indication (in % estimated from the assumptions in BASE) of the magnitude of the variation introduced for each of the exogenous assumptions. The assumptions with a higher % difference from what was considered in BASE (energy prices and low hydro) do not necessarily lead to the higher variations in GHG emissions (Figure 5.1).

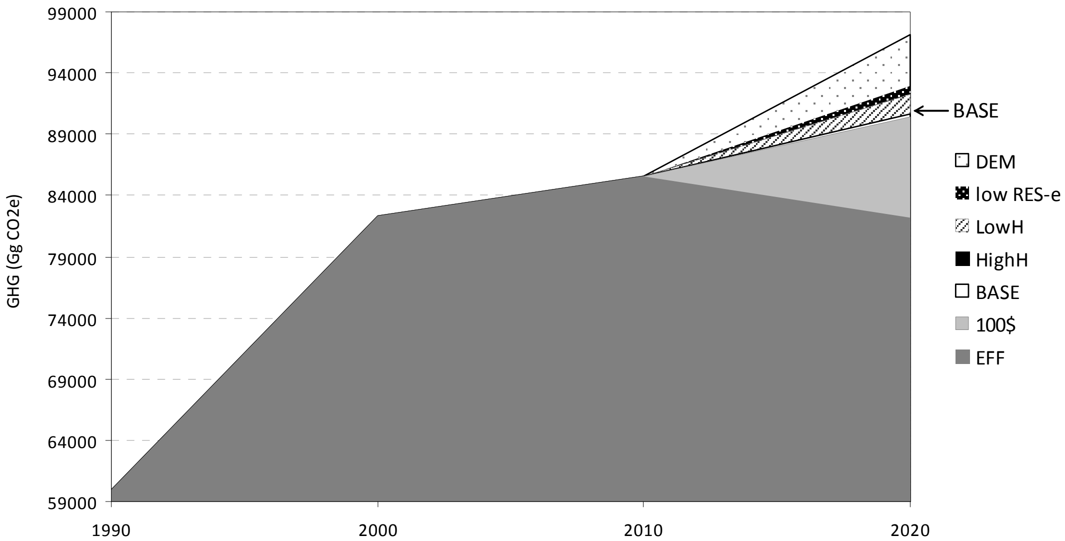


**Figure5.1 – Variation in GHG emissions from 1990 to 2020 for the modelled scenarios**

The GHG emission estimates of the three scenarios related to costs and availability of primary energy (LowH, HighH and 100$) lead to variations in 2020 total national GHG emissions that are less than 2% different from BASE (Table 5.7 and Table 5.8). The EFF scenario is the one with a higher difference in 2020 emissions from BASE (less 9%), followed by DEM with emissions roughly 7% higher than BASE. The delayed or slower implementation of policy incentives & investments to RES-E leads to an increase in emissions of only 2.5%. In overall terms it seems that the emission changes are not significant. In this analysis it should be remembered that emissions from F-Gases, waste and non-energy agriculture emission sources were not estimated by TIMES_PT and are thus identical in all scenarios (see Seixas *et al.*, 2009 for a detailed description on how these non-energy GHG emission estimates were made).

**Table 5.7 – Indicative variation in assumptions in 2020 compared to BASE and corresponding variation in GHG emissions**

| Scenario | % variation in assumption input in the model compared to assumption as in BASE in 2020 | % variation in total GHG[a] emissions in 2020 |
|---|---|---|
| **EFF** | -42% demand for energy services in buildings, since this can be met with more efficient technologies. This is a proxy measure of the variation in the assumption weighting the different assumptions for the different technologies with the weight of the useful energy service demand they can potentially affect (space heating, lighting, refrigeration, etc.) | -9.3% |
| **DEM** | +5% for energy services demand modelled as useful energy (agriculture, buildings and non-energy intensive industry)<br>+1% for passenger transport and +8% for freight transport<br>-2% for energy intensive industry (modelled as Mt) | +7.1% |
| **Low Res-e** | -43% RES-e installed capacity | +2.5% |
| **LowH** | -62% availability factor for hydro plants | +1.7% |
| **HighH** | +23% availability factor for hydro plants | 0.0% |
| **100$** | +72% oil and gas prices and +49% coal price | -0.3% |

[a] Because the TIMES_PT model deals exclusively with emissions from combustion and productive processes (approximately 81% of national emissions in 2005 (APA, 2008)), to verify compliance with GHG targets emissions not estimated in TIMES_PT were also considered (GHG emissions from solvents use, non-combustion agricultural activities, waste management, and f-gases) from Seixas *et al.* (2009).

**Table 5.8. GHG emission estimates for 2020 (Gg CO2e)**

| Sector/Scenario | 2005 | 2020 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | BASE | EFF | DEM | low RES-e | LowH | HighH | 100$ |
| Energy Supply | 28283 | 31720 | 32627 | 32627 | 30713 | 31778 | 31720 | 31719 |
| Industry & Solv. | 15964 | 15146 | 13104 | 13104 | 16833 | 16398 | 15146 | 15124 |
| Transport | 19861 | 21570 | 15875 | 15875 | 22617 | 21648 | 21570 | 21639 |
| Commercial | 3437 | 2841 | 940 | 940 | 2891 | 2891 | 2841 | 2828 |
| Residential | 2652 | 2512 | 2787 | 2787 | 2989 | 2628 | 2512 | 2239 |
| F-Gases | 799 | 2137 | 2137 | 2137 | 2137 | 2137 | 2137 | 2137 |
| Agriculture | 9059 | 9074 | 9074 | 9074 | 9074 | 9074 | 9074 | 9074 |
| Waste | 7151 | 5679 | 5679 | 5679 | 5679 | 5679 | 5679 | 5679 |
| National Total | 87205 | 90677 | 82223 | 82223 | 92933 | 92233 | 90677 | 90439 |
| t CO2e/Meuros GDP | 684 | 537 | 487 | 487 | 551 | 547 | 537 | 536 |
| Total Non EUETS | | 48535 | 48535 | 41106 | 41106 | 50875 | 49384 | 48535 |
| Total EUETS | | 42142 | 42142 | 41117 | 41117 | 42058 | 42849 | 42142 |
| % Variation from 2005 | | | | | | | | |
| EU ETS | | 16 | 13 | 19 | 15 | 18 | 16 | 16 |
| Non EU ETS | | -4 | -19 | 6 | 0 | -3 | -4 | -5 |
| Total | | 4 | -6 | 11 | 7 | 6 | 4 | 4 |
| % Variation of total emissions from BASE | | _ | -9.3% | 7.1% | 2.5% | 1.7% | 0.0% | -0.3% |

In Figure 5.2 is presented the 2020 sector emission variations calculated as % from BASE scenario emissions. The difference in emissions in the EFF scenario is mostly due to less 67% emissions from commercial buildings than in BASE and to a lesser extent to reduced emissions from transport and industry. The causes for these lesser emissions are the faster substitution of existing equipment by more efficient ones. The EFF scenario also has more 42% emissions from CHP than BASE due to the higher activity of new gas CHP plants. The DEM scenario, as expected, has higher GHG emissions from all modelled sources due to the higher demand for energy services. In the low RES-e scenario, the delay in implementation of RES-e incentives & infrastructures is not translated in an increase in emissions for the power sector. However, the demand sectors do increase emissions as less electricity is used.

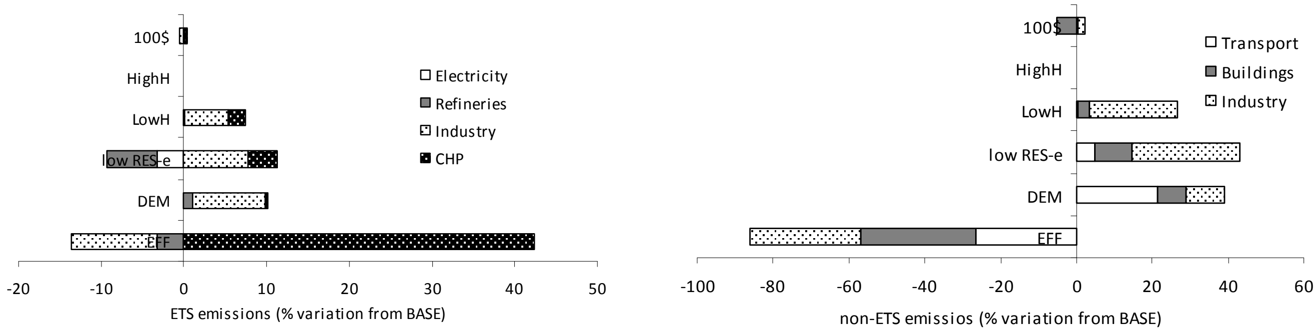


**Figure 5.2 ETS and Non-ETS GHG emission estimates for 2020 represented as % variation from the BASE scenario**

Although the overall differences in GHG emissions are never above 10% compared to BASE emissions, they still have an impact in compliance with the energy-climate policy package, especially regarding the RES target of 31% for 2020 (EU Commission, 2009b) (TableTable 5.9). The RES share of final energy consumption of the BASE scenario is 27% and the different exogenous assumptions can lead to differences of more 4% which allow complying with the target (as happens for the EFF scenario), or less 4% (low RES-e scenario). These differences in RES share are due to changes in all sectors energy profile, depending on the scenario. Regarding the compliance with GHG emissions targets (EU Commission, 2009a) the differences in scenarios (Table 5.8) are more relevant for the non-ETS emissions especially for the EFF scenario (less 19% emissions in 2020 than in 2005).

**Table5.9. RES share of final energy consumption in 2020 (PJ)**

| Sector/ Scenario | BASE | EFF | DEM | low RES-e | LowH | HighH | 100$ |
|---|---|---|---|---|---|---|---|
| Electricity | 136 | 142 | 145 | 112 | 101 | 147 | 145 |
| Heath & cooling | 100 | 99 | 105 | 101 | 102 | 71 | 76 |
| Residential | 48 | 51 | 49 | 49 | 49 | 24 | 20 |
| Commercial | 10 | 14 | 13 | 10 | 10 | 11 | 13 |
| Industry | 43 | 34 | 43 | 42 | 43 | 36 | 43 |
| Transport | 31 | 26 | 33 | 18 | 31 | 27 | 27 |
| Final Renewable Energy (a) | 267 | 267 | 284 | 232 | 234 | 245 | 248 |
| Total Final Energy (b) | 976 | 866 | 1072 | 974 | 973 | 846 | 853 |
| % Renewables (a/b) | 27 | 31 | 26 | 24 | 24 | 29 | 29 |
| % diff of a/b from BASE | | 4 | -1 | -4 | -3 | 2 | 2 |

## 5.5 Discussion

From the results presented before it appears that the most relevant assumptions in a TIMES model for overall GHG variations are the ones related to the socio-economic development (macro-economic and population growth). This view is shared by ECN (2010), IEA (2012a) and DECC (2011). The assumptions on end-use efficient technology deployment are the next most important. On the contrary to what is perceived by policy makers, fossil fuel prices and the availability of renewable energy resources present only minor variations on GHG emission (less than 2% of the Baseline).

Several studies as the SRES (IPCC, 2000), van Vuuren *et al.* (2009) or EMF (EMF, 2011) use multi model approaches allowing to capture and address the range of outcomes from different models using the same or similar assumptions. This was clearly not the approach used in this paper. Although those multi model studies are extremely relevant to better inform science and policy making, the higher time and efforts that they entail are frequently not compatible with the timings and budgets available to national climate policy makers. In that context typically one or two complementary models are used to generate GHG emission scenarios. Acknowledging this 'real life' constraint, we have focused into looking at the range of outcomes of one model only (TIMES_PT).

One of the limitations of the work here presented is that it could be argued that the larger differences in scenarios are caused because we did not use the same range of variation for all the modelled assumption (i.e. we did not model 1%, 5% and/or 10% changes from BASE on oil prices, on demand for energy services, etc.). Nonetheless, we believe our analysis is still valuable since all the assumptions and their variants, from economic growth rates to hydro availability, were developed within an actual climate policy process. They result from the actual discussion with policy makers and national stakeholders while developing the 2020 GHG emission scenarios used by the Portuguese Ministry of Environment. Thus, the different ranges for variation of the assumptions translate the actual expectations and perceptions of policy makers on their plausible variations.

Most emission scenarios used in climate policy consider different degrees of policy implementation, which are typically dealt with via different scenarios, each reflecting a different degree of implementation (usually simply by considering scenarios with and without policies). ECN/PBL (2012) has a different approach by assessing the uncertainty in the policies' effects (i.e. their effectiveness) and not on their implementation. According to ECN/PBL (2012), the implementation of the P&M is not considered an "uncontrollable external uncertainty" but instead dependant on controllable political will and thus not to be subject to an uncertainty analysis. We do not necessarily agree with this view as it can be argued that the factors affecting political will are so complex that are in practical terms uncontrollable. In fact, in practical terms most uncertainty assessments of GHG forecasts do not make this distinction in policy implementation and their effectiveness. In most of the cases reviewed in section 5.2 it is considered that a policy can be implemented or not, and if it is implemented, then is assumed effective. In our analysis we have used this later approach.

## 5.6 Conclusions

This paper assesses the contribution of different exogenous parameters for the variations in GHG emissions estimates for the case study of the Portuguese energy system for 2020. To do so seven scenarios were generated for 2020 using the TIMES_PT model: Baseline, Efficiency, Demand, Low Renewable Electricity, Low Hydro, High Hydro and High Oil Price. The

Baseline scenario was developed considering a number of assumptions on exogenous model inputs, such as on demographic and economic evolution, technology deployment, energy resources availability and on the implementation and effectiveness of policy decisions. The other six scenarios are identical to the Baseline scenario but for a variation in one of these exogenous assumptions.

The first main conclusion is that key issues in energy supply in Portugal, the availability of water for hydropower and the price of – to be imported – oil hardly have any influence on the outcomes in terms of greenhouse gas emissions in 2020. The GHG emission estimates of the scenarios where exogenous parameters were varied lead to variations in 2020 total national GHG emissions less than 9% different from the Baseline. This has consequences in two directions. Improvement in model quality should not focus on these issues; and policies should not build on these elements. A policy-relevant consequence that should be further explored is the possibility that increasing oil prices, as a policy measure, as through carbon taxes, has a limited effect on overall climate performance.

The second main conclusion is that overall emissions levels as modelled for around two decades from now are very much dependent on general socio-economic development and population growth, and also but to a lesser degree depend on developments in end-use efficiency. Should we then focus at reduced growth for reaching climate targets?

The third conclusion is on what we can learn from this exercise in scrutinizing the TIMES-type partial equilibrium models. Are the conclusions valid beyond the outcomes for Portugal? As they are linear optimization models, they tend to be most sensitive to one driver at a time. The question is: can we be sure that, for example, a carbon tax would have a limited effect? Or would the effect occur only after "all other mechanisms" have worked out, taking more than two decades? Or would the limitation be an artefact of partial equilibrium modelling, with all mechanisms in reality working simultaneously? Nobody can answer these important questions now. We hope that with our primary analysis we have set up a rich field of further study.

## 5.7 Appendix – Energy services and materials demand assumptions in TIMES_PT

For all seven scenarios the macro-economic drivers in section 5.2.2 were used to derive a detailed materials and energy services demand for 2020 which is thoroughly described in Fortes *et al.* (2008). The demand projections were developed using a bottom-up approach for the residential and commercial sectors and top-down approach for the industry and transport sectors. For the residential and commercial sectors, detailed assumptions were made on: stock of existing and new buildings; evolution of occupancy rate; average building area; evolution of heating and cooling comfort requirements per $m^2$; evolution of per capita water and cooking useful energy requirements, among other. These assumptions consider past statistics and forecasts on: population growth, private consumption and planned touristic developments. The demand for energy services for the residential sector is disaggregated for single urban houses, single rural houses and apartments and considers two climatic regions: South and North of Portugal. For the industry and transport sectors a relationship was assumed between the demand for energy intensive materials (steel, paper, glass, cement, lime, ammonia and chlorine), transport and other energy services required for industry and evolution of sector gross added value (GAV). This relationship includes the effect of a price evolution factor, income and price elasticity of final demand to GAV, and assumptions on the autonomous efficiency improvement in industry (van Regemorter and Kanudia, 2006 and Fortes *et al.*, 2008). Both the socio-economic and the materials demand projections were validated through an extensive stakeholder consultation process during 2008.

The final demand projections are thus differentiated across sectors and scenarios (Table A):

- Industry: i) quantities of steel, paper, glass, cement, lime, ammonia and chlorine ii) Useful energy for the remaining industries (ceramics, chemical, other industry);

- Residential: useful energy demand for hot water, cooling and heating, lighting, cooking, refrigeration, cloth washing and drying, dish washing and other electric appliances;

- Commercial: useful energy demand for hot water, cooling and heating, lighting, public lighting, cooking, refrigeration and other electric appliances;
- Transport: passengers and freight transportation trough road and railway expressed in pkm (passenger-kilometer) and tkm (ton-kilometre) and aviation and navigation expressed in useful energy demand;

The overall trend is for an increase in 2020 of more than 100% of 2000 values for all demand categories (Table A). For example, in the residential & commercial sectors useful energy for heating in 2020 will increase approximately 152% from 2000 values in the BASE scenario and others, except for DEM where it increases 161%. Cooling increases 222% in the BASE scenario and others and 235% in DEM, and water heating increases 163% in BASE and others and 167% in DEM. In the industry and transport sectors, the differences between BASE scenario & others and DEM do not necessarily lead to higher energy needs in DEM because in the development of the underlying macro-economic scenario is considered a reduction of energy intensive activities (e.g. other industry).

**Table A. Differences between scenarios regarding demand for end-use energy services until 2020 using the index 2000 = 1000**

| Demand type | Year/Scenario | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| Heating | BASE & OTHER | 100 | 124 | 140 | 147 | 152 |
| | DEM | 100 | 124 | 141 | 152 | 161 |
| Cooling | BASE & OTHER | 100 | 138 | 165 | 191 | 222 |
| | DEM | 100 | 138 | 165 | 195 | 235 |
| Water Heating | BASE & OTHER | 100 | 122 | 143 | 155 | 163 |
| | DEM | 100 | 122 | 144 | 157 | 167 |
| Chemistry | BASE & OTHER | 100 | 92 | 103 | 121 | 133 |
| | DEM | 100 | 92 | 103 | 121 | 141 |
| Other industry | BASE & OTHER | 100 | 85 | 86 | 91 | 97 |
| | DEM | 100 | 85 | 84 | 87 | 89 |
| Pkm | BASE & OTHER | 100 | 110 | 129 | 145 | 157 |
| | DEM | 100 | 110 | 127 | 143 | 156 |
| Tkm | BASE & OTHER | 100 | 127 | 138 | 157 | 178 |
| | DEM | 100 | 127 | 137 | 150 | 164 |
| Paper | BASE & OTHER | 100 | 97 | 124 | 142 | 156 |
| | DEM | 100 | 97 | 123 | 142 | 155 |
| Cement | BASE & OTHER | 100 | 98 | 106 | 107 | 107 |
| | DEM | 100 | 98 | 103 | 107 | 107 |
| Glass | BASE & OTHER | 100 | 117 | 141 | 169 | 182 |
| | DEM | 100 | 117 | 141 | 169 | 181 |
| Iron & Steel | BASE & OTHER | 100 | 150 | 244 | 375 | 370 |
| | DEM | 100 | 150 | 244 | 375 | 370 |

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