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

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Untangling the web

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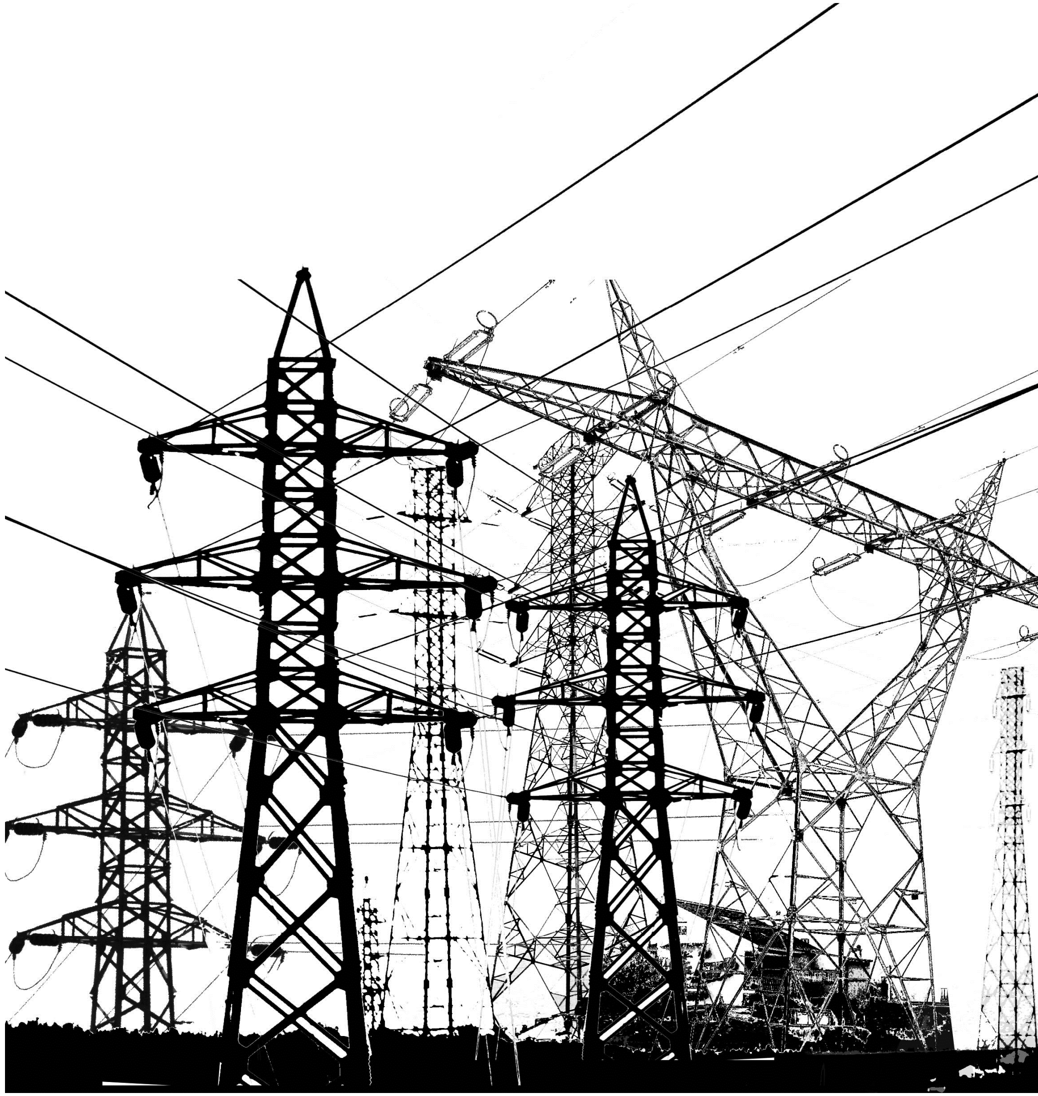
Sofia Simões



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Contents

1 General Introduction

“There are currently more than 100 pieces of legislation in place covering the entire spectrum of environmental problems. Of these, only 12% require Member-States to provide evaluative information on the effects of the implemented policy measures”

European Environment Agency, 2001. Reporting on environmental measures: Are we being effective? Environmental Issue Report No. 25. Copenhagen, European Environment Agency

“A patchwork of policies, burdens and new regulations keeps building up without sufficient coherence, balance, or properly thought-out economic assessment”

Secretary General of EURELECTRIC - Union of the Electricity Industry, Closing the circle of competitiveness: the need to reorient European electricity policy, EURELECTRIC, June 2005, Lyon, France.

These two quotations played a major role motivating the research work undertaken in this dissertation. When defining the objectives of my PhD I found extremely relevant that two different key stakeholders in the energy and environment policy arena, with intrinsically different perspectives (EEA as a public government organisation and EURELECTRIC as an association of mostly private companies), seemed to agree that there was not enough assessment on the policy instruments in place. I have found later that this view was shared by many other stakeholders, including researchers. Another quotation that has caught my attention was made by Sorrel and Sijm (2003), as follows:

"(...). The net result may be a mix of overlapping, interacting, and conflicting instruments which lack any overall coherence. In short, a policy mix may easily become a policy mess."

The issue has become increasingly relevant as the expanding climate change policy area has been bringing together environment and energy policy making. In fact, it is not always easy to clearly separate what are energy and what are environment policies. Therefore, being an over-optimistic PhD student, I decided to try to contribute in finding a way out of what I considered "the tangled web" of environment and energy policy instruments in place along power systems. In my quest for "untangling the web" I believe that only by providing quantitative estimates on the costs caused by counteracting policy instruments could researchers hope to communicate the relevance of the matter to policy makers, and hopefully, provide guidance on which policy interactions to tackle first. In a nutshell, the main topic of this dissertation is to assess how interactions between energy and environment policy instruments can be quantified.

1.1 The need for environment and energy policy integration

Energy is one of the fundamental factors for economic development. Abundant, cheap energy is considered as a pre-requisite for a prosperous economy, and energy consumption per capita is still used as a key indicator for development. However, the base of most energy systems are still limited resources, such as coal, uranium, oil and gas, which will continue to be essential to produce sufficient energy to satisfy the demand until 2050 (IEA, 2011, IEA, 2012). The subsequent negative environmental impacts (e.g. climate change, air pollution problems, depletion of natural resources) limit even further the availability of these resources deemed necessary for economic development and decrease the well being of the society as a whole. The non-sustainability of the energy systems shows from negative effects on areas as public health, economic development and quality of the environment (Johansson and Goldemberg, 2002; EEA, 2003; DG TREN, 2003.a).

Of all end-use carriers of energy, electricity is probably one of the most important, since it precludes most industrial and service activities. Factors affecting power systems are determinant for economies and for the well-being of populations. Simultaneously, the production and consumption of electricity might also allow for significant effects along the supply chain, as mentioned before. These might be aggravated by the expected growth in electricity consumption. According to the International Energy Agency (IEA) world electricity consumption will grow from 20 000 TWh in 2009 to 40 000 to 49 000 TWh in 2050 (IEA, 2012).

Nonetheless, there is ample room to reduce the consumption of electricity by improving electricity efficiency (Box 2). There is abundant technology already in the marketplace that allows for more efficient production and consumption of electricity. This not only reduces the magnitude of negative impacts associated to electricity systems, but also increases economic competitiveness, since electricity is an important production factor. However, although such technologies already exist and it is widely known that improving energy efficiency will bring economic, environmental and social benefits, its implementation is a slow, gradual process that needs to overcome a series of barriers, largely discussed in literature (e.g. Vine *et al.*, 2003; Worrell and Price, 2003; Wuppertal, *et al.*, 2000; Bergmasth *et al.*,, 2000; Turkenburg, 2002). It is necessary to develop and effectively implement policies to enhance this change in production and consumption systems (Fuchs and Arentsen, 2002; Wuppertal, *et al.*, 2000; Johansson and Goldemberg, 2002).

The European Union (EU) has developed and continues to develop a number of policy initiatives concerning energy and in particular electricity, such as the ones mentioned in Box 1.

Box 1 - Some EU Policy initiatives concerning electricity

Communication from the Commission to the European Parliament, the Council, the European Economics and Social Committee and the Committee of the Regions – Renewable energy: a major player in the European energy market, COM(2012) 271

Communication from the Commission to the European Parliament, the Council, the European Economics and Social Committee and the Committee of the Regions – Energy Roadmap 2050, COM(2011) 0885 final

Proposal for a Directive of the European Parliament and of the Council on energy efficiency and repealing Directives 2004/8/EC and 2006/32/EC. COM(2011)0370 final

A Roadmap for moving to a competitive low carbon economy in 2050, Communication from the Commission to European Parliament, the Council, the European Economic and Social Committee of the Regions, COM(2011) 112 final.

Energy 2020, a strategy for competitive, sustainable and secure energy, Communication from the Commission to the European Parliament, the Council, the European Economics and Social Committee and the Committee of the Regions, COM(2010) 0639 final

Communication from the Commission to the European Parliament, the Council, the European Economics and Social Committee and the Committee of the Regions – On security of energy supply and international cooperation – The EU energy policy: Engaging with partners beyond our borders, COM(2011) 0539 final

Directive 2010/31 of the European Parliament and of the Council of 17 May 2010 on the energy performance of buildings

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity

Directive 2006/32 of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services

Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration

Directive 1996/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity

EU Commission Proposal COM(95)369 final. Proposal for a Council Directive to introduce rational planning techniques in the electricity and the gas distribution sectors

Of these, the Council and European Parliament Directive 96/92/EC of 19 December 1996 concerning common rules for the internal market in electricity is probably the policy initiative that most fundamentally changes the structure of the existing electricity markets (Box 2). This is a major change in the power system of which policy makers and policy researchers should be aware of.

Box 2 - Main features of the liberalisation of electricity markets

According to the EU Directive 96/92/EC, the formal restructuring process of electricity markets has started in February 1999 for the entire EU, even if some countries had already started it before. The major alterations are the requirement for separation of the transmission and distribution activities from the other activities developed by electricity companies and to separate distribution from retail supply of electricity. The electricity companies prior to liberalisation, were typically vertically integrated companies, i.e. companies performing two or more of the functions of generation, transmission and distribution of electricity, and with the restructuring of the electric market there is a tendency for their separation in horizontally integrated companies (companies performing at least one of the functions of generation for sale, or transmission or distribution of electricity, and another non-electricity activity).

Source: Simoes, 2001; Wuppertal et al., 2000

It is difficult to distinguish up to what extent the mentioned Directives, to be implemented in national policy instruments solely have energy policy objectives, such as the need to secure supply reducing consumption and diversifying production, or are also influenced by environment policy objectives, such as the commitment to reduce the emissions of Greenhouse Gases (GHG). The frontier separating what is environment and what is energy policy instruments is not a clear one. For example, energy labelling of appliances might induce a reduction in consumption and thus on the environmental impacts associated with supply of electricity, but this reduction in consumption may also allow for guarantying the adequate dimension of the existing electricity supply infrastructures, and avoiding the necessity to build new ones (Rabl and Gellings, 1988).

This distinction matters since in many cases energy and environment policy objectives are not the same and the implementation of the policy measures mentioned above has to consider a multiplicity of requirements established by other environment policy instruments, such as environmental impact assessment.

Governments worldwide face policy challenges in order to meet the concerns with the threat of environmental damage caused by energy production and use and the design and implementation of policies to tackle these challenges is a very complex task. Moreover, environmental impacts are only one of many concerns for decision makers, along with security of energy supply and affordability. Although there are efforts to integrate environment into energy policies, following the Cardiff initiative1, according to the World Energy Outlook already in 2002, the security of energy supply "has moved to the top of the energy policy agenda" (IEA, 2002). The EU Commission (DG Energy and Transport) acknowledges that there is still room for improvement in this integration of environment in energy policies, namely by "enhancing energy efficiency, with a strong focus on demand-side management" (EU Commission SEC(2001)502, 2001).

On the other hand, although environment policies do not interfere directly with such objectives, most of the environment policy instruments (see Box 3) somehow condition energy supply and/or demand by imposing restrictions to the use of natural resources (e.g. establishing land use restrictions or emission limit values) or by providing incentives to change the supply and demand profiles (e.g. creating a EU market for the emissions of CO2 and thus an incentive for shifting to low-carbon fuels or promoting energy efficiency; establishing environment taxes on electricity or subsidising

[1] The 1998 European Council in Cardiff formulated an initiative to aiming to more effectively integrate environmental aspects into sectoral policy making, following the articles 2 and 6 of the Treaty of the European Union. In 2001 the Council adopted environmental integration strategies in the energy area, among other (EU Commission SEC (2001)502, 2001).

electricity produced from renewable sources). Regarding the nomenclature of policy instruments it should be noted that there are many different classifications. However, in this dissertation the intention is not to discuss or clarify them. Instead this research simply aims to assess interactions between a portfolio of instruments, regardless of their classification.

Due to its size, the amount of emissions produced and its visibility, the electricity generators have tended to be a central area in environment policy making (Midttun and Koefod, 2003). Therefore, electricity generators are also a central point for the conflicting effects of opposite energy and environment policy objectives to be felt upon.

Box 3 - Nomenclature of policy instruments

Policy instruments, and specifically environment (or energy) policy instruments, are instruments that are utilised to enforce and implement environment/energy policies. According to Hanks and Sillén (1999), policy instruments can be divided in: directive based regulation ("traditional use of government regulations whereby a public authority sets standards, monitors and enforces compliance to these standards, and punished transgressions"); economic instruments ("efforts to encourage beneficial behaviour by altering the prices of resources and of goods and services"); voluntary initiatives (this category includes a very broad range of instruments, from negotiated environmental agreements, self-auditing and voluntary disclosure, voluntary programmes, eco-labelling and other measures to enhance awareness on environment/energy issues) (Hanks and Sillén, 1999).

Once again, to distinguish energy from environment policy instruments and the reverse it is not immediate. Nonetheless, it seems clear that some environment policy instruments may act as constraints to energy supply and thus, clearly interfere with the main objectives of traditional energy policies (Figure

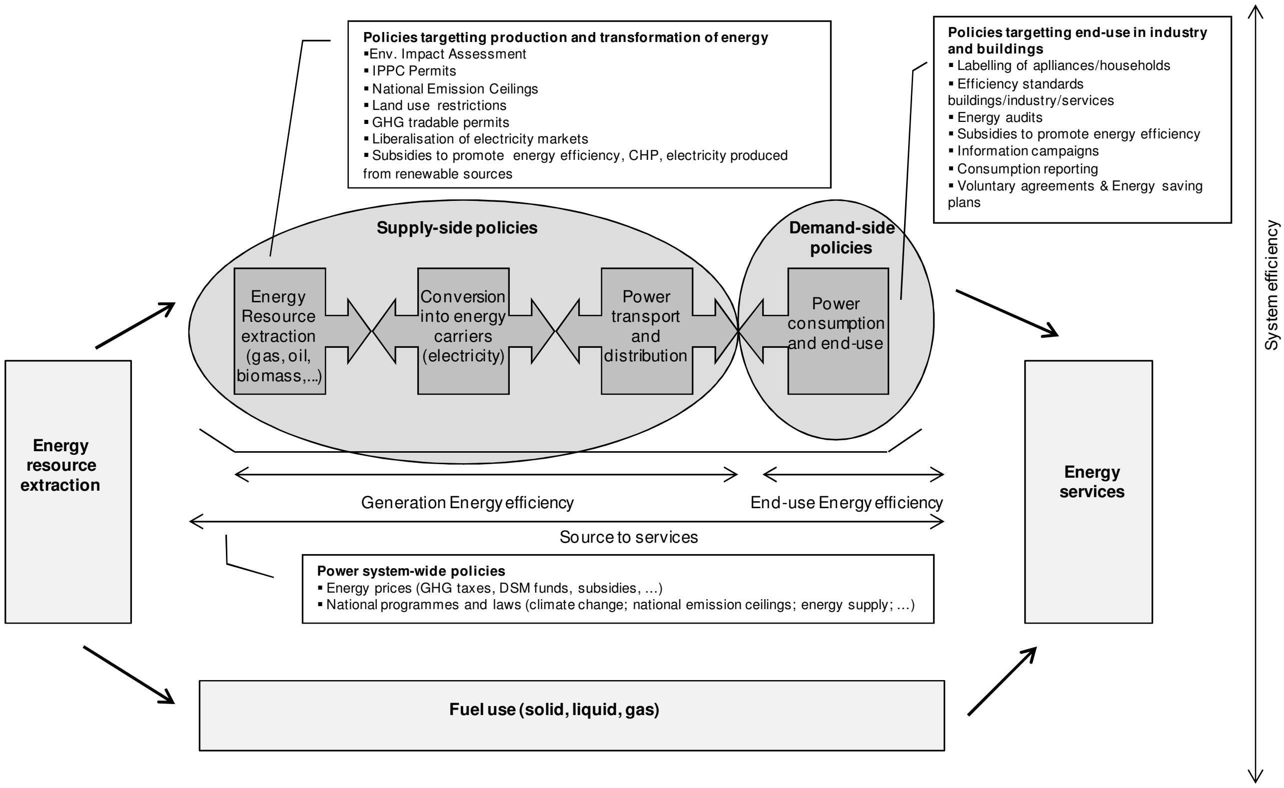

Figure 1 – Power system and some energy and environment policy instruments in place, illustrating potential for fragmentation and inconsistencies

The inverse situation also occurs; that is, energy policies might also negatively affect environment purposes. Biofuels deployment as on-going in the EU might have severe negative environment impacts (Pimentel, 2003; Kim and Dale, 2005; Phalan, 2009).

The conflict in objectives of policy instruments and measures, mostly targeting the same stakeholders along the electricity system, is likely to hamper the effectiveness of each of them.

1.2 Striving for energy and environment policy integration

As mentioned before, it is acknowledged that the disarticulation of energy and environment policy instruments generates costs and inefficiencies that stretch already limited government budgets and hamper the efficiency and effectiveness of all policy instruments in place (Briassoulis, 2004; Greening and Bernow, 2004; RIVM et al., 2001; EU Commission COM(2004) 394 final). For example, CO_2 charges for emissions reduction are counteracted by on-budget aids to subsidising oil and coal infrastructures, or subsidies to renewable electricity generation are counteracted by restrictions of hydropower for water conservation purposes.

Accordingly, policy makers have been taking efforts to integrate environment and energy policy goals, as in the 1998 European Council in Cardiff and in the 2001 Council's environment integration strategy in the energy area (EU Commission SEC (2001)502, 2001). This was reinforced by the European Council of March 2007 which has decided to "develop a sustainable integrated European climate and energy policy".

Despite these well-intentioned efforts, little policy integration has actually been achieved (Coffey & Dom, 2004; EEB, 2003; Constantinescu and Janssen, 2003; EU Commission SEC (2001)502, 2001). This is due to four main flaws: 1) the intrinsic limitations of the policy making process; 2) the vertical approach used for integration focusing on the broad policy goals and not on the policy instruments, 3) the historical lack of systematic policy evaluation efforts as an integral part of the policy development process, and 4) the subsequent lack of systematic identification of priority areas for policy integration.

Regarding the limitations of the policy making process, human capabilities and the existing evaluation methods do not allow for the apprehension of all the dimensions of complex problems. Therefore, it is not realistic to expect that policies can develop perfectly coordinated instruments capable of simultaneously addressing all social, economic and environmental problems. Instead, policy making is incremental, i.e. the result of continual step-by-step readjustments that aim for slight modifications of existing policy goals, handling one issue at a time (Lindblom, 1959). Moreover, policies result from the aggregation of "many politically self-contained programs and activities" (Schulman, 1975), which have to be negotiated by differently empowered lobbies (Dahl and Lindblom, 1953). Thus, according to public policy analysis literature, policy integration is hampered from the start, also the integration of energy and environment policy. However, although optimal policy integration is unattainable, it is still possible to achieve some piecemeal improvement of optimality. The ultimate objective of this dissertation is to contribute for the best possible policy integration, highlighting the most relevant counteracting policy instruments, as an essential first step to improvement.

To do so it is necessary to change the current approach for policy integration starting from the policy goals. Most of the policy integration efforts developed so far seems to be nothing more than vague statements on the integration of equally vague broad policy goals. These attempts merely result in the addition of environmental goals to sector policies (e.g. energy or transport policy shall be environmental sustainable), without actual integration of the instruments and procedures (Briassoulis, 2004). This fundamentally hampers the cost-effectiveness of policy integration, since despite beautifully formulated policy goals the effects of any policy are dependent on its instruments design and implementation. Although the rationale behind this approach starting at policy goals is that eventually integration will trickle down to the level of the policy instruments, this did not happen yet. Meanwhile, there are a number of policy instruments in place that potentially counteract each other. These are more than is minimally required in empirically overlapping domains.

This brings up the third flaw of the current policy integration approach – systematic policy evaluation efforts as an integral part of the policy development process. Although detailed analysis of different energy policies have been done (e.g. industry energy efficiency by Worrell and Price (2003); household appliances by Menanteau (2003), Uyterlinde and Jeeninga, (1999) and even on all energy efficiency policies by the World Energy Council (2003), and although the majority of authors acknowledges the importance of performing integrated evaluations of outcomes of policy instruments, this is a very complex task.

Furthermore, policy evaluation is a relatively new field and came rather late to the energy/environment field compared to other policy issues (e.g. health, education). The problem has been stressed because of the seriousness of environmental degradation and impacts of energy systems on global human/natural systems. Not only this is a new research field, but also it is fragmented in concepts, theories and views as its development is exponential. The lack of policy evaluation is a common feature of both energy end environment policy fields. For environment policy EU policies have developed so fast that, according to a study of the European Environment

Agency, there are currently more than 100 pieces of legislation in place covering the entire spectrum of environmental problems. Of these, only 12% require Member-States to provide evaluative information on the effects of the implemented policy measures (EEA, 2001). No newer references seem to be available.

The lack of systematic policy evaluation is probably the cause for the fourth flaw of the policy of the current policy integration approach - the lack of systematic identification of priority areas for integration. The policy integration efforts made so far seem to be based on subjective qualitative assessments, such as “energy contributes to greenhouse gas emissions, thus energy and environment policy should be integrated”. However, a more robust approach is necessary to deal with the myriad of energy and environment policy instruments in place. Which of these interact with other instruments? Which interactions are antagonistic or synergetic? And, more importantly: Which of the interactions are significant regarding the overall policy success? Which counteractions might be avoided? Such questions have to be answered in order to improve optimality.

1.3 Methods for policy evaluation and assessment of interactions between instruments

Acknowledging the beforehand mentioned questions, a new interest starts to rise on the study of collateral effects of policy measures, such as the effects of the policies deigned for reducing acidifying emissions on the GHG emissions and the opposite (Brink, 2002) or different energy policies aiming for energy efficiency, such as voluntary agreements and efficiency standards (Menanteau, 2003). The 6th Environmental Action Programme for the European Union (Article 10) explicitly called for improvements in the policy decision-making through ex-ante and ex-post evaluations. This also addressed energy (efficiency) policies tackling climate change (Article 5). As a result of this initiative, the Commission launched the system of *Integrated Impact Assessment* to address significant environmental, economic and social impacts arising from major EU policy (proposals) in 2002. However, it has been argued that the quality of the evaluation studies is low and that the actual effects of the studies on the policy decision-making are unknown, even in cases in which comprehensive analyses have been performed (Jordan and Lenschow, 2010).

The scientific literature on interaction between policies and policy instruments is divided in three main fields: policy evaluation (e.g. Mickwitz, 2003; Mickwitz, 2009 and Jordan and Lenschow, 2010); applied policy analysis (e.g. Oikonomou, 2010; IEA, 2011; and Böhringer *et al.* 2009), and more theoretical economic policy analysis (stemming from Tinbergen, 1956 and followed up by many authors as Hoel, 2012).

Economy-energy-environment models, such as MARKAL, TIMES, PRIMES, RAINS or GEM-E3, have been widely used for the analysis of policy effects and to support decision-making (van Harmelen et al., 2002; Greening, 2004; Capros *et al.*, 2008; DGEC, 2011; ENEA, 2012; AEA, 2011). However, these models have been sparsely used to assess how different policy instruments interact with each other. Here I try to bring such models use one step further by illustrating how they can be useful in energy and environment policy integration.

A quantitative approach that estimates the losses or gains on effectiveness and cost-effectiveness of interacting policy instruments is most useful to support successful policy integration. Such methodology allows assessing the relevance of counteracting effects between policy instruments, to set priorities for their integration, and to test more integrated policy designs. For this I use a bottom-up TIMES technology model, which is widely used. It has been implemented for Portugal as a country example in the TIMES_PT model. Bottom-up models adopt a partial equilibrium representation of the energy system, describing it with high technological detail. On the other hand, top-down models, also known as Computable General Equilibrium models, describe the interaction between the energy system and the economy as a whole representing the energy sector in an aggregated form by production functions (Böhringer, 1998).

The bottom-up modeling approach complements not only top-down modeling analysis, but also other analytical approaches. Optimization models can only capture part of the overall picture as they do entail numerous limitations (e.g. unrealistic portrayal of decision-making rules used by energy agents – e.g. households; representation of market imperfections, etc.). Given the nature, functioning and context in which policy instruments are introduced, it is highly unlikely that one single policy evaluation method will provide a comprehensive assessment. Therefore, several evaluation methods are needed to fully capture the empirical and normative aspects of policy instruments and provide useful comparative evaluations. In this dissertation the emphasis was placed on using a bottom-up optimization model. Nonetheless, a top-down model has been used for comparison with the bottom-up TIMES model, assessing how outcomes differ based on choice of model. This modeling is one key step in developing a methodological basis for improving policy performance.

1.4 The Portuguese case-study

Environmental policy making in Portugal is relatively recent (the Law that established the framework for environmental legislation dates from 1987 – Law 11/87 of 11 April) and is strongly dependent on the European Union's directives. As a result of this, many of the implemented policy instruments seem not adapted to adequately fit to the Portuguese reality and thus, seem not effective (Almeida, Lopes, Carvalho, 2000; Santos *et al.*, 1999; OECD, 2011). Additionally, there is room for improvement regarding the enforcement of both energy and environment policies (IEA, 2009; OECD, 2011).

Portuguese Energy Policy was for the first time formally defined and adopted in April 2003[2]. The promotion of sustainable development is acknowledged as one of the key objectives to be met, together with securing the supply and promoting the competitiveness of Portuguese economy. The question on how to meet its objectives in practice is crucial. This is especially relevant since:

- There is a significant potential for energy saving in Portugal (see Box 3 for electricity savings);
- About 90% of the Portuguese primary energy is imported, severely burdening the national trade balance;
- Between 1990 and 2005 the country was still increasing the energy intensity of its GDP and until 2009 its electricity consumption per

[2] The most recent Portuguese energy policy is named ENE2020 and is dated from 2010, but the same approach to sustainable development applies.

capita. The country has a rapidly growing electricity consumption although it has decreased in 2008 for the first time since 1990 [3];

- Portugal has to make a strong effort to meet its commitment to increase its non-EU-ETS GHG emissions only 1% of the 2005 levels, established within the EU 20-20-20 energy climate policy package (EU Decision COM(2008) 17, EU Commission COM(2008) 30).

It seems that all conditions point to a favourable setting to promote energy efficiency, both for environmental and economical purposes. However, many of these were also present in the past and the actual improvements have been slow (EU Commission COM(2010) 639 final, Wuppertal, *et. al.*, 2000, Simoes, 2001). Up to what point can the integration of energy and environment policies objectives in Portugal enhance this improvement? And how can this integration be executed?

[3] On average since 1990 to 2009 3% per year, with episodes of 8.1% average annual rates being reached within the residential and services sector during the 90's.

Box 3 – Potential for electricity saving in Portugal

A study promoted under the EU SAVE programme in 1992-1994 has identified the technical potential for savings by replacing some of the existing equipment, with other more efficient ones. The study is essentially based on the substitution of the existent equipments for more efficient ones available in the market in 1992 (the time frame for the study was 1992 to 2000). It did not consider the utilisation patterns and the difficulties with the implementation of these new equipment. The results point to saving potentials ranging from 27% saving per year (4236.3 GWh/yr) in the industry sector to 40% saving per year (4508.6 GWh/yr) in the services sector.

These values simply represent the technical potential for the reduction of electricity and it is important to refer that they are probably outdated, since the study used the year of 1992 as a baseline and since then many alterations took place, such as the introduction of natural gas.

The National Energy Efficiency Action Plan (NEEAP) (RCM 80/2008) sets an overall target of 10% minimum energy savings by 2015 compared to a baseline scenario, but does not set specific targets for electricity savings. The NEEAP defines specific targets and incentives for stimulating energy efficiency in buildings through increase of insulation, double glazed windows, solar thermal, heat pumps, efficient biomass heating equipment, and A+ and A++ appliances.

Source: Simões, 2001; Júlio, Cabral, Costa and Almeida, 1997; Baía, Cabral and Almeida, (n.d.); RCM 80/2008.

1.5 Research questions and Thesis Outline

The objective of this dissertation is to contribute to the understanding of how energy and environment policies can be further integrated in order to improve its cost-effectiveness, considering the currently on-going debate on the transition to more sustainable energy systems. The dissertation aims to assess the necessity and benefits of developing integrated policy approaches to the energy systems in general, and electricity in particular, regarding not only the integration of energy and environment policy objectives, but also the integration of different policy instruments along the electricity system.

In order to do this, the following main research questions are raised:

- A) What divergences exist between the objectives of energy and environment policies and how relevant are these?

This question is addressed in Chapter 2 (Tangled web) where a qualitative framework to systematically assess the divergences between such policy instruments is presented. The reasons for these divergences are also discussed in this chapter. Chapters 3 (Cost of energy and environmental policy) and 4 (Savings of energy savings) also deal with this question by quantifying divergences between current environment and energy policies, as a proxy for the policy instruments themselves.

- B) How well can we assess the interactions between energy and environment policies and instruments? In particular, how can they be quantified?

This methodology is presented in Chapters 2, 3, 5 and 6. In Chapter 2 (Tangled web) is presented a conceptual methodological framework for the assessment. In Chapter 3 (Cost of energy and environmental policy) is presented a methodology for quantitative assessment using the TIMES energy system model to quantify interactions between energy and environment policies and measures. In Chapter 5 (Effects of exogenous assumptions) is performed an assessment of the methodology's limitations by studying how the TIMES model responds to systematic variations in exogenous inputs. In Chapter 6 (Top-down and bottom-up modelling to support low carbon scenarios) is presented a comparison between differences in outputs of the bottom-up TIMES model outputs and the alternative model paradigm the top-down GEM-E3 model.

- C) How do the different energy and environment policies instruments & measures along the power energy system interact with each other and how does that interaction affect their effectiveness and cost-effectiveness?

This is addressed in Chapter 2 (Tangled web) in a qualitative manner and quantified in Chapters 3 and 4. In Chapter 3 (Costs of energy and environmental policy) interactions of broad energy and environment policy options are quantified as a ban on nuclear or no carbon capture and storage in fossil power plants. In Chapter 4 (Savings of energy savings) the quantification of interactions focus on more specific policy options either targeted on the supply side of the power system or on the demand side.

- D) How can energy and environment policy instruments be better integrated in order to improve their overall effectiveness and cost-effectiveness?

Suggestions are made in Chapter 2 (Tangled web) namely on structuring trade offs and on Chapter 4 (Savings of energy savings) particularly on energy efficiency and permits to large fossil power plants.

These main questions are interconnected and encompass a number of more specific questions, which are addressed in detail from Chapters 2 to 6, as shown in Table 1.1.

Table 1.1 - Overview of the research questions addressed in each chapter of the thesis

Chapter	Main Research questions			
	A What divergences	**B** How well can we assess interactions	**C** Extent of the interactions	**D** How can instruments be better integrated
2 A Tangled Web	●	● (qualitative assessment of interactions)	● (qualitative assessment of interactions)	●
3 Cost of energy and environmental policy	● (quantitative assessment of interactions)	● (quantitative assessment of interactions)	● (quantitative assessment of interactions)	
4 Savings of energy savings	● (quantitative assessment of interactions)		● (quantitative assessment of interactions)	●
5 Quantifying the contribution of different exogenous assumptions		● (limitations)		
6 Top-down and bottom-up modelling		● (limitations)		

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2 A tangled web: assessing overlaps between energy and environmental policy instruments along the electricity supply chain*

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Abstract

A large number of overlapping energy and environmental policy instruments is targeting the various stakeholders in the electricity supply chain (producers, transmission and distribution companies and the diverse group of consumers). Although synergies between different policy instruments exist, e.g. reducing acidification and climate change by reducing energy consumption, there are also measures whose effects counter each other. Such counter effects arise not only within different environmental policy instruments but also with energy policy instruments. In this paper we survey the overlaps in the policy instruments that target the EU electricity system and characterise their interactions. A framework for further assessment and analysis of overlaps and co-effects between policy instruments is presented. The development of policies and their implementation using specific instruments may then be better aligned. A brief discussion on how trade-offs can be structured is made, as well as some notes on issues to be considered towards policy integration.

2.1 Introduction

The use of electricity for provision of energy services is pervasive throughout the economy. It represented 22% of the OECD countries' final energy consumption in 2009 and was the major final energy carrier in industry and buildings[4] (IEA, 2009). Thus, policies affecting the electricity system condition economies and wellbeing of populations. Presently there is a large number of energy and environmental policy instruments in place which overlap with each other in as much as they share the same targets for policy. The various stakeholders along the electricity supply chain and the end consumers are targeted by many different policy instruments, each aiming to steer their behaviour in a particular direction (Midttun & Koefod, 2003, OECD, 2005). In most cases the steering effects[5] of the policy instruments are also affected by the other instruments in place, i.e. the policy instruments have co-effects. These co-effects occur not only within the same policy field, but also between instruments of different policy fields.

For example, within the field of environmental policy, climate change policies implemented by reducing energy use, or by shifting from coal to gas, contribute to the effectiveness of acidification and air quality policies since they reduce acidifying, tropospheric ozone, chemicals and primary

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[4] Electricity represented 31% of final energy consumption of industry and 42% of final energy consumption in buildings in OECD countries in 2009 (IEA, 2009).

[5] By steering effects of policy instrument(s) we mean the resulting change(s) in behaviour caused by the implementation of the instrument(s). These can be either intentional (resulting directly from the implementation of the instruments' objective, e.g. incentives to replace appliances with more efficient ones steering consumers to buy type "A" equipments) or unintentional when unexpected changes in behaviour occur. This is for example the case of rebound effects in general. In the previous example of efficient appliances, one unintentional steering effect of the instrument(s) aiming for the larger deployment of efficient appliances is the sometimes in higher energy consumption as consumers still maintain their older, inefficient appliances functioning as backup or acquire larger appliances (see Greening, et al., 2000).

particulate matter emissions (RIVM *et al.*, 2001, Bollen *et al.*, 2009). On the other hand, emission limit values to air might conflict with emission limit values to water due to relocation of pollutants from air to water (or waste) following the implementation of end-of-pipe technology in chimneys. Examples of co-effects between environmental and energy policy instruments are the CO_2 charges for emissions reduction that are counteracted by the on-budget[6] aids to subsidising oil, gas and coal infrastructures, or the subsidies to renewable electricity generation whose effect is limited by the restrictions of hydropower for water conservation purposes.

Naturally, the more policy instruments in place, the more the potential for overlaps, leading to more co-effects that might significantly reduce overall cost-effectiveness. Therefore, the fact that a large number of new policy instruments are being developed and implemented in OECD countries in order to curb CO_2 emissions (IEA, 2010; EU Commission COM(2008) 30; EU 2003) adds relevance to the assessment of overlaps and co-effects between them.

This issue has increasingly gained the attention of policy makers and researchers. On the research arena, work on interaction between policies/instruments can be found in three main literature areas: policy evaluation (e.g. Mickwitz, 2003; Mickwitz, 2009 and Jordan and Lenschow, 2010); applied policy analysis (e.g. Oikonomou, 2010; IEA, 2011; and Bohringer *et al.* 2009), and more theoretical economic policy analysis (stemming from Tinbergen, 1956 and followed up by many authors as Hoel, 2012). It is widely acknowledged that the non-coordination of energy and environment policy instruments generates costs and inefficiencies that stretch already limited government budgets and hamper the efficiency and effectiveness of all policy instruments in place (EEA, 2005; Briassoulis, 2004;

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[6] "Visible in budget accounts or able to be estimated from budget accounts" (Valsecchi et al., 2009). Several authors (van de Beers and de Moor, 2001 and IEA, 2001 in OECD, 2005) estimated that in 2001 the annual subsidies to energy producers in OECD countries ranged from USD 20-80 billion per year via grants, loans and tax exemptions. Roughly a third of the amount was allocated to coal production in 2001, notably in Germany, Spain and France, although these subsidies follow a decreasing trend (IEA, 2001 in OECD, 2005).

Greening and Bernow, 2004; RIVM et al., 2001; EU Commission COM(2004) 394 final). Moreover, the excessive amount of instruments, their high complexity and variety makes the impact assessment of new proposed instruments more difficult and unreliable due to the interferences with existing ones. The same applies to verifying the compliance of the regulated entities. Accordingly, policy makers are taking efforts to integrate environment and energy policy goals. The 1998 European Council in Cardiff formulated an initiative aiming to more effectively integrate environmental aspects into sector policy making, following the articles 2 and 6 of the Amsterdam Treaty of the European Union (EU). In 2001 the Council adopted environmental integration strategies in the energy area, among other (EU Commission SEC (2001)502). In the same year a Sustainable Development Strategy for EU was adopted adding an environmental component to the Lisbon Strategy, which was reviewed in 2006 (Council of the European Union, 2006). This process finds its ultimate formulation in the Europe 2020 strategy of 2010, with policy integration as a main means to better reach sustainability goals (European Commission COM(2010) 2020 final.

This type of integration of policy goals is known as *Intrasectoral* or *Vertical* policy integration. It reflects an incrementalist attitude which mostly results in the addition of environmental goals to sector policies, with little actual integration of the instruments and procedures (Briassoulis, 2004). Therefore, it is not surprising that little has actually been achieved (Nilsson and Nilsson, 2005; EEA, 2005; EEB, 2003; Lafferty and Hovden, 2003; EU Commission SEC(2001) 502, 2001). It is necessary to move from vague statements on the integration of equally vague broad policy goals, to a concrete integration at the level of the policy instruments, where the conflicts between different objectives are more clearly visible. An approach to do so entails systematically assessing conflicts between instruments in place and changing their configuration. Such systematic approaches have been suggested mostly in the field of environmentally harmful subsidies (OECD, 2005; Valsecchi *et al.*, 2009).

This paper tries to contribute to a better integration of energy and environmental policy instruments by: 1) providing a framework to assess overlaps and co-effects between instruments in place alongside electricity systems, and 2) making suggestions for pursuing the integration of energy and environmental policy instruments. . The paper does not aim to present a thorough assessment of the overlaps and co-effects, but merely to suggest a systematic methodology that can be used to do so. The framework does not aim to supply a quantified assessment of the significance of the co-effects between instruments, but primarily contributes to a better framing of the problem. The paper starts by discussing the background for non-coordination within and between energy and environmental policy instruments. This is followed by a brief overview of the research done in this field. A characterisation of policy instruments is made to set the scene regarding the energy and environment policy instruments in place alongside electricity systems. Building on that, the framework to assess overlaps in policy instruments is then presented, and its application exemplified. Finally, a short discussion on how trade-offs can be structured is made, as well as some notes on issues to be considered towards policy integration.

2.2 Background for non-coordination of energy and environmental policies and related studies

2.2.1 Why energy and environment policy instruments are not integrated

The ultimate goal of energy policies has been (and according to the International Energy Agency, will continue to be) to guarantee an adequate supply of competitively priced energy to foster economic development. At EU level the "(...) central goals for energy policy [are] (security of supply, competitiveness, and sustainability)" (EU Commission COM(2011) 112 final:2). However, in practical terms the minimisation or mitigation of caused environmental impacts is a much secondary goal of energy policy (see Nilsson and Nilsson, 2005; EEA, 2005; EEB, 2003; Lafferty and Hovden, 2003). The ultimate goal of environmental policies is to protect natural resources[7]. This **difference in policy goals,** most frequently implemented

[7] Regarding environmental policy, the objective of the EU's DG Environment is "(...) to protect, preserve and improve Europe's environment for present and future generations. It proposes policies and legislation that protect natural habitats, defend clean air and water, ensure proper waste disposal, improve knowledge of the toxicity of chemical substances, and help European businesses move towards a sustainable economy" (DG Environment, 2010:1). The protection of first three (natural habitats, clean air and water)

by different agencies and organisations, is an important cause for non-coordination between energy and environment policy instruments (although not the only one as discussed in this section).

However, **environmental and energy policy instruments are partly overlapping**, since both concern natural resources. Environmental policy instruments intrinsically condition electricity supply and demand by imposing restrictions to the use of natural resources (e.g. establishing land use restrictions or emission limit values) or by providing incentives to change the supply and demand profiles (e.g. creating a market for the emission permits of CO_2 and thus an incentive for shifting or establishing environmental taxes on electricity). Energy policies also condition the fulfilment of environmental policy's goals. The liberalisation of the electricity markets is argued to lead to the decrease of electricity prices and thus reduces incentives for energy saving (Joskow, 2008; Vine *et al.*, 2003; Fuchs & Arentsen, 2002) that allow the minimisation of the environmental impacts associated to energy supply. The loss of control over technology choice may disincentive public investment in environmentally preferably technologies.

Besides this more normative cause, other **aspects of organisational and procedural nature** contribute to lack of integration of energy and environment policy instruments (Persson, 2004; Nilsson and Nilsson, 2005). Energy and environment are autonomous policy sectors that rely on separate specialised vertical organisations (Briassoulis, 2004), with divergent political objectives and interests. The procedures of these organisations further contribute to the non-coordination since there is lack of collaboration among them - from the supra-national level (e.g. the Directorates-General of the EU Commission) to national organisations, weak administrative coordination

is irrefutably the protection of natural resources. We argue that "ensuring proper waste disposal and improving knowledge of the toxicity of chemical substances" are pursued merely to secure the first three (natural habitats, clear air and water). To "help European businesses move towards a sustainable economy" can be seen also a mean to secure the protection of natural resources in order to ensure the survival of economic activity. It is besides the point of this paper to enter into a discussion of the motives behind such concern with natural resources be it the protection of human well-being or perhaps more altruistic concerns with integrity of ecosystems.

and low degree of consultation of national authorities (Robert *et al.*, 2001 in Briassoulis, 2004).

Not only public authorities have responsibilities in lack of policy coordination. Different private lobby groups actively seek to influence political outcomes (Nilsson and Nilsson, 2005). Environmentalists and business lobbies have a prominent role in both formulation and implementation of policy instruments aiming to "*give voice to different aspects of environmental policy, making sure that all aspects are considered in the political trade off and reflected in the implemented policy*" (Aidt, 1998: 2). Therefore, lobbies intrinsically add entropy to the policy process hampering coordination of policy instruments. Lobbies also deliberately act towards the weakening/strengthening of policy instruments depending on how they perceive these to affect their interests. These deliberate actions might result in instruments that seriously counteract each other, depending on the influence of their promoters over policy-makers.

On a more empirical/practical level, other motives for the occurrence of counteracting co-effects in policy instruments are first the lack of awareness to the issue, and secondly the **lack of knowledge** on its impact on cost-effectiveness. This in turn is due to the very rapid pace of development and implementation of policies which does not include systematic policy evaluation practices. According to a study by the European Environmental Agency, there are currently more than 100 pieces of EU environmental legislation in place covering the entire spectrum of environmental problems. Of these, only 12% require Member-States (MS) to provide evaluative information on the effects of the implemented policy measures (EEA, 2001)[8], let alone that counteracting influences would be specified between them.

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[8] This corresponds to 13 EU directives and regulations on: integrated pollution prevention and control, lead in petrol, monitoring forest damage, air quality framework, screening for lead, contained use of genetically modified organisms, sewage sludge, titanium dioxide and nitrates emissions to water, habitats and species conservation, cohesion fund, rural development regulation and the greenhouse gas monitoring mechanism (EEA, 2001).

Therefore, it is not surprising that although detailed analysis of individual effects of energy and environment policy instruments on certain sectors is being done[9], there is still a lack of systematic evaluation practices of individual policy instruments' effectiveness and efficiency (EEA, 2001, Vehmas, 2005). Moreover, there is yet much to be done assessing the impacts on effectiveness caused by interactions between individual policy instruments or between combinations of policy instruments (Worrell and Price, 2001; OECD, 2005; Oikonomou and Jema, 2008).

2.2.2 State of the art

Following the concerns about environmental policy integration previously mentioned, and the growing complexity of environmental policies, a new interest starts to develop in the study of the unintended effects of specific environmental and energy policy instruments. Different names are used for these: side-effects (Raadschelders *et al.*, 2003), spillovers (RIVM *et al.*, 2001), rebound effects (Muster, 1995), co-benefits or co-damages (Kleijn and van der Voet, 2002), incidental impacts (Valsecchi *et al.*, 2009) or feedback effects (Worrell and Price, 2001). Most studies in this area focus mainly on identifying the occurrence of specific unplanned effects of instruments and how much these will affect the respective environment/energy objectives, and not so much on understanding the mechanisms of interactions between the different policy instruments.

Some examples of studies of unintended effects of policy instruments are the work developed by RIVM et al. (2001) that performed repeated simulations of the DPSIR[10] chain combining cost-benefit analysis and integrated environmental assessment "for a selection of policy packages with the aim of identifying the most cost-effective set of policy responses" (ibid.:168) for all

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[9] Such as the studies on policy instruments to promote industry energy efficiency by Worrell and Price (2001); on household appliances by Menanteau (2003) or Boardman (2004); on support schemes for renewable electricity by Lauber (2004), on energy taxes by Vehmas (2005) or on energy tax exemptions on aviation fuel by van Beers *et al.* (2007), to mention but a few.

[10] Driving Forces-Pressure-State-Impact-Response (DPSIR) (EEA, 1999).

environmental problems. The White and Green Project (n.d.) used a technical-economic model to study the cost-effectiveness effects that the combination of white certificates, green certificates, CO2 emissions trading and an energy tax might have. Uyterlinde & Jeeninga (1999) used a similar approach for evaluation of combinations of energy efficiency policy instruments in households. Valsecchi et al. (2009) adapted the OECD (2005) framework to identify and assess environmentally harmful subsidies (including energy ones).

Although all authors acknowledge the importance of coherently integrating different policy instruments (within environmental policies, within energy policies and between those two policy areas) and provide suggestions on how to do so within the scopes of their respective studies, their approach is partial. It considers either the environmental problems/themes and not the energy issues (RIVM *et al.* study) or a selection of a few of the policy instruments in place (the other studies). This happens not only in these studies but in the majority of the literature in this area (Oikonomou and Jema, 2008). Sorrell (2003), within the INTERACT EU Project, and Oikonomou and Jepma (2008) take a step further. The former assesses in detail the mechanism of interaction between the EU ETS and other climate policy instruments, whereas the latter propose a framework to analyse interactions between all energy and climate change policy instruments, instead of focusing on only pairs of instruments. However, both cases focus on climate policy instruments only. Energy and other environmental instruments are out of scope.

In a formal modelling sense, a converse position can be maintained: the number of instruments should equal the number of goals (see Tinbergen, 1956). In this reasoning it is assumed that goals can be specified independently and that all instruments and goals are linked in one model involving all intermediary variables. Reality is not so easily modelled, but the basic point remains: too many instruments will create unnecessary costs for reaching given goals.

In this paper a broader policy scope is suggested than climate policy while using specifically electricity systems as a focal point. Because, in all probability, the significance of overlaps in policy instruments increases with the number of instruments, overlaps should be firstly screened at a general policy level for the electricity system, without targeting one specific policy area. This initial overall screening allows for getting a more complete picture of all overlaps from which the more problematic ones can be singled out. To do so, however, it is necessary to evaluate and rank overlaps according to their impact on overall cost-effectiveness for the electricity system.

This paper considers a larger number of policy instruments from the two different policy fields and includes the different groups and activities that constitute electricity systems. Moreover, a framework is developed to systematically assess overlaps and co-effects between instruments. This can be the starting point of a methodology for the quantification of impacts of co-effects of policy instruments.

2.3 Tangled web – energy and environment policy instruments in place in electricity systems

This section presents an overview and characterisation of policy instruments both currently in place and that will be implemented within years, in order to set the scene for the assessment of their overlaps and co-effects. Generic types of policy instruments in place across the EU were considered instead of specific policy instruments implemented in one particular country. This allows for a more complete overview of potential overlaps between different policy instruments without being restricted to the range of instruments implemented by specific governments. For the purpose of this overview electricity based transport was not considered particularly relevant, as electricity in transport represents only 1% of final energy consumption in 2009 in OECD countries (IEA, 2009), and thus is not included. This situation will most probably change as increasing policy focus is given to electric vehicles, but nonetheless we did not cover specific policy instruments for these at this point.

For the characterisation of the instruments, as presented in Figure 2.1 and in Appendix A, the following aspects are considered relevant since they give information on different levels of interaction between the instruments:

1. **Objective of the instrument**, which refers to the explicit objective of the instrument as stated in the documents that formulate it. This is usually more specific than the broader policy goal that led to the development of the instrument.

2. **Mechanism of instrument** used to steer behaviour (Command-and-control (CAC); economic/market-based and moral suasion and voluntary initiatives[11]).

3. **Target stakeholder(s)**, i.e. those whose behaviour the policy instruments primarily aims to steer, such as primary energy suppliers; electricity generators; transmitters; distributors & retail suppliers; appliances manufacturers and distributors; several types of consumers (household, services, industry), among other. Although policy instruments can affect the behaviour of other stakeholders than the ones intentionally targeted we have not included these, for the sake of simplification.

4. **Action according to the DPSIR framework**, as developed by the European Environmental Agency from the OECD Pressure-State-Response model. According to the adaptation made by RIVM et al. (2001), policy instruments can be part of macro-economic policy or sector specific when designed to reduce or eliminate the underlying causes of the problems, such as market failures[12] (acting at the level of the Driving forces); or be source-oriented (act at the level of the Pressures), effect-oriented (act at the level of the State of the environment) or curative (acting at the level of the Impacts).

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[11] This category includes a very broad range of instruments, from negotiated environmental agreements, self-auditing and voluntary disclosure, voluntary programmes and other education/information measures to enhance awareness, see Huppes and Simonis (2010).

[12] Other underlying causes besides market failure are missing markets, information gaps, policy inconsistency and implementation failure (RIVM, *et al.*, 2001).

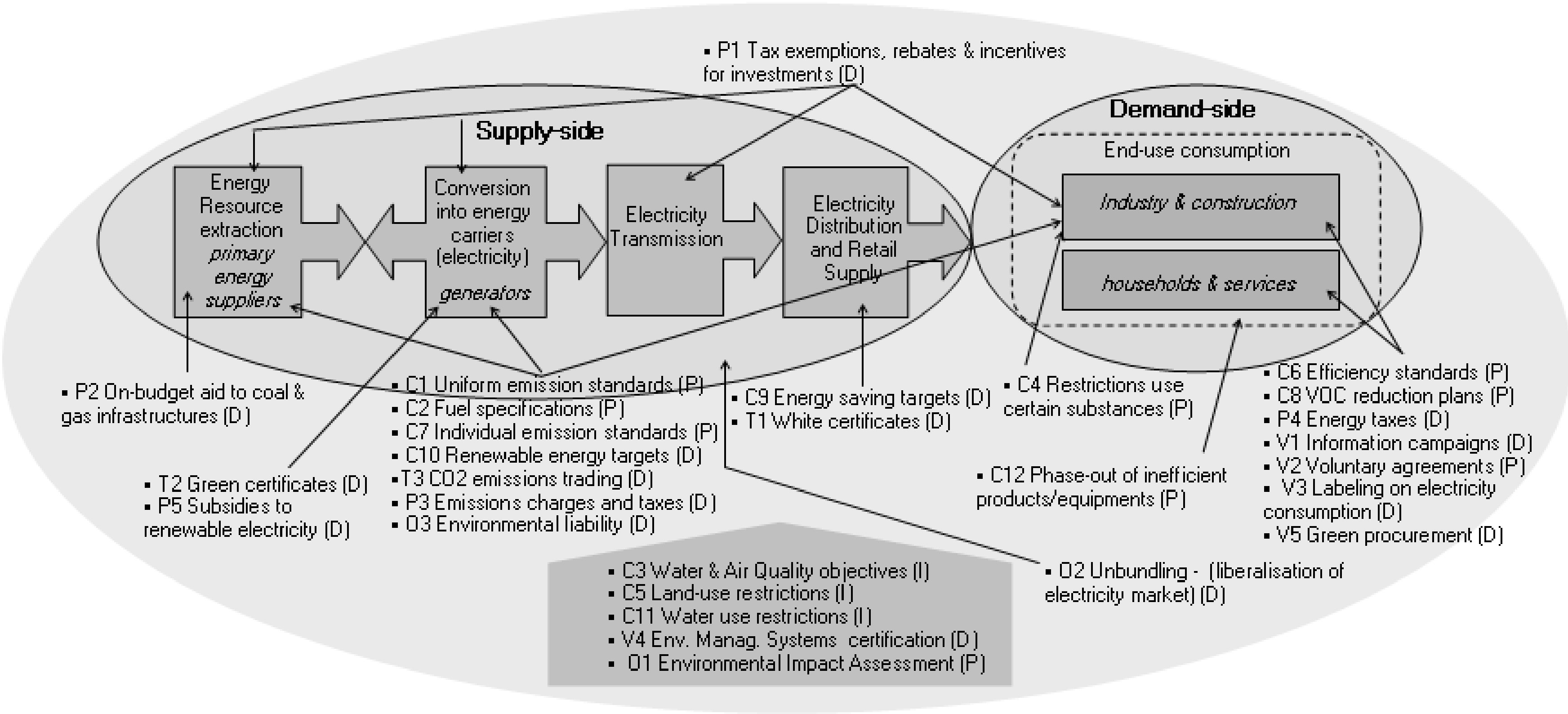

Figure 2.1 – electricity system and some energy and environmental policy instruments: a tangled web. Each instrument is identified with a letter and a number identical to the one used in Appendix A where a characterisation of instrument is presented. C – Command-and-Control; T – Tradable permits; P – price; V – moral suasion & voluntary and O – Other. The letter in between brackets indicates the type of action according to the DPSIR framework.

The characterisation of instruments also considers the instrument's **place of intervention in the electricity system**, closely related to the targeted stakeholders (extraction of primary energy sources; electricity generation; electricity transmission; electricity distribution and end-use consumption, or at a more broad scale, supply or demand of electricity). Aspects related to the institutional dimension[13] are not explored here, although they are particularly relevant since one of the barriers to the integration of policy instruments is that the benefits might not be felt at sector level in the short-term and only at the broader societal level (Persson, 2004).

Figure 2. 1 presents the electricity system as considered for the purpose of this paper. The supply and demand sides are identified together with some of the energy and environment policy instruments. Each policy instrument is shown linked to the stakeholder(s) that it directly targets. Therefore, indirect effects of one instrument over other stakeholders are not represented as this would make the picture even more complex. In the figure is also indicated the mechanism of the instrument and the type of action according to the DPSIR framework. A more complete characterisation of the policy instruments is presented in Appendix A.

A total of 27 different generic types of instruments are or will be in place along electricity systems, creating quite a complex picture. Even so, the instruments here depicted do not result from an exhaustive review and other specific policy instruments for waste management, transport, noise and accidents are not represented here. These 27 instruments are quite varied regarding mechanisms used and targeted stakeholders. Whereas most policy instruments target a specific stakeholder or groups of stakeholders, there are three environmental instruments (quality objectives, land and water use restrictions) that do not directly target any of the represented stakeholders and three instruments that are of a more transversal nature and directly affect all players (environmental impact assessment, environmental

[13] These refer to the co-ordination between the institution(s) responsible for design, implementation, monitoring and enforcement of the instruments, which can operate at different administrative levels, be it different sectors (e.g. energy, finance, transport, environment) or different hierarchic levels (i.e. EU, national, regional or local).

management systems and unbundling within the liberalisation of electricity market).

Both energy and environmental policy instruments are predominantly command-and-control (11 of the 26), but there are also quite a few (8) economic instruments (essentially subsidies). All stakeholders are targeted by a similar number of policy instruments, with the exception of electricity distributors & retail suppliers and transmission system operators. Whereas instruments targeting household and services are essentially moral suasion and voluntary, other players have their behaviour steered mostly by command-and-control and economic mechanisms.

2.4 Assessing overlaps and co-effects between policy instruments

2.4.1 Concept of overlaps and of co-effects of policy instruments

The concepts of side-effects, spillovers, rebound effects, co-benefits or co-damages, feedback effects or incidental impacts used in literature are closely interrelated and all refer to the unintended effects that the implementation of one or more policy instruments might bring upon other environmental or energy objectives. It is not the goal of this paper to look into the different unintended effects approached by each concept. Instead the paper focuses on the overall systemic effects between policy instruments. The current concepts do not clearly link the affected environmental or energy objectives with the specific policy instruments designed to achieve them. This subtlety is important because to optimise overlaps in policy instruments already in place it is necessary to consider not only how environmental or energy policy objectives are affected, but also the formulation of the overlapping policy instruments.

Therefore, it is considered useful to clarify the concepts of overlaps and co-effects of policy instruments. For the purpose of this paper, the relevance in overlaps of two or more policy instruments increases to the extent that 1) they share the same target stakeholder and 2) that their steering effects occur within related policy goals. Two policy instruments that steer the behaviour of totally different stakeholders and whose steering effects are not at all related (e.g. induce consumers to reduce alcohol intake, as part of health policy, and drive industry to implement energy efficiency measures, within energy policy) are of course not overlapping. However, if the stakeholders are different and the steering effects are closely related (e.g. induce households to reduce electricity consumption and drive industry to implement energy efficiency measures) there is a relevant overlap.

This overlap is even more relevant if different instruments steer the behaviour of the same target stakeholder. Those steering effects are likely to affect each other. For the purpose of this paper it can then be said that the policy instruments have co-effects, i.e. effects on each other felt at the level of its intended steering effects. The co-effects of policy instruments can be complementary (the steering effects of the instruments supply mutual needs or offset mutual lacks) or counteracting (the steering effect of one or more instrument counteracts the action of the other(s). This rationale of overlaps and co-effects in policy instruments is depicted in Figure 2.2.

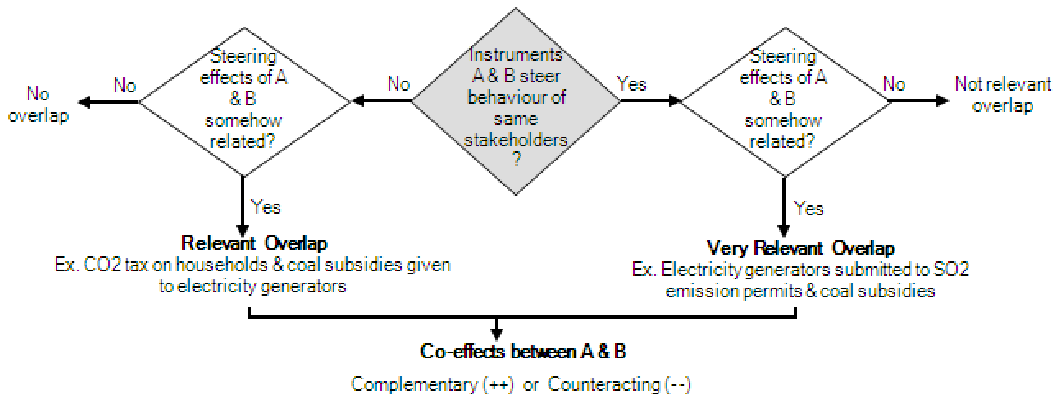

Figure 2.2 – Policy overlaps and co-effects in the context of this paper.

All policy instruments in Figure 2.1 (and Table 2.1 in next section) have relevant or very relevant overlaps since they either target the same stakeholders or have steering effects within related policy goals.

2.4.2 Framework to assess overlaps and co-effects

The question to be answered when assessing co-effects of two or more policy instruments is to what extent they overlap and how their steering effects affect each other. To understand this, the objectives of the instruments, its mechanisms and the targeted stakeholders have to be looked upon, as follows:

1. A **screening** of the objectives of the different policy instruments is made to assess as to what point they are **overlapping** (i.e. to what extent they either target the same stakeholder and/or they steer related behaviour of stakeholders, represented with +) or not (-). Note that, as mentioned before, it was already established that all policy instruments covered here are overlapping.

2. Their respective **mechanisms** are analysed to understand how well the instruments are coordinated. At this stage this can be done at two levels: a) no-coordination (0) - the instruments do not acknowledge the existence of other or b) some coordination (+) in the instruments (expressed as derogations or alterations in scope, among other).

3. The **steering effects** of the different instruments are analysed to identify if they are complementary (+; the objectives of the instruments steer the behaviour of the target stakeholders supplying mutual needs or offsetting mutual lacks), or counteracting (-; the objectives of at least one of the instruments steers the behaviour of the same stakeholders in a way that hampers the steering effect aimed by the other instruments).

This framework does not consider the actual effectiveness of the implemented policy instruments, in the sense that it do not assess, neither qualitative nor quantitatively, if the instrument was successfully implemented or if it failed to achieve its objectives, and how those successes or failures are affected by overlaps and co-effects between instruments. This would be extremely difficult due to the lack of policy evaluation assessments and the large number of instruments in place. The framework instead focuses on looking into the policy instruments' design translated into their written formulation Therefore, it cannot be used to assess the relevance in terms of quantified cost-effectiveness of the co-effects between policy instruments, but only to assist in a better understanding of how are instruments related to each other and in identifying priority areas for further analysis.

Because this framework focuses on the policy instruments and actors or stakeholders, it also does not address the other components of the policy process (objects, goals and the structures and procedures). Including these components would be relevant to understand the motives behind each overlap and co-effect but that is not the purpose of the framework. It merely aims at providing a systematic approach to identify and assess them.

Starting from the policy instruments depicted in Figure 2.1, targeting specific stakeholders, we have screened (in Table 2.1) their objectives as explicitly stated in the legislative texts (to the possible degree). By doing so, we avoid entering into a subjective allocation of "implicit" policy objectives which could be highly debatable. As it is, this identification of objectives can already be criticised. For example, P3 (emission charges and taxes) have the explicit objectives of internalising environmental costs, raising revenues and cover costs of policy instruments, but not to reduce emissions. Nonetheless, the identification of explicit objectives allows for better assessing their overlaps and co-effects. If all instruments are placed within the broader goal of "protect natural resources" or promote "secure, competitive and sustainable energy" there is no progress made towards the current *status quo*.

Table 2.1. Policy instruments objectives and grouping into clusters of objectives to assess co-effects (the codes for policy instruments correspond to the characterisation presented in Appendix A)

#	Objective of reviewed policy instruments	Policy instruments	Cluster of policy instruments objectives			
			Environment	End-use efficiency	Competitive supply	Secure supply
1	Reduce emissions	C1, C2, C4, C7, C8, T3	✓			
2	Minimise risk of environmental damage	C3, C11, O3, O1	✓			
3	Minimise environmental impacts	C5, V5	✓			
4	Improve overall (environmental) performance	V4	✓			
5	Increase end-use energy efficiency	C6, C9, T1, V2, V3, C12		✓		
6	Increase awareness for end-use energy efficiency	V1		✓		
7	Internalise environmental costs	P3, P4	✓			
8	Cover cost of policy instruments	P3, P4	✓		✓	
9	Raise revenues	P3, P4	✓		✓	
10	Increase energy/electricity from renewable sources	C10, T2, P5				✓
11	Promote security of energy supply	P1, P2				✓
12	Improve efficiency of electricity supply, price gains & quality of service	O2			✓	
13	Provide affordable energy	P1, P2			✓	

Most of the objectives of the reviewed instruments contribute both to broad energy and environmental policy goals. It is not straightforward to separate energy and environmental policy instruments, but groups or clusters of overlapping, but yet complementary, policy instruments objectives can be made to better assess co-effects between them. The screening of objectives allows stating that there are relevant overlaps within each cluster and between clusters since most of the instruments in Table 2.1 steer the behaviour of the same stakeholders and/or their steering effects occur within related policy objectives (we have established in section 2.2.1 that broad environment and energy policy goals are closely related, and in this section the linkages of objectives in Table 2.1 within each cluster). We have grouped the instruments in clusters according to how complementary their co-effects are within each cluster:

- *Environmental Cluster* - includes instruments with objectives that fall within the policy areas implemented by the EU's DG Environment. Policy instruments with objectives 1 to 4 (reduce emissions, minimise risk, impacts and improve overall performance) and 7 (internalise environmental costs) overlap each other because they mostly[14] target the same stakeholders (industry, electricity generators and primary energy suppliers), each steering their behaviour to reduce/control damage to the environment;
- *End-use efficiency cluster* – includes instruments in the policy areas of energy efficiency of the EU's DG Energy, i.e. that explicitly mention in their formulation end-use energy efficiency. Policy instruments with objectives 5 and 6 are complementary (Increase end-use energy efficiency and awareness end-use energy efficiency) because they both steer the behaviour of the same stakeholders (retail suppliers and/or industry & buildings) to supply the same need of promoting end-use energy efficiency;
- *Competitive supply cluster* – includes policy instruments in the policy areas of the EU's DG Energy and aiming for more affordable electricity,

[14] The exception are the instruments C5 (Land use restrictions), C11 (Water use restrictions) and V4 (Certification of environmental management systems) that do not target explicitly any stakeholder (or target all).

i.e. with objectives 12 and 13 (Improve efficiency of electricity supply, price gains & quality of service and provide affordable electricity) which steer the behaviour of mostly overlapping energy suppliers (electricity generators, primary energy suppliers, distribution & retail supply) to provide more competitive, affordable energy (and electricity);

- *Secure and diverse supply cluster* – includes instruments in the policy areas of the EU's DG Energy promoting security of energy supply and renewable energy (which contributes to security of supply through the diversification of energy sources, many of which are endogenous to the EU). These include objective 11 (promote security of supply) which overlaps with objective 10 (increase use of energy/electricity from renewable sources), since these are mostly the same stakeholders (primary energy suppliers and electricity generators) whose behaviour is being steered to generate more energy/electricity. Although it could be argued that the promotion of end-use energy efficiency also contributes to the security of supply, the targeted stakeholders are different (demand *versus* supply stakeholders) which is why we have separated the instruments in two clusters.

Prior to exemplifying how to implement the framework to assess overlaps and co-effects at the level of policy instruments (Table 2.2) we do it at the more general level of the different clusters of instruments. At this point we have already established that there are significant overlaps for these instruments. At the cluster level there is no point in looking into the coordination aspect since this is dependant of each instrument's formulation, which can only be assessed at the level of the instruments themselves. The advantage of firstly implementing the framework at cluster level is to allow for gradually increasing the level of complexity and that only to the necessary extent. Basically, if we can to some extent infer on the types of co-effects at the cluster level, it might not be necessary to detail further the assessment for each policy instrument. Therefore, regarding the co-effects between different clusters:

i) There is the potential for complementary effects (+) between the Environmental and End-use efficiency clusters, since when steering behaviour of (albeit different) stakeholders to reduce end-use energy consumption is also achieved a reduction of environmental impacts associated to energy supply;

ii) It is not straightforward to assess the types of co-effects between the Environmental and Competitive supply clusters and this has to be done at the policy instruments level. Both clusters target the same stakeholders (mostly supply-side and industry). However, although P3 (Emission charges and taxes) and P4 (Energy taxes) are in both clusters and thus there is also here potential for complementary co-effects (+), the same cannot be said for other instruments in the Environmental cluster and the Competitive supply instruments P1 (Tax exemptions…), P2 (On-budget aids to coal and gas) and O2 (Unbundling) which have potential for counteracting co-effects (-). We discuss this in the policy instrument level assessment in Table 2.2;

iii) Likewise, is not straightforward to assess the co-effects between the Environmental and Secure supply clusters. Both clusters target the same stakeholders (mostly supply-side electricity and industry). In one hand increasing electricity generation from renewable resources (C10 RES targets, T2 Green certificates and P5 Subsidies to RES electricity) might (or not depending on the energy sources and types of environmental impacts considered) contribute to the objectives in the environmental cluster (+ co-effects). On the other hand, the instruments in the secure cluster P1 (Tax exemptions…), P2 (On-budget aids to coal and gas) might have counteracting co-effects (-) with the instruments of the environmental clusters (see Table 2.2);

iv) The clusters End-use efficiency and Competitive supply target different stakeholders mentioned and their steering effects can potentially be counteracting (-) as P1 (Tax exemptions…) and P2 (On-budget aids to coal and gas) can potentially lead to cheaper final energy prices thus reducing the incentive for end-use energy efficiency.

v) Between the End-use efficiency and Secure supply clusters, although targeting different stakeholders (again demand versus supply stakeholders), there is a potential for complementary co-effects (+) as when steering behaviour of stakeholders to reduce end-use energy consumption, the overall needs for energy are reduced decreasing for example dependency from external imports;

vi) Finally, Competitive and Secure supply clusters target the same stakeholders (suppliers) and there are potentially counteracting co-effects (-) as typically renewable electricity technologies (C10, T2, P5) are costlier than fossil ones (at the present and assuming externalities are not considered), and since P1 (Tax exemptions…) and P2 (On-budget aids to coal and gas) add cost to electricity generation to ensure security of supply (see van de Beers and de Moor, 2001 and IEA, 2001 in OECD, 2005).

Table 2.2 exemplifies the application of the above mentioned framework to a few of the characterised instruments. To do so for the whole of environmental and energy policy instruments is outside the scope of this paper. We do not go into detail into assessing the overlaps between instrumented (denoted with +), as was already discussed. Therefore we focus on the coordination of mechanism (+ or 0) and assessing complementary (+) or counteracting (-) steering effects caused on their target stakeholders.

Both emission standards within C7 IPPC and the T3 CO_2 emissions trading have emission reduction as an objective and both steer stakeholders towards emission reduction. Hence they are classified as having complementary co-effects (+). IPPC permits should not consider CO_2 emissions of the plants within the scope of the CO_2 emission trading Directive, showing some coordination of the two instruments (+). Similarly C7 IPPC, T3 CO2 emission trading and P5 Feed-in tariffs have complementary co-effects (+) as the promotion of renewable electricity contribute to pollution prevention and control and abate CO2 emissions. However, there is no specific coordination in their texts (0) regarding feed-in tariffs and vice-versa.

Table 2.2. Assessment of co-effects of selected energy and environment policy instruments. (Env) - Environmental cluster, (End)- End-use efficiency cluster, (Comp) – Competitive supply cluster, (Sec) – security of supply cluster

Policy instrument	C7 IPPC	T3 CO2 trade	P5 Feed-in Tariffs	C6 Eff. Targets	C12 Phase-out ineff. prod./eq.	P1 Tax exemptions	P2 On-budget aid
C7 Individual emission standards IPPC (Env)		+overlap + mechanism + effect	+ overlap 0 mechanism + effect	+ overlap + mechanism + effect	+ overlap 0 mechanism + effect	- overlap 0 mechanism - effect	- overlap 0 mechanism - effect
T3 CO2 emission trading (Env)			+ overlap 0 mechanism + effect	+ overlap 0 mechanism + effect	+ overlap 0 mechanism - effect	- overlap 0 mechanisms - effect	- overlap 0 mechanism - effect
P5 Subsidies to renewable electricity Feed-in tariffs (Sec)				+ overlap 0 mechanism - effect	+ overlap 0 mechanism - effect	+ overlap 0 mechanism - effect	- overlap 0 mechanism - effect
C6 Efficiency Targets (End)					+ overlap + mechanism + effect	+ overlap 0 mechanism - effect	+ overlap 0 mechanism 0 effect
C12 Phase-out inefficient. products/equip. (End)						+ overlap 0 mechanism - effect	+ overlap 0 mechanism - effect
P1 Tax exemptions on fossil fuels (Eff and Sec)							+ overlap + mechanism + effect
P2 On-budget aid to coal & gas industry (Eff and Sec)							

C6 end-use energy efficiency targets, T3 CO_2 emissions trading and C7 IPPC applicable to industry and have complementary co-effects (+) since while pursing the former, overall energy consumption is decreased and with it associated pollution (C7 IPPC and CO_2 emissions from T3). However, the CO_2 emissions trading Directive does not establish an explicit link with existing C6 energy efficiency legislation (0). Coordination of the mechanisms of the two instruments might or might not occur depending on what to extent energy consumption benchmarking is effectively used in the allocation criteria. On the contrary, while implementing IPPC permits the regulator is encouraged to use energy efficient benchmarks defined in the Best Available Techniques Reference Documents (+ some coordination).

The P5 Feed-in tariffs and C6 end-use energy efficiency targets are found to have counteracting co-effects (-) because the former steer electricity generators to generate more electricity (from RES0, whereas the latter aims to reduce final energy consumption (Pehnt et al., 2009). There is no explicit coordination of the instruments mechanisms (0).

The C12 Phase-out of inefficient products/equipments has complementary co-effects (+) with C6 end-use energy efficiency targets as both steer consumers to reduce end-use energy consumption and with C7 IPPC as between C& and C6. The mechanisms of the instruments C6 and C12 are coordinated (+) as the phase-out regulation stems from the eco-design directive included in C6. However, we find that there are counteracting co-effects between this instrument and T3 CO2 emissions trading and P5 feed-in tariffs to RES. On the latter the counter effect is similar to what happens between P5 and C6. For the case of T3 it has been argued that this phase-out brings down the demand for electricity and associated CO2 emissions thus brings down the price for CO2 permits (Frondel and Lohmann, 2011).

The steering effects of P1 tax exemptions on fossil fuels and P2 On-budget aids to coal and gas industry are likely to have counteracting co-effects with all the other presented instruments in Table 2.2 since they steer stakeholders to adopt technologies and energy carriers that increase emissions (C7, T3), counteract the overall penetration RES electricity (P5) and the incentives to C6 save energy (see Vehmas, 2005 and Matschoss, 2002). Thus, on a very simplistic way, merely by looking into Table 2.2 the seemingly most relevant conflicts found in the tangled web stem from these two instruments.

By performing such a generic assessment to the characterised policy instruments in place it is possible to systematically identify the types of co-effects between them. This can be an essential first step in the development of a methodology to quantify its impact in terms of the overall cost-effectiveness of the instruments in place.

2.5 Towards integration of energy and environment policy instruments

Due to human limitations in understanding all the dimensions of complex problems (as to achieve sustainable electricity systems) it is not realistic to expect that policies can develop perfectly coordinated instruments capable of successfully addressing all social, economic and environmental problems. The step-by-step policy making approach, handling one issue at a time is in many cases the best possible solution. In fact, one cannot talk about the relevance of policy integration if there are not several elements to integrate. It is only because we have now achieved a more mature state in environmental and energy policy making that integration can become a concern.

Looking back to the times of implementation of the reviewed policy instruments, one can realise that they were implemented over a long time-frame (approximately 30 years) and the more recent ones seem better coordinated, mostly due to the great umbrella of climate change policy (see the energy climate policy package, EU Commission COM(2008) 30 and the roadmap for moving to a competitive low carbon economy, EU Commission COM(2011) 112 final). Climate change policies seem to be the ideal meeting point between energy and other environmental policies, or at least for demand-side energy and environmental policies. Nonetheless, there is still large room for improvement in achieving commitments between these two areas, as there are still many different policy objectives, as was shown in Table 2.1. Moreover, climate change is but one of the environmental problems to be dealt with. For other environmental problems this intrinsic drive for integration might not apply, such as conservation of biodiversity; toxicity policies; nutrient and acidification policies; and climate policies are relevant together.

2.5.1 Structuring trade-offs

In such cases where there are quite different policy goals, the optimisation of co-effects of the policy instruments and development of a unitary integrated policy is not possible or even desirable. Likewise, in some cases policy objectives besides being different might directly or indirectly contradict each other. For example, supplying energy at the lowest costs might imply reliance on few energy sources/suppliers whereas ensuring security of supply requires a more diverse portfolio that includes more expensive resources/suppliers. Horizontal integration[15], or the integration of policy instruments of different sectors inevitably brings out the issue of trade-offs (Lafferty and Hovden, 2003). The different components to integrate usually do not have the same weights and there is the risk that the output of integration will only be a dilution (Liberatore (1997), in Persson (2004:14); Nilsson and Nilsson, 2005).

Not only is it necessary to assess the trade-offs between two different policy instruments (A), but also between having them separate versus their integration (B) (Figure 2.3). For simplification it is necessary to reduce the analysis to two things to be traded any one time. But even if it is possible to isolate just two policy goals and two costs of these policies involved, with two simple policy instruments; there is not one *numeraire* available to express different non-market effects. Reflecting this, the approaches to structure trade-offs in policy integration are mostly quite vague and generic. For instance, Collier (1994), in Persson (2004:13) suggests that the ideal approach for structuring such trade-offs would be to use Pareto optimality[16]

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[15] *Intersectoral* or *horizontal* policy integration refers "*to the establishments of relationships among policies with respect to a given issue (e.g. environmental protection) or to several interlinked issues* (…)"(Briassoulis, 2004) and typically entails a central authority that develops a comprehensive cross-sectoral strategy for environmental policy integration. This approach is acknowledged as being more effective than intrasectoral policy integration but is more difficult to implement since it requires "*substantive coordination and a willingness to prioritise among sectors*" (Lafferty and Hovden, 2003).

[16] In a Pareto optimal solution it is not possible make one person better without making another person worse off. In multi-criteria situations, as is the case, this can be translated

as criterion to do so, but he also acknowledges that due to lack of knowledge this is not feasible in practice and thus a set of probably less optimal criteria could be used. The literature for policy integration essentially focuses on criteria to assess if policies are integrated and not on how to actually integrate policy instruments already in place (Persson, 2004).

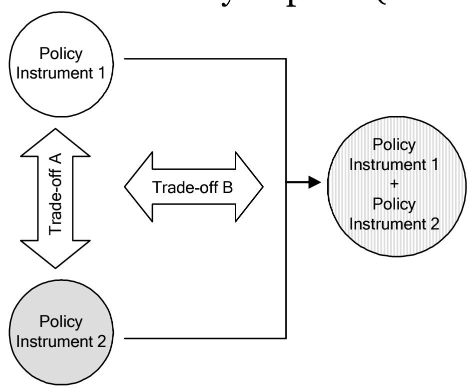

Figure 2.3 – Trade-offs to be structured

A starting point for a set of criteria to integrate energy and environment policy instruments could be to consider an approach similar to the one of the Water Framework Directive. Different water uses have to be combined, some of which are partly conflicting amongst each other such as ecological protection and drinking water supply. For uses that "*adversely affect the status of water but which are considered essential*" derogations from the requirement to achieve good status are provided "*so long as all appropriate mitigation measures are taken*" (Environment DG, 2010). In cases where the water quality damaging activity is open to alternative approaches (similar to the case of power generation where other means of power generation can be used), derogations are provided, but subject to three conditions: "*i) that the alternatives are technically impossible, ii) that they are prohibitively expensive, or iii) that they produce a worse overall environmental result*" (*ibid.*). The question, of course, is how to deal with the somewhat subjective nature of these conditions.

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as to make an improvement in one of the considered criteria without damaging at least one other criteria. In other words, a solution can be considered Pareto optimal if "there is no other solution that performs at least as well on every criteria and strictly better on at least one criteria".

Finally, for further structuring of trade-offs it is necessary to increase the objectivity of the criteria to use, which can only be done if there is more information on the functioning of co-effects of policy instruments and on their quantitative impacts on overall effectiveness and efficiency.

2.5.2 Improving the current policy making

The fact that currently there is lack of coordination between policy instruments does not mean that policy approaches should follow one single line. Authors seem to agree that a package of diversified policy instruments integrated into coherent policy packages can be more effective. However, if these several policy instruments are not seen as part of one unified policy and its co-effects are not dealt with, its effectiveness and efficiency will surely be reduced (White & Green, n.d.; Uyterlinde and Jeeninga, 1999; Worrell and Price, 2001; Boardman, 2004).

The difficulty is that the policy making process is too complex to ensure that this is always done, especially since there is lack of supporting methodologies and tools. In the policy integration literature much can be found on the necessary steps for policy integration (normative, organisational and procedural). However, these suggestions are more directed towards the integration of policies than of policy instruments. As a starting point to gain insights into concrete suggestion for the integration of policy instruments it seems to be more useful to look into the many analyses of individual instruments made, despite the fact that these intrinsically result from a non-integrated approach and thus provide limited input towards the development of a generic policy instrumentation framework.

On a different level, and because the role of public policy has been recurrently discussed in relation to the liberalisation of electricity markets, it is relevant to state here that to minimise conflicts in policy instruments, governments should have a strong role in policy development and implementation sending out clear signals to stakeholders (this view is shared by many authors, such as Boardman, 2004; Wuppertal, et al., 2000; Uyterlinde and Jeeninga, 1999). Not only that, but also governments should pay more attention to the signals sent by the stakeholders to 1) minimise distortion of policy goals due to lobbying (at policy development level), and 2) ensure stability at policy implementation level.

2.6 Conclusions

Currently there is a multiplicity of energy and environmental policy instruments in place that target the various stakeholders in the electricity system. More than thirty years of environmental and energy policy making have created a tangled web. This has led to significant overlaps between policy instruments. Some of these overlaps are synergistic but quite a few steer the behaviour of stakeholders in opposite directions, compromising the overall policy effectiveness. Although several studies have looked into such interactions of policy instruments they are limited to specific pairs or groups of instruments from the field of energy policy and/or climate policy. In this paper we presented a framework in which to consider both the energy policy instruments as well as those from the broad field of environmental policy (climate policy is seen as a segment of the wider field of environmental policy).

In order to do so, the paper established the concept of overlaps of policy instruments that measures the extent to which: 1) target stakeholders are shared, and 2) their steering effects occur within related policy goals. If there are relevant overlaps in policy instruments co-effects between them will occur, i.e. effects on each other felt at the level of its intended steering effects. These can be complementary, synergetic or counteracting.

The proposed framework systematically assesses overlaps and co-effects of policy instruments looking into their objectives, mechanisms and targeted stakeholders. The first step of the framework is the screening of the objectives of the different policy instruments to assess to what extent they steer related behaviour of the same stakeholders, followed by the identification of the type of overlap (complementary or counteracting). The coordination of the policy instruments' mechanisms is then analysed and classified in two straightforward levels: a) no-coordination - the instruments do not acknowledge the existence of other or b) some coordination in the instruments (expressed as derogations or alterations in scope, among other). Finally, divergences in the target stakeholder's steering effect are assessed.

The seemingly most relevant conflicts found in the tangled web are between hidden subsidies provided to energy supply infrastructures and environmental command-and-control regulation. Although there are policy instruments acting both on the supply and the demand side, these do not necessarily lead to integration of supply and demand-side policy instruments.

Due to lack of information on analysis of policy instruments it is not possible at this stage to assess the relevance of the identified co-effects regarding overall efficiency, effectiveness and equity. More work is needed on methodologies for the qualitative and quantitative assessment of co-effects of policy instruments. Furthermore, the approach to assess co-effect presented in this paper concerns the interactions between policy instruments and therefore is limited to only two of the components of the policy process (the policy instruments and actors or stakeholders). The other components - objects, goals and the structures and procedures – are not approached here. It has to be noted that to achieve policy integration it is not enough to simply secure the integration of its instruments, because the effects of the policy instruments are dependent of the context and thus of all the other components of the policy process. Nonetheless, integration at level of the policy instruments is a good starting point towards the next challenge, the integration of the policy processes in all its components.

Achieving sustainable electricity systems is a very complex problem, which our limited human minds can only grasp partially. Thus, it simply might be unrealistic to aim for fully coordinated policy instruments. Likewise, policy instruments do not necessarily have to follow one single line. Coherent policy packages can be more effective, as long as its co-effects are assessed and dealt with. While governments develop and implement such packages it is fundamental to make sure that clear signals are sent out to stakeholders. While doing so governments should pay more attention to minimise distortion of policy goals due to lobbying (at policy development level), and ensuring stability at policy implementation level.

Finally, we have focused on electricity systems but the proposed framework could be adapted beyond electricity, to the whole energy system, for example to include production and use of refined oil products and renewable heat, among other. Other developments would be to go in more depth into the environmental policy instruments that here, because they do not target specific stakeholders in the electricity system, we have only identified without further analysis. This is the case of water and air quality objectives, land use restrictions, and water use restrictions, among others. Another step further with the proposed framework would be to try to quantify some of these overlaps and co-effects, estimating the variations in overall cost-effectiveness for the electricity/energy system, for example by using an energy-economy-environment energy system model. All these developments would naturally increase the complexity of the tangled web but nonetheless we believe the framework implementation is still manageable and worthwhile.

2.7 Appendix A

Table 2.3. Overview of some energy and environment policy instruments in place along electricity systems

#	Policy Instrument/Mechanism	Objective of the instrument [a]	Target stakeholder [b]	DPSIR	Responsible for implementation & implementation date [c]	Supply / demand	Example
Command and Control							
C1	Uniform emission standards (air, water & soil)	Reduce emissions by setting uniform emission limit values per sector/activity	Industry & services (primary energy suppliers & generators are covered by IPPC)	Pressure	Environmental agency 1970 (air) & 1975 (water)	Supply & Demand	NO_x, SO_2, VOC, particles, metals, P, NO_3, organic pollutants among other – several Directives
C2	Fuel[d] specifications	Reduce emissions to air	Industry, electricity generators, primary energy suppliers	Pressure	Energy agency 1975	Supply & Demand	S content in heavy fuel oil - Directive 99/32
C3	Water & air quality objectives	Minimise risk of environmental damage	–	Impact	Environment agency 1975 (water) & 1980 (air)	Supply & Demand	NO_x, SO_2, O_3, Pb, particles, benzene, CO, metals, pesticides, microorganisms, among other-Directives 04/107, 08/50, 08/105, 06/7, 98/83
C4	Restrictions of use of certain substances / products	Reduce emissions by decreasing use of substances	Industry (manufacturers of products using such substances), although other stakeholders that use products have to adapt	Pressure	Economy/ industry agency 1976	Supply & Demand	O_3 depleting substances - Regulation 2037/00; F-gases – Regulation 842/06; biocidal products-Regulation 1451/07; VOC in paint & varnish-Directive 04/42

#	Policy Instrument/Mechanism	Objective of the instrument [a]	Target stakeholder [b]	DPSIR	Responsible for implementation & implementation date [c]	Supply / demand	Example
C5	Land use restrictions	Minimise environmental impacts by restricting access	All	Impact	Municipalities, regional and national authorities 1979	Supply & Demand	Natura 2000 network – Directives 79/409 & 92/43; national action in all member states
C6	Efficiency Standards	Increase end-use energy efficiency in buildings, household appliances and industrial processes	Builders & industry (manufacturers of appliances & other)	Pressure	Energy Agency 1996	Demand	Directive 09/125 Eco-design framework in Energy-related products & regulations e.g. 245/09, 643/09 (household appliances), 649/09 (electric motors); Directive 10/31(buildings); national regulation e.g. Portugal & Sweden
C7	Individual emission standards – IPPC permits	Reduce emissions by setting individual emission limit values based on Best Available Techniques	Industry, electricity generators, primary energy suppliers	Pressure	Environment agency 1999	Supply & Demand	Directive 08/1
C8	Emission reduction plans	Reduce emissions by implementing individual reduction plans	Industry & services that use solvents above certain limits	Pressure	Environment agency 2001	Demand	Directive 99/13 for VOC emissions
C9	Energy saving targets	Ensure more efficient end-use of energy by imposing annual energy saving standards	Member States (ensure action by retail suppliers / distributors)	Driving Forces	Energy agency 2004-2006	Supply	Directive 06/32 on the promotion of End-use efficiency and energy services
C10	Renewable energy targets	Promote use of energy from renewable sources (RES) by setting targets for overall share of energy from RES in gross final consumption & in transport	Member States (ensure action by generators, retail suppliers & industry & construction)	Driving Forces	Energy agency 2001-2003	Supply & Demand	Directive 09/28 on the promotion of the use of energy from renewable sources & subsequent national plans

#	Policy Instrument/Mechanism	Objective of the instrument [a]	Target stakeholder [b]	DPSIR	Responsible for implementation & implementation date [c]	Supply / demand	Example
C11	Water use restrictions	Minimise risk of environmental damage	–	Impact	Environment agency 2008	Supply & Demand	Water Framework Directive 02/60
C12	Phase-out of inefficient products/equipments	Increase end-use energy efficiency	Industry (manufacturers) and households	Pressure	Energy agency 2009/2012	Demand	Regulation 244/2009 phasing out incandescent lamps
Economic/Market based							
Tradable permits/quotas							
T1	White Certificates	Increase end-use energy efficiency by issuing mandatory targets for improvements combined with tradable titles	Energy distribution companies (that implement activities in Industry, services & households)	Driving forces	Energy agency and distributors of gas and electricity 2002	Supply	UK Energy Efficiency Certificate Trading; Italy Energy Efficient Titles; France Energy Saving Certificates
T2	Green Certificates	Increase electricity generated from renewable sources by issuing mandatory targets combined with tradable titles	Electricity generators	Driving forces	Energy agency 2001	Supply	Belgium, Italy, Netherlands, Sweden, UK
T3	CO2 emission trading	Reduce emissions	Industry, electricity generators, primary energy suppliers	Driving forces	Environment agency 2005	Supply & Demand	Directive 2003/87 (amended)
Price							
P1	Tax exemptions, rebates and incentives for investments	Promote economic development; security of energy supply	Industry, electricity generators, primary energy suppliers	Driving forces	Finance ministries 1970's	Supply & Demand	DK abolished payment of royalties on gas and oil production; tax exemptions provided to less profitable NL gas fields; reduced VAT for domestic energy use in UK and PT; subsidies to insulation in low-income households

#	Policy Instrument/Mechanism	Objective of the instrument [a]	Target stakeholder [b]	DPSIR	Responsible for implementation & implementation date [c]	Supply / demand	Example
P2	On-budget aid to the coal & gas industry infrastructures	Promote regional economic development; security of supply & lower emissions (for gas)	Primary energy suppliers	Driving forces	Finance ministries & EU 1990's	Supply	Denmark, Greece, Ireland and Spain have provided state aid to the gas infrastructure, Germany supports domestic coal mining
P3	Emissions charges and taxes	Reduce emissions by internalisation of env costs; cover cost of policies & raise revenues	Industry, electricity generators, primary energy suppliers	Driving forces	Finance ministries 1992	Supply & Demand	NO_x charge in SE, FR; NO_x tax in DK, ES; SO_2 tax in SE; CO_2 tax in SE & DK
P4	Energy taxes	Reduce environmental damage by internalisation of env. costs, cover cost of policies & raise revenues	Consumers (industry but mainly services & households)	Driving forces	Finance & environment 1997 (electricity in FI) 2001 (UK levy)	Demand	Directive 03/96, UK climate change levy; electricity consumption tax in FI; combined energy & CO_2 tax in NL; FI, DK & SE
P5	Subsidies to renewable electricity or from CHP	Increase electricity generated from renewable sources or combined heat and power production	Electricity generators	Driving forces	Electricity regulator 2001	Supply	Portugal, Denmark, Germany, Spain use different approaches as feed-in tariffs; obligation to purchase & competitive tender
Moral suasion and voluntary initiatives							
V1	Information campaigns	Increase awareness (typically for increasing end-use energy efficiency)	All, most usually households & services	Driving forces	Energy agencies, municipalities & retail suppliers 1970's	Demand	Eco Top Ten in DE; Topten.pt in PT; Eco n'home in UK, IT, BE, FR, PT, DK; SE info on electricity bills and many more at national level; EU level Public Awareness Campaign for Energy Sustainable Europe

#	Policy Instrument/Mechanism	Objective of the instrument [a]	Target stakeholder [b]	DPSIR	Responsible for implementation & implementation date [c]	Supply / demand	Example
V2	Voluntary agreements	Increase end-use energy efficiency	Industry & services	Pressure	Energy agency 1990's	Demand	NL Energy Covenants; also in DK, DE, FR, SE, IR, SP; EU Green light Programme; Energy Star Programme; EU agreements on TV & DVD players, refrigerators & freezers, washing machines
V3	Labelling on electricity consumption	Increase end-use energy efficiency by providing information on electricity consumption	Industry (manufacturers of appliances) and households	Driving forces	Energy Agency 1992	Demand	Directives 10/30, 03/66, 02/40, 02/31, 99/9, 98/11, 96/60, 95/13; Regulations 1059/10, 1060/10, 1061/10, 1062/10
V4	Certification of environmental management systems	Improve overall environmental performance	All	Driving forces	Certification organisations 1993	Supply & Demand	EU Regulation 1221/2009 (EMAS); ISO 14001 standards
V5	Green procurement	Reduce environmental impacts all al levels by taking into account environmental criteria when procuring goods, services or work	All end-use consumers	Driving forces	1980's (some Member States), 2004 (EU public procurement), 2006-2012 (EU energy services)	Demand	Directives 04/17 & 04/18 for EU public procurement; Directive 06/32 on the promotion of End-use efficiency and energy services
Other							
O1	Environmental impact assessment	Minimise environmental impacts by imposing minimisation/mitigation measures	Industry, electricity generators, primary energy suppliers	Pressure	Environment agency 1985	Supply & Demand	Directives 09/31, 03/35, 97/11 and 85/337

#	Policy Instrument/Mechanism	Objective of the instrument [a]	Target stakeholder [b]	DPSIR	Responsible for implementation & implementation date [c]	Supply / demand	Example
O2	Unbundling (Liberalisation of electricity market)	Improve efficiency of electricity supply, price gains & quality of service	Electricity companies: Generators, transmission, distribution & retail supply	Driving forces	Energy agency, electricity regulator 2004	Supply & Demand	Directive 09/72
O3	Environmental liability	Prevent and remedy environmental damage by creating obligation to bear the cost of preventive and remedial action	Industry, electricity generators, primary energy suppliers	Driving forces	Environment agency 2007	Supply & Demand	Directives 06/21 and 04/35

[a] Refers to the policy instruments' explicit objective. [b] Refers to the stakeholders that are directly targeted, i.e. those whose behaviour the policy instruments primarily aims to steer and thus does not consider the indirect effects over other stakeholders. [c] Year of first implementation of such type of instrument across the EU. [d] Since transportation is not included in the scope of this paper the lead content of petrol and sulphur content of diesel are not considered in the table. Although these fuels are used by other sectors than transport, the quantities are not relevant when compared to other fuels.

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3 Cost of energy and environmental policy in Portuguese CO2 abatement – scenario analysis to 2020*

* This chapter is published in Energy Policy Journal Vol. 36, Issue 9, pp. 3598-3611. doi:10.1016/j.enpol.2008.06.004. Co-authors: João Cleto, Patrícia Fortes, Júlia Seixas and Gjalt Huppes.

Abstract

This paper quantifies the contribution of Portuguese energy policies for total and marginal CO_2 abatement costs (MAC) for 2020. The TIMES_PT optimisation model was used to derive MAC curves from a set of policy scenarios including one or more of the following policies: ban on nuclear power; ban on new coal power plants without carbon sequestration and storage; incentives to natural gas power plants, and a cap on biomass use. The different MAC shows the policies' effects in the potential for CO_2 abatement. In 2020 in the most encompassing policy scenario, with all current and planned policies, is possible to abate only up to +35% of 1990 emissions at a cost below 23 € t/CO_2. In the more flexible policy scenarios it is possible to abate up to -10% of 1990 emissions below the same cost. The total energy system costs are 10-13% higher if all policies are implemented – 76 to 101 B€ - roughly the equivalent to 2.01-2.65% of the 2005 GDP. Thus, from a CO_2 emission mitigation perspective the existing policies introduce significant inefficiencies, possibly related to other policy goals. The ban on nuclear power is the instrument that has the most significant effect in MAC.

3.1 Introduction

Climate change is currently one of the hot topics in energy and environment policy making. Multiple policy instruments are being developed to address the problem, aiming to coordinate the objectives of climate change mitigation with the ones of the European energy policy: security of supply, competitiveness and sustainability (EU Commission COM(2007) 1 final). Examples include policies promoting renewable energy sources. It is clear that the way forward in European energy policy making includes climate change mitigation. However, it is not clear how policy options made in the past in a different context contribute to this objective. This paper quantifies the significance of the current Portuguese energy policies for the national CO_2 marginal abatement costs (MAC) for 2020. The results can be of utmost relevance for shaping cost-effective energy and climate change policies, avoiding unnecessary costs

Portugal has assumed the commitment to limit its greenhouse gases (GHG) emissions below +27% of 1990 levels under the Kyoto Protocol and the EU Burden-Sharing Agreement. In 1990 60 779[17] Gg CO_2e were emitted, and thus 77 391 Gg CO_2e per year are allowed in 2010-2012 (IA, 2006b). However, the Portuguese GHG emissions have been increasing sharply and the country is far from its goal: the 2010 emissions estimated are 45-48% above 1990 levels if no additional mitigation policies are adopted (IA, 2006a). CO_2 emissions from energy consumption and industrial processes are approximately 71% of total national 1990 emissions and are expected to grow in 2010 up to 80% of total national emissions (IA, 2006a).

This is due to the high national dependency of imported fossil fuels, mostly oil. In 2005 about 84% of the national primary energy demand of 1 132 PJ was met by imported oil, coal and gas (DGGE, 2007). Renewables are the only national energy resources, especially hydro for power generation, and biomass used both in cogeneration and in the residential sector. Transport and industry bear the lion share of the national final energy demand, with 44% and 26% respectively of total final energy demand in 2005. Electricity generation is also highly dependant of imported coal, gas and oil which

[17] Including Land Use, Land-Use Change and Forestry.

accounted for 65-83% of generated electricity in the 1999-2007. Renewables are responsible for the rest of generated electricity, especially hydro which accounted for 39-11% of total electricity generated in 1999-2007. The other renewable power sources are wind and biomass (respectively 20% and 16% of 2007 renewable electricity) (DGGE, 2007a). Nuclear power is not used and is considered politically unacceptable by the several governments so far. Aware of the diverse fragilities of the national energy system, the national energy policy is based on three strategic goals: energy security, sustainable development and national competitiveness (Cabinet Resolution no. 169/2005).

Among the myriad of energy and environmental policies in place the following are considered as the most relevant regarding effects on CO_2 emissions for the 2010-2020 period: i) ban on nuclear power; ii) incentives to the distribution and licensing of natural gas power plants; iii) feed-in-tariffs to promote renewable electricity; iv) minimum consumption of biofuels of 5.75% of the consumed diesel and gasoline in transport in 2010, following the Directive 2003/30/EC; and last but not the least, the CO_2 emission cap following the EU burden sharing agreement.

All these instruments have an impact in the national energy system, which in this paper is quantified in terms of total and marginal abatement cost (MAC) for CO_2 emissions. The knowledge of the cost of reducing an additional unit of CO_2 is fundamental to define the emissions reduction potential within a feasible cost range, and thus to support the development of emission control policies. MAC on CO_2 for Portugal have been estimated by several global and multiregional models (e.g. POLES, PRIMES, TIMER, GAINS). However, in these studies the Portuguese curves are not public and the analysis does not assess the impact of existing policies (Das *et al.*, 2007; Russ and Criqui, 2007; Capros and Mantzos, 1999; EEA, 2005; den Elzen, *et al.*, 2007; Klaassen, *et al.*, 2005). The objective of this paper is twofold: to present the marginal abatement costs curve for CO_2 emissions for the Portuguese energy system in 2020, and to quantify the impact of the current Portuguese policy instruments on marginal and total cost. For this, a set of alternative policy scenarios, including different combinations of the existing policies are modelled in the bottom-up optimization model TIMES_PT for the 2000-2030 period.

The paper starts by presenting an overview of the TIMES_PT model. Next, the modelled energy scenarios are described, prior to the presentation of the results regarding impact of the planned and existing policies on CO_2 MAC curves, total system costs, primary and final energy consumption, and sector abatement. The validity of the results is assessed through a sensitivity analysis. The significance of the studied policy instruments and limitations of the results are discussed in the concluding section.

3.2 TIMES_PT model

TIMES_PT[18] is a linear optimisation bottom-up technology model generated with TIMES[19] model generator. TIMES was developed by ETSAP[20] of the International Energy Agency. The generic model structure can be adapted to simulate a particular energy system, which may be local, national or multi regional. TIMES models are widely used to evaluate the impact of energy and environment policies and to perform technological assessments (Tosato, 2006).

The ultimate objective of a TIMES model is the satisfaction of the energy services demand at the minimum system cost. For this, TIMES simultaneously decides on equipment investment and operation, primary energy supply and energy trade, according to the equation 1 (Loulou *et al*, 2005a).

[18] The implementation of the TIMES model for Portugal has been undertaken within the EU FP7 research project NEEDS – New Energy Externalities Developments for Sustainability (www.needs-project.org). The NEEDS RS2a research team is responsible for the model structure and new technologies databases. The authors are responsible for the base-year information, for the validation of technologies information, and for calibration and validation of the national model.

[19] Acronym for The Integrated MARKAL-EFOM system. TIMES is the successor of two older ETSAP bottom-up energy models: Markal - MARKet Allocation Model and EFOM - Energy Flow Optimisation Model, developed in the 80’s.

[20] Energy Technology Systems Analysis Programme

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1 + d_{r,y})^{REFYR-y} \bullet ANNCOST(r, y) \quad (1)$$

NPV: net present value of the total costs

ANNCOST: Total annual cost

d: general discount rate

r: region

y: years

REFYR: reference year for discounting

YEARS: set of years for which there are costs[21]

For each year, the TIMES model computes the discounted sum of the annual costs minus revenues. In the case of TIMES_PT, both investment costs and fix and variable operation and maintenance costs of the energy supply and demand technologies are considered. Energy taxes are also included in the model, namely the ISP which is the tax on oil products and other energy carriers and is differentiated by energy carrier. The revenues usually considered within TIMES models include subsidies, recuperation of sunken material and salvage value. However, these are not included in TIMES_PT. More information on TIMES development and equations can be found in Loulou e*t al* (2005a and 2005b).

3.2.1 TIMES_PT Model structure

TIMES_PT represents the Portuguese energy system from 2000 to 2030. The following sectors are modelled: primary energy supply; electricity generation; industry; residential; commercial; agriculture, and transport. Energy, materials and monetary flows, energy demand and supply technologies are modelled in detail, including mass balances. The model structure for the

[21] All years in the horizon + past years if costs have been defined for past investments + a number of years after the life time of the technology if some investment and dismantling cost are still being incurred, as well as the Salvage Value.

Portuguese system, presented in Figure 3.1, was adjusted from the model structure developed under the NEEDS[22] project.

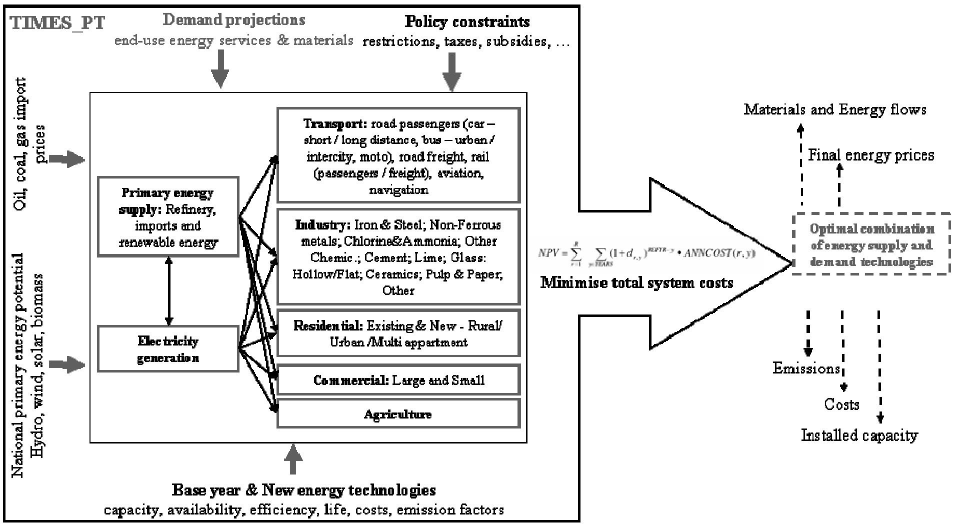

Figure 3.1. Structure of the TIMES_PT model.

The implementation of TIMES_PT is supported by a detailed database, with the following exogenous inputs: (1) *end-use energy services and materials demands*, 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 ceilings or energy taxes.

The TIMES_PT model finds the optimum combination of energy supply and demand technologies to satisfy the demand, i.e. the model designs an energy system with the lowest possible total costs. Thus, the main model outputs include the installed capacity of the different technologies, its greenhouse gas

22 NEEDS – New Energy Externalities Developments for Sustainability (www.needs-project.org)

emissions, primary and final energy and material flows, final energy prices and, as mentioned, overall system costs.

It should be noted that TIMES_PT is a partial equilibrium model, and thus does not model the economic interactions outside of the energy sector. Among other limitations of these types of models, it does not assume technology R&D costs nor considers in detail demand curves and non-rational aspects that condition investment in new, more efficient technologies, such as preferences motivated by aesthetics or social status. The model assumes that stakeholders have perfect market foresight.

3.2.2 Energy and materials demand projection

The materials and energy demand projections for Portugal are differentiated according to economic sector and end-use energy service. These were generated by the national macroeconomic projections from the GEM-E3[23] model within the NEEDS project. For a EU-22 GDP growth target of 2 to 2.5% - depending on the country - GEM-E3 combines projections of population growth, world energy prices, technical progress, energy intensity and labour productivity evolution, generating a series of national macroeconomic drivers. These are: GDP growth; private consumption as a proxy for disposable income; price evolution and sector production growth for industry, services, transports and agriculture. In TIMES_PT, these macroeconomic drivers are transformed into the different final annual end-use demand projections (DEM_t), according to equation 2 (adapted from van Regemorter and Kanudia, 2006),

$$DEM_t = DEM_{t-1} * (1 + DRGR_t * ELASI) * (1 + PRGR_t * ELASP) * (1 - AEEi_t) \quad (2)$$

DEM – Final demand (materials or end-use energy)

DRGR - Macroeconomic drivers

[23] GEM-E3: General Equilibrium Model for Energy-Economy-Environment: http://www.gem-e3.net/

ELASI and ELASP– income and price elasticity of final demand to DGDR provided by Leuven University[24]

PRGR – price evolution factor from GEM-E3

AEE_i - autonomous efficiency improvement factor in industry from GEM-E3

The residential sector requires a more detailed approach to generate the demand for heat, cooling and hot water, since they depend on the characteristics of the dwellings. Figure 3.2 illustrates the approach to deal with the residential sector demand for energy end uses, following the NEEDS framework (van Regemorter and Kanudia, 2006). The projection of energy end-uses for the residential sector involved several steps: (1) the projection of the number of dwellings and its allocation by category (rural, urban single house or urban apartments); (2) the projection of the heat/cooling/hot water demand per dwelling by category, and (3) the projection of the total demand. The main data sources were the National Directorate for Energy and Geology (DGGE, 1996), the National Statistics Institute (INE 2000a; INE, 2001; INE, 2002; INE, 2003; INE, 2004), and the SIAM Project[25] (Aguiar *et al.*, 2002).

[24] Energy, Transport & Environment Working Group of the CES - Department of Economics of the Leuven Catholic University: http://www.econ.kuleuven.be/ew/academic/energmil/default.htm

[25] The SIAM project stands for Climate Change in Portugal: Scenarios, Impacts and Adaptation Measures. More information can be found at: http://www.siam.fc.ul.pt/overview.html

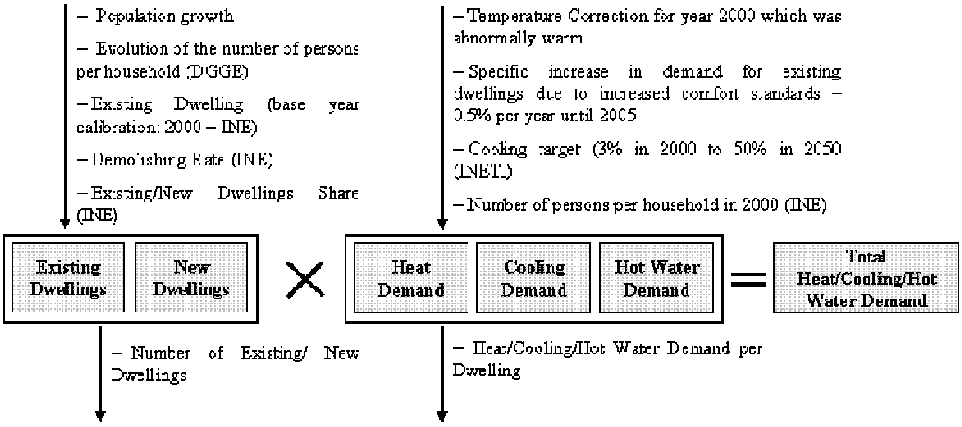

Figure 3.2. Projection of the demand in the residential sector for hot water, heating and cooling.

The GEM-E3 macroeconomic drivers were validated through its comparison with national demographic, macroeconomic, and sector scenarios, which was complemented by an extensive stakeholder consultation process. Major adjustments were made in the transport and commercial sectors for which the GEM-E3 generated projections were replaced by those provided by the National Climate Change Programme (PNAC) demand (IA, 2006a). Some of the final energy and material demand growth trends considered in TIMES_PT are presented in Table 3.1.

Table 3.1. Evolution of the population, GDP and demand for some of the end-use energy services and materials considered in TIMES_PT (2000 = 100).

Type of demand/year	2000	2005	2010	2015	2020	2025	2030
Population	100	103	105	105	105	105	104
GDP	100	105	118	132	145	160	175
pkm	100	103	109	113	117	120	124
tkm	100	101	118	129	137	145	153
Space Heating	100	127	132	136	137	139	140
Space Cooling	100	159	203	252	294	336	382
Water Heating	100	103	111	117	120	122	124
Clinker	100	101	113	121	127	133	140
Glass	100	101	115	123	131	138	145
Pulp	100	97	106	109	111	112	114
Iron & Steel	100	98	103	104	104	104	103

3.2.3 Other exogenous information inputs

A detailed explanation of the other exogenous information inputs, especially regarding the technology database, can be found in the appendix. Here is just briefly mentioned the most relevant aspects, namely:

- *Carbon capture and storage* is considered assuming a storage potential of in TIMES_PT in a simplified way due to the lack of information on the storage potential for Portugal and neighbouring countries. Thus, a conservative estimate of 5000 Gg CO_2/year storage potential is assumed available from 2015 onwards. This corresponds to 6% of the emissions modelled in TIMES_PT in 2020, according to PNAC (IA, 2006a). This potential has a great uncertainty, which was dealt with a sensitivity analysis, described in the results section.

- Average *primary energy imports prices* projections were adopted from DG TREN and IEA scenarios, namely 1.35-1.75 $€_{2000}$/GJ for coal, 6.51-5.79 $€_{2000}$/GJ for crude oil, and 3.84-4.60 $€_{2000}$/GJ for natural gas, respectively for 2000 and 2020 (DGTREN, 2006). TIMES_PT does not consider the effects of extreme situations, such as oil price peaks due to political instability or natural catastrophes. Uranium fuel prices, as UO_2 reactor fuel at the power plant, are of 0.4 $€_{2000}$/GJ and kept constant in time, as suggested by the IEA (2001).

- The model considers long term *price elasticity of demand* for the different materials and energy end-uses (Loulou *et al.* 2005a).

- The definition of national primary energy potentials - essentially renewable resources such as water, solar, wind, biomass and biofuels - was based on several national studies and expert opinion (Table 3.2). It should be stressed that there is a large uncertainty due to the lack of data for some cases. Uncertainty on hydro potential was dealt with via a sensitivity analysis.

- TIMES_PT uses a homogeneous discount rate of 4% which is not differentiated between sectors.

Table 3.2. National Primary Energy potentials considered in TIMES_PT.

Primary Energy	Used in 2000 →Potential in 2030 (% increase from 2000 to 2030)	Reference
Wood products (PJ)	71.7→100 (+28%)	Expert opinion
Biogas production (PJ)	0.1→29 (+100%)	GPPAA- MADRP (2005) and extrapolation of National Climate Change Waste Management Scenarios (IA, 2006a)
Crops for biofuel production (PJ)	0.0→15 (+100%)	Extrapolation based on Gonçalves, H., Joyce, A., Silva, L. (eds) (2002c)
Biofuels production (PJ)	0.0→50 (+100%)	Expert opinion based on 2008 expected installed capacity
Municipal Waste (PJ)	7.3→10 (+27%)	Extrapolation of National Climate Change Waste Management Scenarios (IA, 2006a)
Industrial Waste - Sludge production (PJ)	0.0→2 (+100%)	Expert opinion
Hydro (PJ)	40.2→95 (+58%)	Pinho, M. (2007)
Wind off shore (GW)	0.0→2 (+100%)	Expert opinion
Wind on-shore (GW)	0.1→5 (+98%)	2010: Estanqueiro, I. (2004) and 2030: conservative Assumption based on Pinho, P. (2007)
Solar- water and space heating (PJ)	0.8→38 (+98%)	Gonçalves, H., Joyce, A., Silva, L. (eds), 2002b
Solar thermal - electricity generation (GW)	0.0→2 (+100%)	Expert opinion
Geothermal (PJ)	0.6→8 (+93%)	Extrapolation based on Gonçalves, H., Joyce, A., Silva, L. (eds), 2002a
Waves (GW)	0.0→5 (+100%)	Cruz, J., Sarmento, A. (2004)

3.2.4 Calibration and validation

The model was calibrated for the year 2000 and validated for 2000 and 2005, using the official national energy balances. Model calibration required a set of restrictions:

1. To replicate real evolution of 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 estimates since there are no exact forecasts at the moment, although they are in line with the national transmission operator studies (REN, 2008). This corresponds to a growth of imports of 255% and of 121% for exports. Thus, trade uncertainty under the liberalised Iberian electricity market is not considered;

2. A maximum growth was set for new CHP plants in industry, based on historical data and on the sector (national CHP association) future expectations. Thus, in 2001, 32% of all electricity consumed in industry was from CHP, and in 2010 this figure will be 38%, 45% in 2020 and 50% in 2030. These limitations on maximum CHP reflect real CHP constraints such as geographical proximity of potential end-users of heat;

3. Following the past evolution of the energy profile of the residential, commercial and agriculture, there will be no further penetration of coal in these sectors;

4. Due to resistance to change, imperfect information, and aesthetics or other subjective preferences it is assumed that the penetration rate of new technologies with alternative fuels in the residential and commercial sectors is delayed by inertia factors. These were defined for the replacement of existing lighting and electric appliances 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;"

5. Only 85% of the residential and commercial sector needs can be met with natural gas, due to geographic and technical limitations (GALP, 2007);

6. No dedicated heat power plants will be implemented – all heat will be produced with CHP - and all new CHP plants are associated with specific demand sectors such as refining, industry, commercial or residential. This follows the current and planned CHP promoting policy.

3.3 Energy and environment policy scenarios

Six energy and environment policy scenarios were considered to assess the contribution of existing policies in the CO_2 MAC curves for 2020. The difference between scenarios is the level of implementation of existing Portuguese energy policies until December 2005. The reference scenario, hereafter mentioned as policy scenario, considers the most relevant Portuguese energy policies in place, as follows:

1. A ban on nuclear power due to the political unacceptability of this option in the modelled time horizon;

2. Incentives to natural gas combined cycle power plants following the energy sources diversification policy and support to use of natural gas. This is modelled as a minimum installed capacity of at least 1100 MW from 2010 to 2030;

3. New coal power plants will only be available from 2015 onwards following energy sources diversification policy and support to use of natural gas;

4. It is assumed that "conventional" coal power plants without sequestration will not be implemented from 2015 onwards, following expected GHG control policies;

5. Electricity generation from municipal waste will continue until 2030 following present waste management policy which sets a minimum target for energetic use that corresponds approximately to 3.01 TWh generated electricity in 2020 and 2030(IA, 2006a);

6. Electricity generation from wood residues will continue at least until the end of the lifetime of plants existing in the year 2000 following forest fire control policies objectives;

7. A minimum of 1.1 GW installed capacity of wind onshore is set up in 2005, following the existing feed-in-tariffs for renewable electricity, although this is not included in the costs of renewable electricity generation technologies in TIMES_PT. This represents 9% of total 2005 installed capacity of 13.55 GW;

8. In 2010 biofuels consumption will be at least 5.75% of the consumed diesel and gasoline in transport, following the Directive 2003/30/EC;

9. The tax on oil products, differentiated according to the energy carriers, was included, as presented in Table 3.3.

The other studied five alternative policy scenarios are identical to the policy scenario except for the level of implementation of some of the assumed policies, as follows and as summarised in Table 3.4:

1. No policy – excludes all policies assumed in the policy scenario;

2. Nuclear – policy scenario allowing nuclear power. Because Portugal has no nuclear power plants at the moment it is assumed that such plants will only be operating from 2015 onwards, since it is considered that at least 8 years will be necessary to select a site, train personnel and obtain the necessary permits;

3. Conventional coal – policy scenario allowing conventional new coal power plants;

4. No incentives to gas – policy scenario without incentives for combined cycle natural gas power plants;

5. No biomass – policy scenario with a cap on biomass domestic production and imports, which does not allow for biofuel production. The cap was set at 2005 levels the most recent value on total national biomass consumption. The limit is set for wood and wood waste and for biofuels. This represents roughly 60% of the available national wood potential until 2020 and 4% of the biofuels potential assumed in **Error! Reference source not found.**. This scenario does not correspond to one explicit current energy policy, but was studied since future national policies point towards an increased used of biomass for biofuels production and electricity generation. The objective is to assess what is the effect in MAC if biomass is not available in the expected quantities.

Table 3.3. Tax on energy products considered in TIMES_PT in €/PJ.

Energy carriers	Tax on energy products (€/PJ)		
	2001	2005	2010-2030
Coal – RCA, supply & industry	-	0.15	0.16
Coal – electricity & CHP	-	-	-

Energy carriers	Tax on energy products (€/PJ)		
	2001	2005	2010-2030
Oil– residential & commercial	6.68	2.48	3.73
Oil – electricity & CHP	-	-	-
Oil - agriculture	1.63	2.11	2.78
Oil - industry	0.69	0.38	0.38
Gas – RCA[a], supply & industry	0.20	-	-
Gas – electricity & CHP	-	-	-
Gas - transport	0.20	2.60	2.72
LPG – RCA & industry	0.16	1.58	0.69
LPG - transport	8.70	4.52	6.82
Diesel - agriculture	8.98	11.48	14.22
Diesel - transport	6.68	8.54	10.58
Gasoline - transport	11.46	18.04	20.57
Biofuels[26] - transport	8.98	11.48	14.22
Kerosene – transport	-	-	-
Heavy fuel oil - transport	-	-	-
Naphtha - industry	-	-	-
Biomass – all sectors	-	-	-
Electricity – all sectors	-	-	-

[a] RCA stands for Residential, Commercial and Agriculture.

Increasingly strict CO_2 emissions caps were set for each of the six policy scenarios to build the marginal abatement cost curves for CO_2 emissions for 2020. The caps are constant for the 2020-2030 period and range from a maximum increase of CO_2 emissions of 90% (91 141 Gg CO_2) compared to 1990 levels, to a maximum decrease of 60% (19 188 Gg CO_2). Besides the CO_2 cap for 2020 to 2030, all scenarios consider the Portuguese commitment under the Kyoto Protocol (and the EU burden sharing agreement), which corresponds to an increase of 27% of 1990 emissions in the first commitment period of 2008-2012 [27].

[26] Biodiesel, ethanol, methanol

[27] This obligation was implemented in the TIMES_PT model as a cap of 63 344 Gg CO2 from 2010 to 2015. This cap value corresponds to 80% of the one fifth national assigned amount (77 391 Gg CO2e) (IA, 2006b), because only approximately 80% of national total emissions are included in the model. TIMES_PT deals exclusively with emissions from combustion and productive processes which account for approximately for 80% of national emissions in 2010 (IA, 2006a). The following GHG emissions sources are not considered in

Table 3.4. Studied policy scenarios and respective policy restrictions.

	Policy	No Policy	Nuclear	Conventional coal	No incentives to gas	No biomass
Ban on nuclear power	✓			✓	✓	✓
Incentives to natural gas power plants	✓		✓	✓		✓
New Coal power plants only after 2015	✓		✓	✓	✓	✓
CCS obligatory for coal power plants after 2015	✓		✓		✓	✓
Electricity from waste and wood waste continued till 2030	✓		✓	✓	✓	✓
Minimum wind installed capacity in 2005	✓		✓	✓	✓	✓
Biofuels >5.75% in transport fuel after 2010	✓		✓	✓	✓	
Tax on oil products	✓		✓	✓	✓	✓
Cap on biomass						✓

CO_2 emission trading is not considered in any of the policy scenarios; neither the EU scheme nor the Kyoto protocol one or the other Kyoto flexible mechanisms. This does not hinder the results, since the main objective is to study changes in the national internal CO_2 MAC curves.

3.4 Results and discussion

3.4.1 Marginal abatement cost curve

The CO_2 MAC curves for 2020 for Portugal obtained with TIMES_PT for the six policy scenarios are presented in Table 3.5 and Figures 3.3 and 3.5. The effect of the policies in MAC curves is assessed in two complementary ways: 1) comparing MAC for the same reduction effort vis-à-vis 1990 emissions, i.e.

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the model and in this paper: from solvents use, non-combustion agricultural activities, waste management, fugitive emissions from fuels and f-gases. The Kyoto cap value also considers 80% of the sinks capacity (2 698.79 GgCO2/year) (IA, 2006a) which is kept constant until 2030, with a CO2 removal cost of 5.5 €/t CO2 (NEEDS Technology Database).

the same CO_2 emissions cap (Figure 3.3), and 2) assessing the motives for the "leaps" in the MAC curves using the classic MAC chart, which plots MAC per abated tonne of CO_2 (Figure 3.5). In this paper differences in MAC are primarily assessed for identical emission caps because this approach better conveys the involved abatement effort, a decisive criterion for policy making.

The introduction of policies significantly increases MAC: the policy scenario has 91 to 42% higher costs than the no policy scenario, respectively for the emission caps of +20% and -60% CO_2 from 1990 levels. The ban on nuclear power is the most important policy influencing costs of marginal CO_2 abatement, as the MAC of the nuclear scenario are similar to the no policy scenario and much lower than for the policy scenario (87 to 29% less for the 0 and -60% caps). The MAC of the other intermediate policy scenarios (no incentives to gas, conventional coal and no biomass) are much closer to the policy scenario and roughly follow the same curve (Table 3.5).

Table 3.5. Marginal abatement costs and abated CO_2 for the six policy scenarios for the +40% to -60% CO_2 emission caps.

	Policy		No Policy		Nuclear		Conventional coal		No incentives to gas		No biomass	
%change/ 1990	Abated Gg CO_2	MAC €/tCO_2	Abated Gg CO_2	MAC €/tCO_2	Abated Gg CO_2	MAC €/tCO_2	Abated Gg CO_2	MAC €/tCO_2	Abated Gg CO_2	MAC €/tCO_2	Abated Gg CO_2	MAC €/tCO_2
+40%	5266	5	0		0		25737	10	4749	5	8575	27
+30%	10326	33	0		0		30798	27	9810	29	13636	37
+20%	14859	37	1300	3	0		35331	37	14343	38	18169	38
+10%	19656	38	6097	8	0		40128	38	19140	39	22965	39
0%	24453	42	10894	14	4057	5	44925	59	23937	42	27762	68
-10%	29250	93	20488	24	8854	31	49722	105	28733	61	32559	99
-20%	34047	120	25285	57	13651	65	54518	129	33530	146	37356	226
-30%	38844	256	30082	127	18448	123	59315	246	38327	252	42153	353
-40%	43641	464	15691	209	23245	261	64112	437	43124	445	46950	625
-50%	48437	754	34879	362	28041	584	68909	724	47921	769	51747	1070
-60%	53234	1460	39676	851	32838	1038	73706	1516	52718	1516	56544	1830

Thus, there are two groups of scenarios regarding MAC behaviour: with and without nuclear power. Figure 3.3 plots the 2020 MAC with % of emission reduction from 1990 levels (or emission increase, represented with a negative sign), up to a maximum MAC of 130 €/t CO_2. As explained in section 3.3, it was estimated that approximately 47 969 Gg CO_2 were emitted in 1990 from combustion and industrial processes activities modelled in TIMES_PT. Without any emission cap, the emissions of the no policy and nuclear scenarios are respectively 58 863 and 52 026 Gg CO_2 which corresponds to a 23% and 8% increase of the 1990 emissions modelled in TIMES_PT. The scenarios without nuclear have much higher no-cap emissions: 94% of 1990 emissions for the conventional coal scenario (92 893 Gg CO_2), 58% for the no biomass scenario (75 731 Gg CO_2), 51% for the policy scenario (72 422 Gg CO_2) and 51% for the no incentives to gas scenarios (71 905 Gg CO_2).

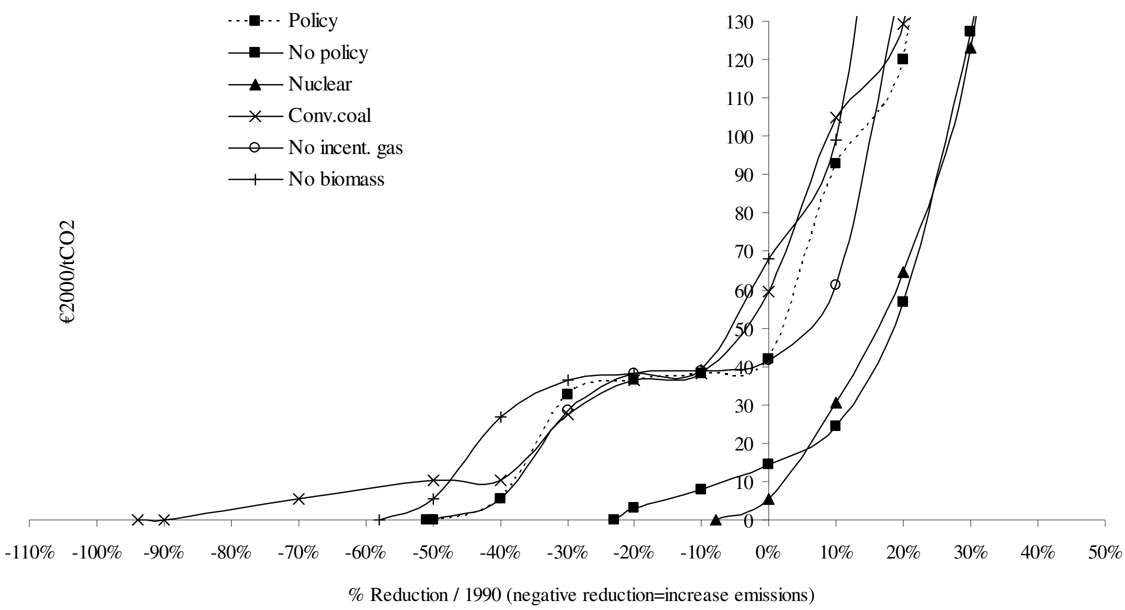

Figure 3.3. Marginal abatement costs curves for the Portuguese energy system in 2020, as % reduction from 1990 levels (the negative sign corresponds to an increase in emissions).

The two scenarios with nuclear power have cheaper MAC as nuclear plays a major role in electricity generation (Figure 3.4). When allowed, the share of electricity generated from nuclear is never less than 71% of generated electricity; roughly to 8.5 GW installed capacity. Such quantities of nuclear power are very likely unfeasible in Portugal due to other concerns than global warming, such as size of the territory and energy security issues. Moreover, because there is no national specific data on waste management costs, these were not included in the model, which could have made nuclear less competitive. Nonetheless, it is useful to assess the maximum reduction in CO_2 emissions and MAC that could be obtained with nuclear power. The differences in the MAC of the nuclear and no policy scenario occur because in the latter electricity is also generated from conventional CHP coal power plants, which are banned in the nuclear scenario and replaced by gas, due to the modelled incentives.

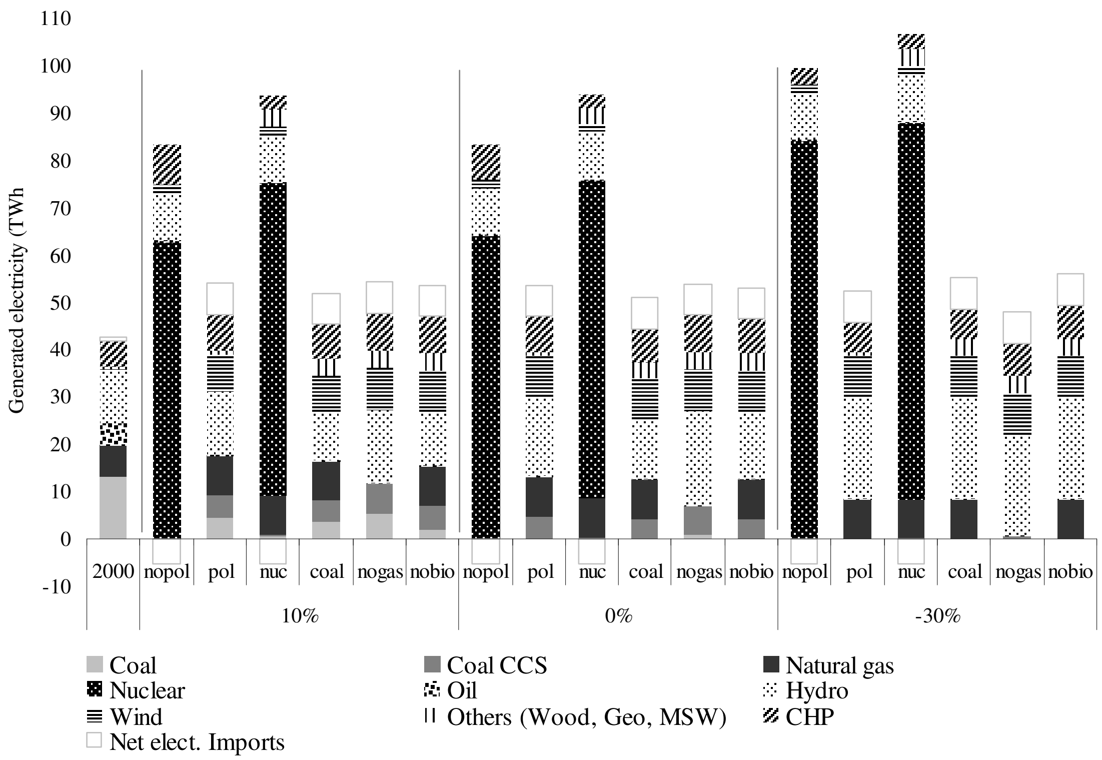

Figure 3.4. Electricity generated in 2020 for the six policy scenarios: nopol - no policy; pol – policy; nuc –nuclear; coal – conventional coal; nogas – no incentives to gas; nobio – no biomass.

In the scenarios without nuclear power the effects in MAC are less significant (differences in MAC below 20%). In fact, for “moderate” CO_2 emission caps of 30% to 10% increase from 1990 these three policy scenarios do not significantly affect MAC (maximum difference of 17% vis-à-vis the policy scenario). These caps are the most probable ceilings following the EU effort sharing negotiation. The biomass limit is the most important policy assumption affecting MAC curves, followed by the ban on conventional coal power plants. The effect of the incentives to gas is less significant, as the no incentives to gas MAC curve follows closely the policy MAC curve except for the -10% and -20% caps.

The limit on biomass increases MAC from 3 to 89% compared to the policy scenario for the +10% to -20% caps because cheap abatement options switching from fossil fuels to biomass (including biofuels) are limited. However, this does not have a significant effect for "moderate" emission caps above 0% (the increase in MAC is less than 11%) when biomass is not playing an important role yet. For such moderate restrictions abatement is achieved primarily by the electricity generation sector for which there is a broad variety of cheap abatement options besides biomass use. For more restrictive CO_2 caps the no biomass scenario MAC become significantly higher (more than 20%) than in the policy scenario, as abatement has to be done by other sectors where biomass plays an important role: industry and residential. In the no biomass scenario biomass is practically all used in the electricity and residential sectors, whereas in the policy scenario biomass use is distributed across all sectors. Thus, for Portugal the use of biofuels in transport aiming to reduce CO_2 emissions is only a cost effective policy for emission caps identical to 1990 levels and beyond.

The ban on conventional coal power plants only has significant effects for emission caps less restrictive than +30% and for the 0% cap. For other caps, differences in MAC of the conventional coal and policy scenarios are below 20%. The ban mostly reduces MAC and thus the policy MAC is lower than the conventional scenario MAC. The exception is the+30% cap for which the policy MAC is 17% higher than the conventional coal scenario. For the other two significantly different caps the MAC of the policy scenario is 88% less in the +40% cap and 41% less for the 0% cap. The differences in MAC between the conventional coal and policy scenarios have two different causes: 1) penetration of very polluting coal gasification plants up to the +30% cap[28]

[28] Up to the +30% cap the ban on conventional coal of the policy scenario leads to a higher penetration of very polluting coal gasification plants that produce methanol and DME

and 2) penetration of conventional coal power plants for the 0% cap and beyond. Therefore, in the conventional coal scenario earlier CO_2 abatement is achieved by reducing the activity of the conventional coal power plants, which is more expensive than stopping the use of coal gasification plants done in the other scenarios. For the +30% cap onwards coal gasification does not occur in any scenario and the conventional coal penetration is anyhow limited by the emission cap, thus levelling abatement options across scenarios. The leap in the MAC curve of the conventional coal scenario for the 0% cap onwards is due to the complete shutdown of conventional coal plants.

The incentives to gas scenario both contributes to increase or decrease MAC, depending on the emission cap, but the variations are less than 20% except for the -10% and -20% caps. In the first case the incentives to gas increase MAC in 34% because cheap abatement switching from coal to gas is less available in the policy scenario. In the -20% cap the incentives to gas decrease MAC in 21% because in the policy scenario it is still possible to replace combined cycle gas power plants with hydro, gas plants with CCS and hydrogen fuel cell CHP. Maximum hydro was installed earlier in the no incentives to gas scenario and thus only more expensive hydrogen CHP are now available.

Figure 3.5 plots the 2020 MAC against abated CO_2. As explained before the starting point of the curve - emissions without any cap - is different for the six policy scenarios, which leads to a different assessment of MAC than in Figure 3.3. For example, a 10 000 Gg[29] CO_2 abatement has a MAC of 5 €/t CO_2 for the conventional coal scenario, of 13 €/t CO_2 for the no policy, 30-31 €/t CO_2

used in the transport sector. When conventional coal power plants are allowed, practically all coal is used to generate electricity, since conventional coal power plants are cheaper than coal gasification. This happens because there is a limited amount of cheap coal available. When conventional coal power plants are not allowed, electricity generation from coal has to be done with coal CCS plants which are 0.38-0.72 €cents/kWh more expensive than conventional coal plants (37-69% more expensive), and 12% less efficient. This cost and efficiency differences are enough to make coal gasification competitive in the scenarios with the ban on conventional coal.

[29] The abated CO_2 is estimated for each policy scenario relatively to its no cap emissions in 2020.

for the policy, no incentives to gas and no biomass scenarios, and 39 €/t CO_2 for the nuclear scenario. However, this does not give any indication of the corresponding very different effort level compared to 1990 emissions: the 10 000 Gg abatement roughly corresponds to a 60% increase in emissions from 1990 levels for the conventional coal scenario, but only half than that for the policy, no biomass and no incentives to gas scenarios. The 9 €/t CO_2 difference between the MAC of these three scenarios and the nuclear scenario corresponds to the abatement of the same 10 000 Gg CO_2, but for the first three this represents a 30% increase from 1990 levels, whereas it is a 10% reduction for the nuclear scenario. Because the effort level was chosen as the comparison criteria for MAC, this figure is here only used to identify leaps in MAC curves for each of the scenarios, which correspond to the adoption of new technologies.

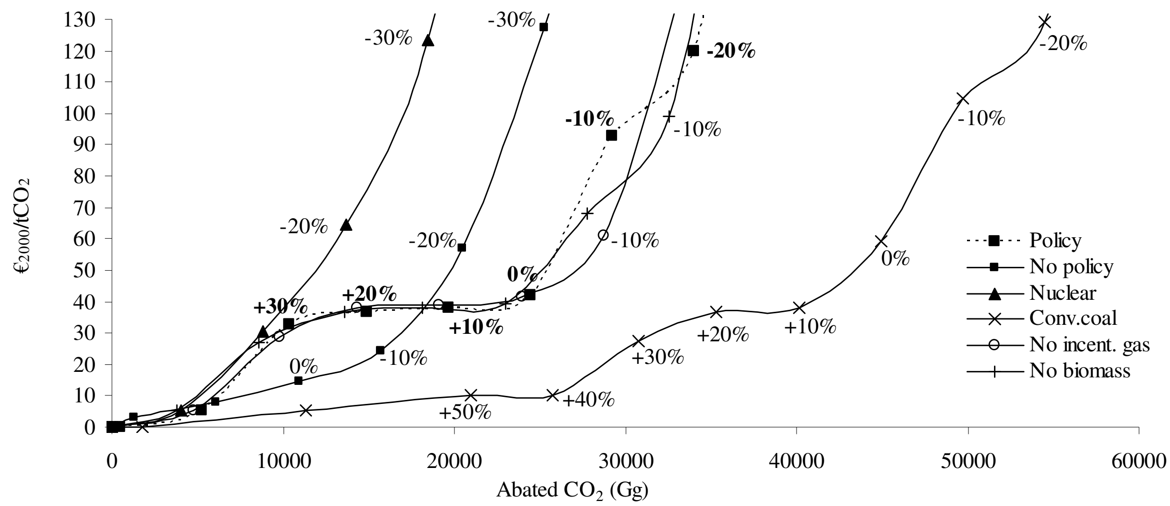

Figure 3.5. Marginal abatement costs for Portugal in 2020. The % values are the CO_2 emission caps compared to 1990 emissions (positive = increase in emissions). The start of each MAC curve corresponds to different CO_2 emission caps since the emissions when there is no cap are also different.

In the policy, no biomass and no incentives to gas scenarios there are two points in which MAC increases sharply: for emissions reductions above 5 000 Gg, from 5.45 to 32.81 €/tCO_2, and for reductions above 25 000 Gg, from 42.09 to 92.92 €/tCO_2. The first "leap" in the MAC curve is mainly due to reductions stopping coal gasification plants, in CHP, electricity generation, and to a less extent, in industry. Reductions are achieved reducing the use of conventional coal and substituting heavy fuel oil CHP plants and boilers by gas ones. The second leap is due to reductions in the same sectors but industry plays a more important role. The abatement is achieved by further reductions of fuel oil CHP plants, which are substituted by a large CHP coal plant with CCS. In the industry sector year 2000 boilers have practically disappeared and more advanced kilns are installed. In the electricity generation sector a new gas combined cycle plant with CCS is installed. At this point, plants that operated in the year 2000 are practically not functioning and hydrogen generation from solar and gas becomes competitive.

The incentives to gas and the biomass limit were found not to have much effect on the shape of the CO_2 MAC, as opposed to the ban on nuclear and the ban on conventional coal. When nuclear is allowed, the MAC curve increases steeply because cheap abatement switching coal to gas in the electricity sector is not available, as can be seen comparing the MAC curves of the policy and nuclear scenarios. On the other hand, of course, the need to abate is less. If conventional coal is allowed the MAC curve will grow very slowly as cheap abatement is available mainly by reducing activity of very polluting coal power plants.

Besides looking at MAC for the different policy scenarios, it is also interesting to assess differences in total system costs for the modelled period (2000 to 2030) (Figure 3.6). The system costs increase with the severity of the emission cap and policy constraints. The costs for satisfying the demand for energy services from 2000 to 2030 decrease 10-13% if no policy assumptions are forced. The difference in total costs compared to the policy scenario is less 76 to 101 B€ which is roughly the equivalent to 2.01 to 2.65% of the 2005 GDP, respectively for CO_2 caps of +10% and -60%. This should not be read as GDP loss – it is simply a metric for comparison of values. Lifting the ban on nuclear is just marginally less expensive than the policy scenario: the difference between scenarios represents at most 0.01% of the GDP, whereas the incentives to gas and ban on conventional coal practically do not affect the total system costs.”

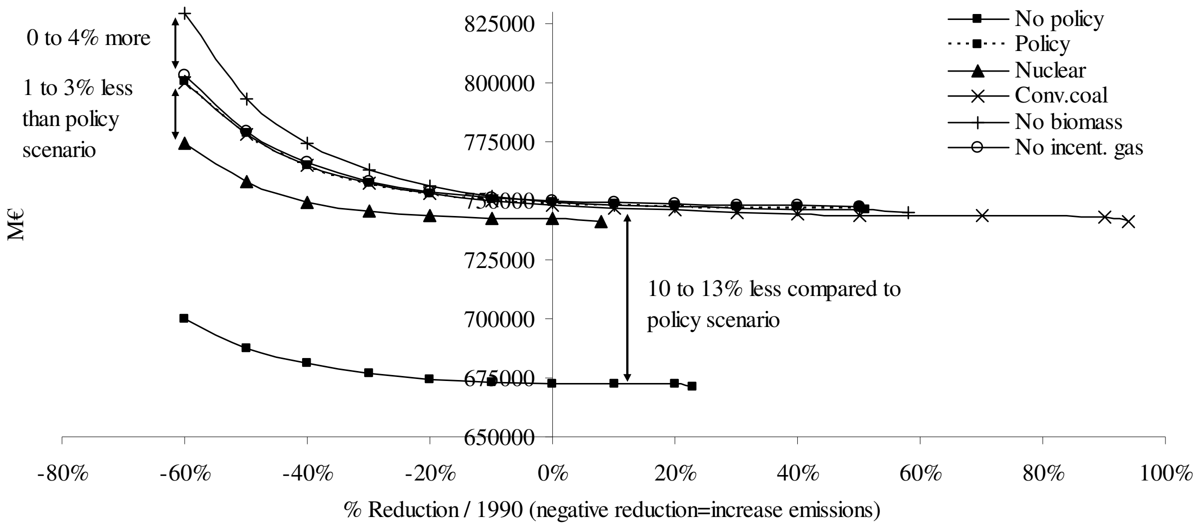

Figure 3.6. Total system costs for the 2000-2030 period (M€). The % values are the CO_2 emission caps compared to 1990 emissions (positive = increase in emissions).

Although the nuclear policy and conventional coal bans, the limit to biomass and the incentives to gas do not drastically affect total system costs, their significance is still important for national mitigation strategies. According to Figures 3.3 and 3.5, for expected carbon prices of European Union Allowances of 23€/t CO_2 in 2020 (Point Carbon, 2007), Portugal should reduce internally up to 8 Mt in 2020 in the policy scenario, compared to its own no cap emissions. This roughly represents an increase of 35% of 1990 levels. With the combination of unlimited nuclear, conventional coal and no incentives to gas, up to 15 Mt (-10% of 1990 levels) could be reduced internally at 23€/t CO_2 (Figures 3.3 and 3.5).

Nonetheless, 8 Mt abatement to get to +35% in emissions is still a large cheap reduction potential, especially when considering that if no additional measures are adopted to curb Portuguese CO_2 emissions, a growth of 77-64% is expected in 2020 (IA, 2006a). The MAC curve for the policy scenario shows that this trend can be altered at low cost.

Finally, it should be recalled that the Portuguese MAC curve does not consider: i) energy instruments that lower the carbon abatement marginal cost[30], as is the case of the renewable electricity feed–in tariffs and CO_2 emissions trading, nor ii) structural changes in the economy. The MAC curves here presented reflect the continued global growth of the current energy intensive industry and no drastic changes in consumer preferences. In the next sections are outlined the fuel and technology changes that can lead to CO_2 abatement in the different policy scenarios.

3.4.2 Primary and final energy demand for the +10%, 0% and -30% CO_2 emission caps

In all modelled scenarios there is a global growth in the demand from 2000 to 2030, despite some response to the increase in energy prices. Because TIMES_PT is an optimisation model, energy efficiency measures are implemented in all scenarios and the primary energy consumption grows less than the demand. However, higher CO_2 emission restrictions result in smaller growth of energy consumption, except for uranium. In the +10% cap the primary energy consumption (excluding uranium) grows 10-22% from 2000 to 2020, whereas in the 0% and -10% caps the increase is of 8-19% and 4-11%, respectively.

The most evident fuel shift is the use of uranium replacing oil and gas in electricity generation, except when the assumed policies state otherwise. Nonetheless, oil continues to represent 31-58% of the overall primary energy supply. The relative importance of renewable and gas increases only if there is no nuclear. Coal's share is reduced in all scenarios from 18% in 2000 to 1-12% in 2020. This shift is also clear for final energy consumption. Coal disappears in all scenarios and the relative importance of oil products decreases, although it continues to be the most important final energy resource. Electricity's share increases from 20% in 2000 up to 37% in 2020 (28% for scenarios without nuclear). The gas share in the overall final energy demand increases in all scenarios from 5% in 2000 up to 16% in 2020. The renewables share increases in all scenarios from 10% in 2000 up to 22%, with

[30] This paper focuses on MAC and only briefly addresses total system costs. However, it should be mentioned that although feed-in-tariffs can lower MAC they usually contribute to higher total system costs since the costs of subsidising renewable technologies are passed to consumers via the electricity tariff.

the exception of the no biomass scenario (renewables are 6-8% of final energy use in 2020). In this scenario, because large quantities of biomass are not available, no biofuels are used in the transport sector and solar and gas replace biomass respectively in the residential and industry sectors.

The fuel switch does not correspond to a shift in the relative importance of economic sectors in the overall final energy demand. In 2020, in all policy scenarios and caps the transport sector continues to be the biggest energy consumer (37-41% of total final energy consumption), followed by industry (25-28%) (Figure 3.7). The commercial sector has the biggest increase in final energy consumption compared with 2000, up to 85% (75-44% increase in the policy scenario), followed by the residential and transport sectors (respectively 25-7% and 15-7% increase in the policy scenario). Finally, the differences in final energy demand in the six scenarios are higher for -30% cap than for the other two studied caps. This is mainly due to demand reductions in response to the increase in prices. For the +10% and 0% caps these demand reductions are smaller or inexistent since the cap can be met mainly by using alternative technologies. As the stringency of the cap increases alternative technologies are no longer enough and demand response plays a more important role in compliance. For more stringent emission caps the differences in energy prices across policy scenarios increase and so do demand responses.

3.4.3 Sector abatement for the +10%, 0% and -30% CO_2 emission caps

The fuel shifts mentioned in the previous section are motivated both by cost reduction and emission caps. Figure 3.8 depicts emission reductions for 2020 compared with emissions for each policy scenario without an emission cap. It should be noted that the sector mitigation in each scenario is different because unabated emissions in each policy scenario are different to start with, as mentioned in the previous section. In the scenarios without nuclear power, clearly electricity generation has the highest cost-effective reductions; it bears 45-74% of the total CO_2 abatement, especially in the conventional coal and no incentives to gas scenarios. The reductions are due to the substitution of coal by wind and by new hydro power plants[31]. The relative importance of the abatement made by electricity sector decreases slightly as stringency of emission caps increase, but even for the more restrictive emission caps industry & CHP are always second in overall CO_2 abatement.

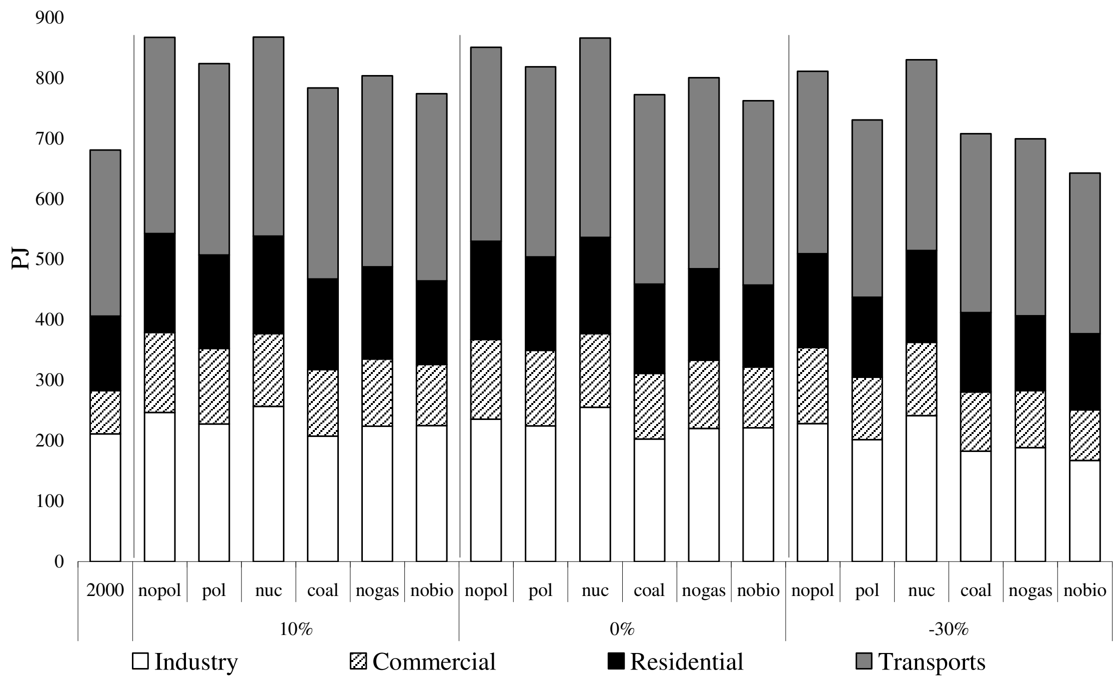

Figure 3.7. Final energy demand per sector in 2020 for the six policy scenarios: nopol - no policy; pol – policy; nuc – nuclear; coal – conventional coal; nogas – no incentives to gas; nobio – no biomass.

[31] It should be noted that the evolution of electricity imports and exports is handled in a simplified way, as mentioned in section 3.2.4, by having set maximum limits on imports and exports for 2020 The resulting net electricity imports in 2020 range from -20 to +26 PJ which represent 5 to 17% of total electricity generated and 6 to 17% of CO2 emissions of the electricity sector (in average 8% of the sectors' emissions). The bias introduced in the results is relevant, although not sufficient to invalidate its usefulness, since the main objective is to understand the dynamics between the different policy scenarios, all of which have the same assumptions regarding electricity trade.

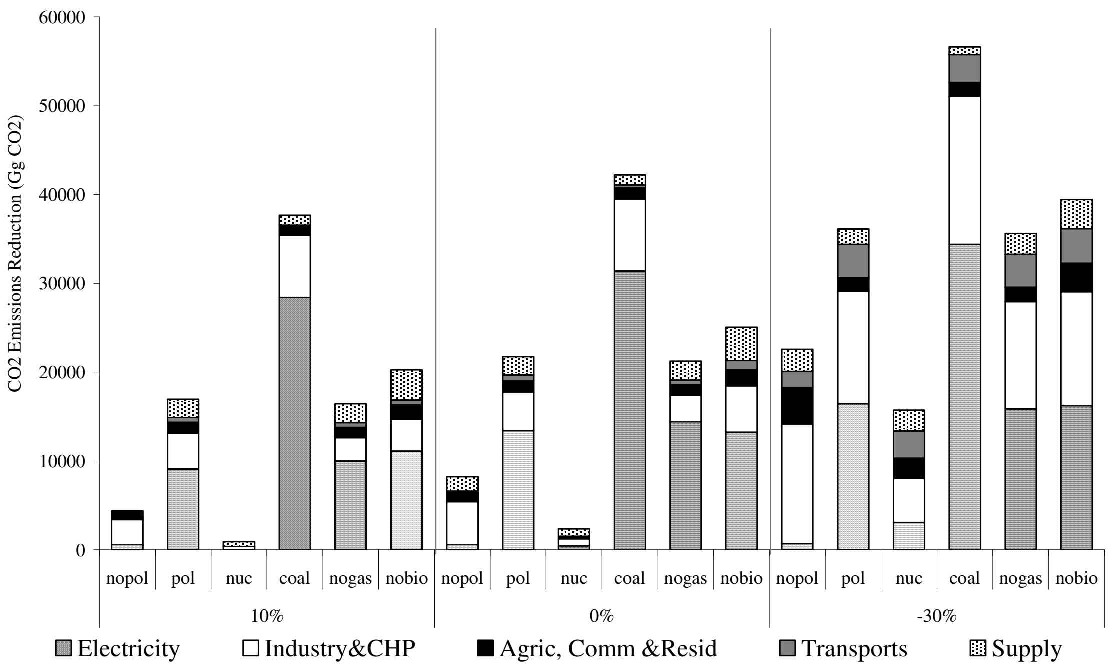

Figure 3.8. CO_2 emission reductions per sector for the six policy scenarios: nopol-no policy; pol – policy; nuc – nuclear; coal – conventional coal; nogas – no incentives to gas; nobio – no biomass. The emission reductions are estimated comparing with the emissions obtained without any CO_2 emission cap

In the scenarios without nuclear, industry & CHP are responsible for 14-35% of total abatement. Abatement in industry in the different policy scenarios is mainly due to: more efficient clinker and ceramic kilns and cement mills, more efficient ammonia production technologies, increased use of CCS, CHP and of green electricity and renewables for process heat in all industry sub-sectors.

With the exception of the conventional coal and no biomass scenarios, the primary energy supply sector also plays an important role in abatement due to the reduction of coal gasification plants (5-17% of total abatement).

The aggregated contribution for overall emissions reductions of the residential, commercial and agriculture sectors is always below 8% in the scenarios without nuclear. The commercial sector reduces its emissions in -4% from 1990 to 2020 only in the policy scenario, and it can increase emissions up to 14-132% of 1990 emissions. Likewise, the residential sector increases emissions 60-165% from 1990. In these two sectors the main technological changes are the almost complete substitution of space heating, water heating and cooling technologies for more efficient and renewable based ones, as a choice for the most cost-effective increases in energy efficiency are - not fully realistically - assumed. In the -30% cap for the scenarios without nuclear 26% and 56% of the water heating is solar based, respectively for the commercial and residential sectors. Heat pumps provide up 47-53% of the heating needed, respectively for the commercial and residential. While the penetration of solar water heating is similar in the scenarios without nuclear, the penetration of heat pumps is higher if conventional coal is allowed, if there are no incentives to gas and especially with the limit on biomass (up to 69% and 67% of heat provided by heat pumps in the commercial and residential).

The transport sector does not play an important role in emission reduction in any scenario. In fact its emissions increase 87-135% from 1990 values. It contributes to 6-11% of the total reduction in the more restrictive cap (-30%) in the scenarios without nuclear. For the other two caps reductions are low (below 4% of total abatement) or none at all. The abatement in the transport sector is mostly due to introduction of using more efficient passenger vehicles and of buses and cars using biofuels: bio ethanol, biodiesel and DME produced from black liquors. The road freight transport sub-sector abates much less than passenger cars. In the no policy and no biomass scenarios abatement is achieved similarly but with less use of biofuels, particularly biodiesel, which is only competitive due to the policy assumption that forced its implementation in 2010. Nonetheless, the contribution of the transport sector for total abatement is the same 10% in the no biomass and in the policy scenarios, where biofuels are used.

3.4.4 Sensitivity analysis

A sensitivity analysis was carried out to the following model's critical parameters: i) hydro power availability factor; ii) costs of CO_2 storage and iii) discount rate. This analysis does not include emission reduction targets, since the main objective is to assess model response to the three studied parameters, and emission caps would bias the results. The results are shown in Table 3.6.

Table 3.6. Values of analysed parameters and respective model results in 2020 for the base case and the sensitivity analysis.

			Hydro availability		Costs of CO_2 storage		Discount rate	
		Base value[a]	Value	% change	Value	% change	Value	% change
Hydro availability	n.a.	[b]	n.a.[b]	-10 to +10	_	_	_	_
Costs of CO_2 storage	€/tCO_2	8.3	_	_	5.8-11.3	-30 to +36	_	_
Discount rate	%	4	_	_	_	_	2-6	-50 to +50
Model results								
Hydro power	PJ	40.24	37-41	-6.9 to +0.9	40	0.0	57-40	+41.8 to 0.0
Stored CO_2	Gg	5000	5000	0.0	5000	0.0	2300-5000	-54.0 to 0.0
Total system costs [c]	B€	750.96	751.42 - 750.90	+0.1 to 0.0	750.91 - 751.05	0.0	925.20 - 629.74	+23.2 to -16.1
Final energy	PJ	1016	1016	0.0	1010-1022	-0.6 to +0.6	1010-1022	-0.6 to +0.6
CO_2 emissions	Gg	72655	72917-72622	+0.2 to +0.1	72654	0.0	68754 -72729	+1.9 to -1.9

[a] For the policy scenario, without any CO_2 emission cap. Even without an emission cap, CCS still occurs because coal is much cheaper than gas and investment in coal without CCS is not allowed (see section 3.3). [b] Because there are eight different availability factors (AF) considered in TIMES_PT they are not all shown here; the two model runs were made for a variation of +10% and -10% for each of these AF. [c] The system costs are discounted and estimated by the model for the total period: 2000 to 2030.

The discount rate is the most sensitive of the studied parameters. Changes of 50% in the discount rate lead to large variations of generated hydro power and total system costs, but not of CO_2 emissions and final energy consumption, which vary less than 2%. On the other hand, total system costs, generated hydro power and quantities of stored CO_2 vary significantly with a reduction of the discount rate (more than 20%). The lowest discount rate hampers the penetration of less capital intensive electricity generation technologies, mainly a new integrated gasification combined cycle (IGCC) coal power plant with CCS. This technology replaces new hydro power plants which are favoured in the low discount rate case. Hydro power plants have both higher life time and specific investment costs than IGCC coal power plants; respectively 5850-3500 €/kW for hydro plants and 1370 €/kW for coal IGCC. Although the decrease in the discount rate leads to a significant difference in parameters, its increase from 4 to 6% practically has no effects, except for the reduction of 16% in total system costs, which is simply the result of higher payment on invested capital.

For the other parameters – hydro availability and costs of CO_2 storage – there are no significant variations (less than 7%). In the particular case of CO_2 storage, it seems clear that the storage costs are not influencing the selection of coal CCS technologies. Coal is so much cheaper than gas[32] that even without any emission cap coal CCS plants are implemented because no-CCS coal plants are banned as mentioned in section 3.3. Although the investment and operation and maintenance costs for no-CCS gas plants are lower than for coal-CCS plants, the cheaper fuel costs make coal CCS plants competitive even when there is no need to abate emissions. This indicated that the critical parameter for CO_2 storage is not storage costs but storage capacity, which is used to its limit in almost all sensitivity analysis.

Therefore, the variations in the model results are relatively small when compared to the large variations of the three critical parameters, which seems to point to the robustness of the TIMES_PT model.

3.5 Conclusions

This paper presents CO_2 MAC curves for the year of 2020 for different policy scenarios of the Portuguese energy system. Six policy scenarios were studied with different implementation of the energy policies currently in place. The reference policy scenario considers the following policies: a ban on nuclear power; a ban on new coal power plants without carbon sequestration and storage (hereafter named as conventional coal); incentives to natural gas

[32] In the no policy scenario in 2020 coal for electricity generation costs approximately 1.78 €/GJ, whereas natural gas costs 5.96 €/GJ. When incentives to gas are considered, the gas price increases to 7.50 €/GJ. This large difference is due to the fact that most of the coal consumed in Portugal for electricity generation is delivered to the power plants at a very cheap cost, since they are located in close proximity to an international harbour. The gas, however, has to be delivered by pipeline, with much higher costs

power plants, and a cap on biomass use. Besides the policy scenario, the following alternative scenarios were studied: no policy, without any of the above mentioned policies; nuclear (policy scenario but allowing nuclear); conventional coal (policy scenario allowing conventional coal); no incentives to gas (policy scenario without incentives to gas); and no biomass (policy scenario with a limit on available biomass). The objective is twofold: to present the Portuguese marginal abatement costs curve for CO_2 emissions, and to quantify the impact of the present policies on the MAC curve.

It was found that the introduction of assumed policies significantly increases MAC: the policy scenario has 91 to 42% higher CO_2 MAC than the no policy scenario. The removal of the assumed policies leads to a significant decrease in total system costs of 10-13% (76-101 B€), roughly the equivalent to 2.01 to 2.65% of the 2005 GDP.

The marginal abatement costs difference in policy scenarios is essentially due to the ban on nuclear power, which is by far the most significant policy affecting MAC. In fact, the MAC of the nuclear scenario are closer to the no policy scenario than to the policy scenario (87-29% lower than the policy scenario MAC), as opposed to the other scenarios whose MAC are less than 20% different of the policy scenario. The limit on biomass also plays a significant role increasing MAC but only for “aggressive” emission caps representing an emission reduction from 1990 levels. For more moderate emission caps biomass is not playing an important role, as cost-effective abatement is done mainly in the electricity sector, without using biomass. Thus, for Portugal the use of biofuels in transport aiming to reduce CO_2 emissions is only cost-effective for reductions of 0% 1990 levels and beyond. The ban on new conventional coal power plants only has significant effects for “moderate” emission caps above +30% and for the 0% cap. The ban mostly reduces MAC as cheap abatement switching off polluting coals power plants is not available. The incentives to gas were found not to have a significant effect in MAC.

With exception of the incentives to gas and biomass limit, the studied policies alter the slope of MAC curves. The MAC curves of the scenarios without nuclear grow slower, due to cheap abatement switching from coal to gas in the electricity sector. The same happens if conventional coal is allowed because cheap abatement is available by reducing the activity of highly polluting coal power plants.

The policy scenario MAC curve shows a large cheap CO_2 abatement (below 23 €/tCO_2) potential up to 8 Mt in 2020. This corresponds to an increase of emissions of +35% of 1990 levels Higher emission reductions imply marginal costs above 33 €/tCO_2 and to maintain 2020 emissions to 1990 levels a cost of 42 €/t has to be dealt with.

Cheap abatement options are provided by electricity generation, CHP and industry. The other sectors have less cost-effective options, such as the transport sector, or their share in total emissions is small, as in the commercial sector. One of the first measures adopted in the policy scenario is the increase of electricity generated from renewable resources from 31% in 2000 to 42-73% in 2020, depending on the emission cap and policy scenario. Thus, it is no surprise that the policy measures that condition the electricity generation sector have the most influence in MAC curve. Regarding the portfolio of renewable electricity technologies, hydro power seems to be the most competitive option. Electricity generated from hydro increases compared to the no cap case already for MAC of approximately 6 €/t CO_2 in the scenarios without nuclear. Wind is the second best option when MAC are around 30-40 €/t CO_2. Solar (either PV or thermal), geothermal or biomass are not competitive even for MAC higher than 100 €/t CO_2.

The results here presented should be handled with some caution due to a series of limitations of the used methodology and of the modelling tool. As to the methodology, the quantification of effects of policies in MAC curves has to be regarded with some caution because some of the model results for the no policy and nuclear scenario are unrealistic. At least 8.5 GW of nuclear power will be installed in 2020, which is highly unlikely, due to energy security and environmental and risk concerns. Another improbable model result is the massive installation of no CCS coal gasification plants to generate DME and methanol. These plants have high environmental impacts, such as SO_2 emissions, which are not taken into account here. Moreover these plants can have CCS technologies which were not considered. Furthermore, in all scenarios an assumption is made regarding the evolution of electricity imports and exports. Nonetheless, the different policy scenarios allow understanding how current policies affect the MAC curves and assessing maximum alterations in curves and CO_2 emissions.

Another relevant model limitation is that major alterations in the value added structure due to increases in fuel prices are not dealt with in TIMES_PT.

Furthermore, the demand for energy and materials is exogenous and only responds to the implemented policy constraints to the extent of the considered demand price elasticities. The demand reduction will influence macro-economic growth and constant gross value added structure of the GDP but this cannot be assessed with a partial-equilibrium model such as TIMES_PT. For example, the model does not show any increase in energy demand of the agriculture and chemical sectors due to increased use of biofuels requiring more fertilisers. This could partially be dealt with by adding such emissions in the emission factors of biofuels, but the feasibility of this option would be limited, as this would be a life-cycle approach mixed with an (quasi-)dynamic approach. Other limitations are the uncertainties in model inputs, especially the assumed potential for CO_2 storage, for sinks, and also some of the national primary energy potentials.

Further interesting model developments would include the consideration of micro generation technologies and of acidifying and particles emissions which significantly interact with CO_2 restrictions.

The most general conclusion is that even the limited set of policies in the energy domain assumed operant in this model exercise has a significant effect on the cost of CO_2 reduction. This interaction of policies therefore seems to be a prime subject for further analysis on cost-effective policy development in the energy and environmental policy domain, not only in Portugal.

3.6 Appendix – Other Exogenous information inputs included in TIMES_PT

The *energy supply and demand technologies for the base-year (2000)* were characterised considering the energy consumption data from EUROSTAT and the official DGGE national energy balance to set sector specific energy balances to which technologies profile must comply. Information on installed capacity, efficiency, availability factor, and input/output ratio were introduced using diverse national sources (IA, 2006a; CELPA, 2003; DGGE, 2005; EDP, 2002; EDM, 2005; ERSE, 2001; ERSE, 2006; IGM, 2000; INETI, 2003; INE, 2000b; LIPOR, 2005; REN, 2005; REN, 2006; SEIA, 2000; PEGOP, 2005; Turbogás, 2005; Valorsul, 2005). This was followed by a bottom-up approach that adjusted the technologies specifications to achieve coherence with official energy statistics. This bottom-up approach was very relevant for the residential and commercial sectors, for which there is less detailed information on existing technologies.

The energy supply and demand *technologies beyond the base year* are compiled in an extensive database with detailed technical and economic characteristics of new energy technologies. This was developed within the NEEDS project and validated with Portuguese stakeholders for industry, electricity generation, and solar technologies.

The costs data on *carbon capture and storage* considered in TIMES_PT refers to the costs of carbon capture and compression and are embedded in the several supply and demand energy technologies in TIMES_PT, using cost data from IPCC (2005) and Hendriks et al. (2004). Only one CO_2 transport technology and one storage technology are included in the model. The following CO_2 storage costs were considered: transportation costs of 3 €/t CO_2, storage costs of 0.3 €/t CO_2 for pumping the gas underground, and cost of investment in the underground storage facility of 5 €/t CO_2 (Hendriks et al., 2004).

TIMES_PT modelling of end-use of energy services and material requires to *breakout fuel consumption by end-use* (e.g. clothes washing, process heat). Several data sources were used: data from CIEMAT[33], within the NEEDS project (REE, 1998; MITYC, 2003); National Inventory Report on GHG (IA, 2006); national studies on renewables (Gonçalves, *et al.*, 2002a e 2002b) and on electricity end-use (Júlio, S. et al., 1997; DGGE/IP-3E, 2004); and the PNAC energy demand scenarios. For the residential sector the *load diagram* data developed by ADENE the National Energy Agency was used (Enertech *et al.*, 2002). The Spanish load diagram data (REE, 1998) was adopted for the commercial sector since there is no Portuguese specific data. Because it was not possible to breakout the energy demand according to the load diagram for industry and transport due to the lack of information, the model does not consider seasonal or daily demand variations for these sectors.

A long-term *price elasticity of demand* of -0.3 is used for the following demands: (1) Industrial products; (2) Energy use in other industrial sectors,

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transport and agriculture; (3) Energy end-uses in the residential and commercial sectors except cooking, which has a price elasticity of -0.2 and -0.1, respectively for the commercial and residential sectors. The elasticity values are generic for EU countries and were supplied by Leuven University.

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4 The Savings of Energy Saving: Interactions between energy supply and demand side options - quantification for Portugal*

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Abstract

Reducing demand by increasing end-use energy efficiency on the demand side of energy systems may also have advantages in reducing fossil dependency and greenhouse gas (GHG) emissions on the supply side. This paper addresses interactions between energy supply- and demand-side policies, by estimating the impact of measures addressing end-use energy efficiency and small- scale renewables uses in terms of (i) avoided large-scale electricity generation capacity, (ii) final energy consumption, (iii) share of renewables in final energy, and (iv) reduction of GHG emissions. The Portuguese energy system is used as a case-study. The TIMES_PT bottom-up model was used to generate four scenarios covering the period up to 2020, corresponding to different levels of efficiency of equipment in buildings, transport and industry. In the current policy scenario, the deployment of end-use equipment follows the 2000-2005 trends and the National Energy Efficiency Action Plan targets. In the efficient scenarios, all types of equipment can be replaced by more efficient ones. Results show that aggressive demand-side options for the industry and buildings sector and the small-scale use of renewables can remove the need for the increase in large-scale renewable electricity capacity by 4.7 GW currently discussed by policy makers. Although these measures reduce total final energy by only 0-2%, this represents reductions of 11-14% in the commercial sector, with savings in total energy system costs of approximately 3000 M€$_{2000}$ - roughly equivalent to 2% of the 2010 Portuguese GDP. The cost-effectiveness of policy measures should guide choices between supply shifts and demand reduction. Such balanced policy development can lead to substantial cost reductions in climate and energy policy.

4.1 Introduction

In 2007, the European Commission (EC) set comprehensive climate and energy policy targets simultaneously focusing on energy efficiency, promotion of renewable energy sources (RES) and reduction of GHG emissions (EU Commission COM(2008) 30). However, although there is good progress towards the RES objective, the Commission has acknowledged that the energy efficiency target is still "a long way from being achieved" (EU Commission COM(2010) 639 final). Moreover, government subsidies and private investments in large fossil and nuclear power plants vastly outweigh those in renewable energy and even more so those in energy efficiency (WWF, ECOFYS and OMA 2011). This seems to support statements by some non-governmental organisations (NGOs) that policy-makers are focussing excessively on the supply side of energy systems, particularly centralised generation options[34], and not enough on end-use energy efficiency (WCD 2000; GEOTA et al. 2011; Wade et al. 2011). Focusing on supply-side energy policies, for instance by supporting large electricity power plants from renewable resources, without at the same time looking for opportunities on the demand side, may generate avoidable costs and burdens (see Lenard, 2009 on benefits of integrating energy efficiency concerns into RES targets). Even though renewable energy sources are perceived by policy makers (and NGOs) as a solution for tackling climate change and reducing energy dependency while pleasing public opinion (ENE2020 2010; WWF, ECOFYS and OMA 2011; EREC and Greenpeace 2010), large renewable energy supply infrastructures, notably large hydropower plants, often generate public opposition (WWF n.d.; WCD 2000; GEOTA et al. 2011) which may lead to delays in implementation or even cancellations, usually incurring extra costs.

[34] Some reasons for this preference of policy makers are: greater familiarity with and reliability of centralised technologies; easier access to more reliable investment funding for such technologies; easier acceptance of the technologies by key institutions such as planning bodies, and the vested interests and lobbying power of various stakeholder groups (WCD 2000). Savings are mostly more diffuse, with more complex behavioural mechanisms involved, and with plain inertia also playing a role (Jaffe and Stavins 1994; Schleich 2009; de Groot *et al.*, 2001; Sorrell *et al.*, 2004).

Also, the supply side of electricity links to the supply of fossil fuels further upstream. Reductions in specific demand might lead to price reductions of fossils fuels, and to increased fossil use elsewhere, based on elasticities of supply and demand. In the case of Portugal, we only note that such global mechanisms will tend to work out more or less the same for all scenarios we studied.

Although the umbrella subject of climate change brings together end-use energy efficiency, RES and other mitigation options, policy makers often prefer to support investments on the supply side, for instance in bio-energy and large-scale hydro, wind and wave power (WCD 2000) or even centralised fossil power plants. Government subsidies are typically maintained along with incentives to use RES[35], albeit in a more discrete manner (EEA 2004; IEA 2001 in OECD 2005). Thus, despite the fact that more recent energy strategies and programmes combine many policies and measures to address climate change, energy security and energy efficiency and to promote RES, there is still a need for quantified assessments of the contributions of the various policies within each major policy objective, and of the synergies and antagonisms caused by different combinations of policy measures. This type of information is highly valuable for identifying the most cost-effective[36] combination of policy measures and for reducing the overall cost of policies.

[35] An example is the Portuguese Portaria no. 765/2010 of August 20th 2010, which defines an annual monetary incentive in euros per installed MW applicable to plants above 50 MW to ensure the availability of plants for dispatch by the Transmission System Operator and to provide an "incentive to investment". This law applies to both existing and new fossil and RES power plants, with a view to promoting security of supply, thus counteracting the 2020 National Energy Strategy (ENE2020) policy objectives of promoting RES and reducing GHG emissions. The value of the incentive ranges from 20 000 to 43 000 euros/MW per year depending on the age of the power plant and the reserve capacity of the electric system.

[36] Although other criteria are relevant to evaluate policies and policy instruments and measures, such as effectiveness, efficiency, feasibility and equity, this paper only focuses on cost-effectiveness, for the sake of simplicity.

Taking Portugal as a case study, the objective of this paper is to explore and quantify the effects of specific uncoordinated supply-side policies and selected demand-side policies, namely end-use energy efficiency and small-scale renewable applications. In particular, we assess the impact of these measures on the economic necessity of expanded centralised fossil fuel capacity expansion. The impacts are quantified in terms of reduced investments in large-scale energy supply and contributions to compliance with energy and environmental policy targets. Although, strictly speaking, all RES technologies are part of the supply side, we consider small-scale renewables technologies as part of the energy demand side, as this approach is also used in several National Energy Efficiency Action Plans (NEEAPs). The reasoning behind this is that policies to incentivise these technologies typically target demand-side consumers (buildings and industry). This paper does not focus on demand-side management as such, but on quantifying some of the specific interactions between large-scale centralised supply and measures that can be adopted by end-use consumers, namely end-use energy efficiency and small-scale RES (such as solar roof PV). Portugal, like most EU countries, is facing a difficult challenge to reduce its external energy dependency, and the promotion of RES is a preferred policy to meet this challenge while also reducing GHG emissions for 2020. For 2020, the EC proposes an increase for Portugal of 1% in GHG emissions not included in the GHG emission allowance of the European Trading Scheme (ETS), hereafter referred to as non-ETS emissions (EU Decision COM(2008) 17). The objective for the whole of the EU ETS is to reduce emissions by 21% of 2005 values (EU Commission COM(2008) 16 final). The RES Directive sets a target for Portugal of a 31% share of RES in the final consumption of energy, and at least a 10% share of biofuels in the final consumption of energy for transport by 2020 (EU Commission COM(2008) 19 final).

In order to meet these targets, Portugal has stepped up its efforts to develop renewable energy sources, setting ambitious policy targets for 2020 and promoting investment in RES, especially for electricity generation (DGEG 2010; ENE2020 2010). The policy incentives in place include, for example, guaranteed feed-in tariffs for renewable electricity, positive fiscal discrimination and an obligation to apply solar thermal technologies, as well as a facilitated tendering/concession process principally intended for large-scale renewable applications. Along with the efforts to promote RES, a number of policies have been developed to promote end-use energy efficiency, namely through the NEEAP (RCM 80/2008), which sets an overall target of 10% minimum energy savings by 2015 compared to a baseline scenario. The NEEAP defines specific targets and incentives to stimulate energy efficiency in buildings through increased insulation, double-glazed windows, solar thermal systems, heat pumps, efficient biomass heating equipment, and A+ and A++ appliances. The most recent assessment of the NEEAP, including the years 2008 and 2009, showed 18% compliance with the 2015 target (ADENE 2010). In addition to the above-mentioned measures, the National Climate Change Programme (PNAC) includes several additional measures, most of which concern the energy supply sector, such as introduction of biomass in coal-powered plants or increased use of combined heat and power (CHP) (RCM 1/2008).

Notwithstanding the national policy developments on renewable energy, concerns about the security of supply, and in particular about diversification of supply, have motivated large investments in new fossil capacity, mainly in combined cycle gas turbines (CCGT). Permits for installations with a capacity of 3.2 GW have been issued, and 1.6 GW capacity was already in operation in 2011. This represents an increase of 73% of the 2005 CCGT capacity and of 24% of the total 2005 electricity generation capacity. If all planned investments in electricity power plants mentioned in the ENE2020 and NREAP (fossil and renewable) are added up, the total installed capacity will have increased by 2020 to 147% or 226% of the 2005 values, respectively, for a conservative business-as-usual scenario or the Road-Map for Renewables scenario developed by the government to comply with the 31% RES target (Seixas et al. 2008). Although in 2005 the future growth of electricity demand was optimistically expected to increase by 4.6% a year until 2020 (REN 2005), it is relevant to assess whether all these investments are strictly necessary from the perspective of meeting GHG and RES targets. Another question is to what extent aggressive demand-side measures (end-use energy efficiency and small-scale renewable applications), i.e. going further than planned in the NEEAP, can contribute to the aforementioned GHG and RES targets while reducing Portuguese national external energy dependency. This paper tries to answer these questions by using the TIMES_PT model to analyse four scenarios, which combine different levels of renewable electricity, different activity levels for the new CCGT power plants and different deployment of efficient and RES-based end-use equipment. These exogenous assumptions are proxies for the specific policy instruments of feed-in tariffs to RES, subsidies to large fossil power plants and the NEEAP policies to promote end-use energy efficiency. The next section presents an overview of the methodology for scenario development, followed by an analysis of the results in section 4.3, a discussion of these results in section 4.4 and the conclusions in section 4.5.

4.2 Methods and model

To quantify the interactions between energy supply and selected demand-side options for Portugal, four policy scenarios for 2020 were generated using the TIMES_PT model: Current Policy (CUR), Demand focus (DEM), Supply focus (SUP), and Supply and demand focus (S&D). In accordance with the structure of Portuguese energy and climate policy, small-scale RES technologies such as solar thermal power, PV roof panels and small biomass boilers are aggregated throughout this paper as part of the demand side. This is the same approach as that used by the EU Member States in their NEEAPs. Since this is not in line with the stricter definition of energy efficiency, we would have preferred to make a different choice, but this was unfortunately impossible in this policy analysis.

The major differences between the four scenarios are: (i) the production of renewable electricity on the supply side, (ii) the level of activity in terms of new CCGT on the supply side and (iii) the implementation level of small-scale renewables and end-use efficient equipments in the demand sectors (buildings and industry). Since no detailed and transparent information was available regarding the exact design of the subsidies to large fossil power plants and regarding the NEEAP policies to promote end-use energy efficiency[37], we did not model the specific policy instruments that are in place. Instead, we used rough assumptions about technology deployment and broader policy targets. The present section briefly presents the TIMES_PT

[37] The Portuguese NEEAP lists a comprehensive set of policy instruments to promote end-use energy efficiency, including small-scale RES technologies like solar thermal panels). However, with the exception of energy certificates for buildings and a tax on inefficient lamps, the measures in most cases do not include quantitative indicators for their implementation (only a quantification of their results in terms of energy savings) and thus cannot be translated into the model.

model, followed by an explanation of the projections for energy services and materials demand we have used, and current and future sources of primary energy supply. Finally, it outlines the major assumptions made in each scenario.

4.2.1 Overview of the TIMES_PT model

TIMES_PT is a peer-reviewed linear optimisation bottom-up technology model generated with the TIMES[38] model generator, developed by the ETSAP[39] of the International Energy Agency. The generic model structure can be adapted to simulate a particular energy system, which may be local, national or multiregional. The ultimate objective of a TIMES model is to satisfy the energy services demand at minimum system cost, by deciding on equipment investment and operation, primary energy supply and energy trade. More information on the development and equations of TIMES can be found in Loulou et al. (2005a and 2005b).

TIMES_PT represents the Portuguese energy system from 2000 to 2030. The model considers both the supply and demand sides, as it disaggregates the following sectors: primary energy supply; electricity generation; industry; residential; commercial; agriculture and transport. Energy, materials and emission flows, energy demand and supply technologies are modelled in detail, including costs. The model is supported by the following exogenous inputs: (1) *end-use energy services and materials demands*, such as residential lighting, machine driving 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 or energy taxes. The model finds the optimum combination of energy supply and demand technologies to satisfy the demand, i.e. the model designs an energy

[38] Acronym for The Integrated MARKAL-EFOM system. TIMES is the successor of two older ETSAP bottom-up energy models: Markal - MARKet Allocation Model and EFOM - Energy Flow Optimisation Model, developed in the 1980s.

[39] Energy Technology Systems Analysis Programme

system with the lowest possible total costs. The main outputs include the installed capacity of the different energy supply and demand technologies, the GHG emissions, primary and final energy and material flows, final energy prices and overall system costs. More information on the details of the TIMES_PT model and its exogenous technology database can be found in Simões et al. (2008). The other exogenous inputs are detailed in the following sections and Appendix 1.

The TIMES_PT model deals exclusively with emissions from combustion and production processes, which accounted for approximately for 79% of national emissions in 2009 (APA 2011), so GHG emissions from solvents use, non-combustion agricultural activities, waste management, and F-gases are not considered in the model. For the purpose of verifying compliance with 2020 GHG targets which include non-energy emissions outside of TIMES_PT, we used the Portuguese emission estimates from Seixas et al. (2008).

It should be noted that TIMES_PT is a partial equilibrium model and does not model the economic interactions outside of the energy sector. Furthermore, it does not consider in detail the demand curves and non-rational aspects that condition investment in new, more efficient technologies, such as preferences motivated by aesthetics or social status. In fact, the model assumes that stakeholders are rational and have perfect market foresight, and that decisions rely purely on cost-effectiveness. Thus, some of the most important barriers to energy efficiency and a shift towards renewables use in industry and buildings are not inherently present in the model. These barriers were exogenously introduced, as described in the section detailing the scenarios we studied. Finally, the model uses a homogeneous real discount rate of 4% not differentiated between sectors. This deviates from the discount rates commonly used per sector in other TIMES modelling exercises (e.g. in EU projects such as RES2020[40] and RealiseGRID[41], where 8.2% is used for large-scale power and steam generation in 2005 and 9% for 2015-2030; 12% for industry, services and agriculture; 17.5% for households and 4-5% for the social discount).

[40] http://www.ecn.nl/nl/units/ps/themas/hernieuwbare-energie/projecten/res2020/

[41] http://realisegrid.rse-web.it/

Therefore, our perspective is not a commercial analysis but a social one, from a national welfare point of view. The TIMES_PT model has been used extensively for research (Simões et al. 2008) and policy support studies (Seixas et al. 2008; Seixas et al. 2010), in close collaboration with public and private energy and industry stakeholders.

4.2.2 Socio-economic scenarios and energy and materials demand projections for 2020

Since the demand projections are crucial, as they drive the whole energy system modelled in TIMES_PT, we first provide a short explanation of the projection methodology we used. The socio-economic scenarios and their respective projections for materials and energy services demand as considered in this paper were generated within the study entitled “PortugalClima2020 - Impact evaluation of the EC climate and energy package in Portugal” for the Portuguese Ministry of Environment (Seixas et al. 2008). The PortugalClima2020 project involved building two different socio-economic scenarios (and their respective demand projections): Tendency and Change. The first assumes a moderate economic and demographic growth, whereas the latter assumes a higher economic growth and an economic shift towards innovation and technology (Ribeiro et al. 2008a). For the purpose of this paper, only the Tendency scenario was considered, since its main objective is to assess how a “business-as-usual” evolution can benefit from end-use energy efficiency and renewable applications. The main socio-economic drivers of the Tendency scenario are summarised in Table 4.1. In the current context of economic crisis, the growth rate for 2011-2015 might seem unrealistic, but we would like to point out that 1.9% is an average growth rate for that five-year period. This average figure may include a recession in 2012 followed by a recovery period until 2015. Moreover, even if the figures were adapted to recent economic changes, they would still involve considerable uncertainty, as the economic growth estimates for Portugal are constantly being revised. Thus, we decided to keep the numbers that have been substantiated for the longer term, and indicate that the dates mentioned might shift to a few years later due to the economic crisis.

The above macro-economic drivers were used to derive a detailed materials and energy services demand for 2020 which is described in detail in Fortes et al. 2008. The demand projections were developed using a bottom-up approach for buildings and a top-down approach for the industry and transport sectors. For the *residential and commercial sectors*, detailed assumptions were made about, among other things, the stock of existing and new buildings; the evolution of occupancy rate; the average building area; the evolution of heating and cooling comfort requirements per m2 and the evolution of per capita useful energy requirements for cooking and sanitary hot water. The assumptions consider past statistics and forecasts about population growth, private consumption and planned tourist industry developments as described in the socio-economic scenarios. The demand for energy services for the residential sector has been disaggregated for single urban houses, single rural houses and apartments, and considers two climatic regions, the south and the north of Portugal. For the *industry and transport sectors*, a relationship was assumed between the final demand for energy-intensive materials (steel, paper, glass, cement, lime, ammonia and chlorine), transport and other energy services required for the industry, and the evolution of the sector's gross added value (GAV). This relationship includes the effect of a price evolution factor, income and price elasticity of final demand on 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 and demand projections were validated through an extensive stakeholder consultation process during 2008 and 2009.

Table 4.1. Main macro-economic drivers until 2020

Annual average growth rate %	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
GDP	0.8%	1.7%	1.9%	2.1%
Private consumption	1.5%	1.5%	1.8%	2.0%
Population	0.6%	0.1%	-0.1%	-0.2%
Gross Added Value				
Agriculture	-0.7%	2.0%	0.5%	1.0%
Industry	-0.9%	1.2%	1.5%	1.6%
Transports	2.0%	1.9%	2.4%	2.8%
Commercial	1.6%	1.0%	1.2%	1.3%

The final demand projections are differentiated across sectors as follows (Figure 4.1):

- Industry: (i) quantities of iron and steel, paper, glass, cement, ammonia and chlorine and (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 transport by road, railway, aviation and navigation, expressed in pkm (passenger.kilometres) and tkm (tonne.kilometres)

The overall trend is an increase up to 2020 of more than 30% of 2000 values for all demand categories, except cement and other industry. For example, in the residential and commercial sectors useful energy for heating in 2020 will increase by approximately 61% relative to 2000 values, cooling by 35%, and water heating by 67%. In the industry sector, steel demand will increase by 270%, cement by 7%, glass by 81% and paper by 55%. Passenger kilometres will increase by 56%, whereas tonne kilometres will increase by 64%.

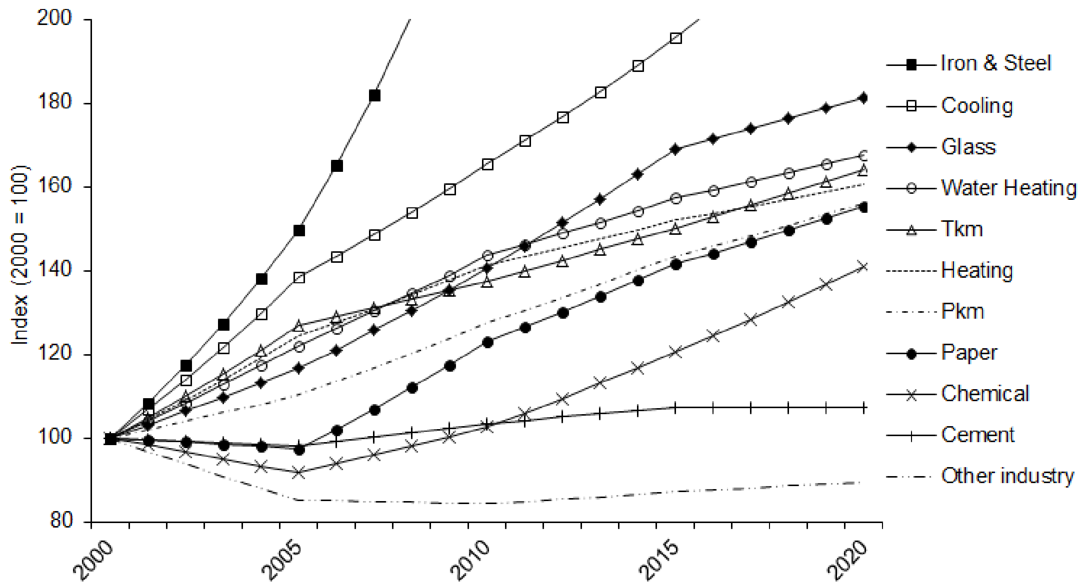

Figure 4.1. Evolution of the demand for materials and energy services. For the sake of simplicity, the demand for ammonia and chlorine was aggregated into "Chemical"; the demand for ceramics was aggregated with "Other industry" and from the useful energy demand of buildings we only depict here the demand for space heating and cooling.

4.2.3 Present and future sources of primary energy supply

The average *primary energy import price* projections (Table 4.2) were adopted from the Reference scenario of the PRIMES and GEM-E3 models used by the EC in preparing its energy–climate policy package (Russ et al. 2007). The oil price vectors were generated by the global POLES[42] model, using scenarios for available oil, new oil reserves that might be discovered and the supply and demand laws. The corresponding gas and coal prices were estimated by Seixas et al. (2008) taking into account the annual relationship between oil and other fossil fuels assumed by the IEA in the Reference scenario of the World Energy Outlook (WEA) 2007 (IEA 2007). It should be noted that these prices do not consider the effects of extreme situations, such

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

as oil price peaks due to political instability or natural catastrophes. Moreover, the most recent values from WEA 2011 are substantially higher, which might have a significant effect on the results, making both renewables and savings more attractive. In view of this, we performed a sensitivity analysis, which is discussed in section 4.3.4, which however yielded no significant differences in results.

Table 4.2. Average primary energy import prices

Year	Oil ($2007/bbl)	Natural Gas ($2007/m3)	Coal ($2007/ton)
2000	35,84	0,21	35,25
2005	57,15	0,27	65,82
2010	53,53	0,22	50,85
2015	56,08	0,24	55,68
2020	58,75	0,25	58,21

The specification of *national primary energy potentials* - essentially renewable resources such as hydro power, solar and wind energy, biomass and biofuels - was based on several national studies and expert opinion (Appendix). It should be stressed that there is a large uncertainty, due to the lack of data for some cases.

4.2.4 Scenarios for quantifying interactions between specific energy supply and demand-side options

The four scenarios we examined were designed to integrate the two major fields of energy policy studied in this paper: promotion of renewable energy, especially in electricity generation, and promotion of end-use energy efficiency, as well as options for CCGT technology activity levels (see also Table 4.3):

- **CUR** involves (i) a moderate target for RES electricity capacity and biofuels use (10.42 GW renewable electricity in 2020, 5.75% biofuels), (ii) a minimum annual activity level for new CCGT (37%) and (iii) a ceiling for deployment of end-use efficient appliances and small-scale RES as in the NEEAP targets, such as insulation applied to a maximum of 8% of existing residential buildings. This scenario more or less represents current energy policy objectives.

- **DEM** involves (i) a moderate target for RES electricity capacity and biofuels use (10.42 GW renewable electricity in 2020, 5.75% biofuels), (ii) no minimum new CCGT activity level and (iii) no maximum deployment of end-use efficient appliances and small-scale RES. This means that the deployment level of such equipments is decided by TIMES_PT based on their cost-effectiveness. This scenario represents a greater policy focus on promotion of end-use small-scale renewables and energy-efficient technologies for buildings and industry, i.e. the demand side of the energy system.

- **SUP** involves: (i) a high target for RES electricity capacity and biofuels use (13.43 GW renewable electricity in 2020, 10% biofuels), (ii) a minimum annual activity level for new CCGT (37%) and (iii) a ceiling for deployment of end-use efficient appliances and small-scale RES based on the NEEAP targets. This scenario represents a greater focus on the supply side of the energy system, particularly regarding investment in large renewable technologies for electricity generation.

- **S&D** involves (i) a high target for RES electricity capacity and biofuels use (13.43 GW renewable electricity in 2020, 10% biofuels), (ii) no minimum new CCGT activity level and (iii) no ceiling for the deployment of end-use efficient appliances and small-scale RES (TIMES_PT model is free to optimise). The S&D scenario thus represents a simultaneous focus on the supply and demand sides of the energy system.

Regarding the **promotion of renewable energy**, the major difference between the CUR and SUP scenarios is the share of renewable energy sources (RES) in electricity generation and in biofuels consumption in transports. The CUR scenario includes (i) the *mandatory target set by the European Biofuels Directive* from 2003 (Directive 2003/30/EC), requiring a biofuels consumption of 5.75% of petrol and diesel use for transport in 2010, which is extended to 2020 and (ii) *current and in-the-pipeline investments* in renewable energy supply infrastructures to achieve the indicative target of 39% of electricity from renewable energy sources (RES-e) for gross electricity consumption by 2010, following the European RES electricity Directive from 2001 (Directive 2007/71/EC). The SUP scenario includes the more ambitious *national target of a biofuels* consumption of 10% of petrol and diesel use for transport in 2010 (extended to 2020) and the *expected but not yet* *implemented* investments in renewable energy supply infrastructures to achieve the indicative target of 45% RES-e for 2010, according to national policy commitments (RCM 1/2008; INAG, DGEG 2010; MEI, 2007a; MEI 2007b).

As mentioned, lack of information and the need for simplification induced us to translate some policy measures into their intended/expected effect in the model. Thus, we modelled lower bounds reflecting minimum installed capacity of RES-e technologies, as expected by policy objectives for 2010 to 2020 (DGEG 2010; MEI 2007a), instead of modelling in detail the existing policy incentives (e.g. feed-in tariffs and tendering procedures) that make investment in and operation of such technologies competitive. In the CUR and DEM scenarios, conservative estimates for 2020 were made, based on the 2007 installed capacity, on issued permits, and assuming a growth rate similar to that verified in 2000-2007 for the cases of non-CHP biomass, PV systems and biogas power plants.

In view of the existing feed-in tariff mechanisms, which we assumed to remain in place until 2020, we assumed that all RES-e technologies operate at their maximum technical capacity, according to specific availability factors (AF) that account for seasonal effects and technological specificities. Also, reflecting the current energy policies, which include incentives for CCGT (Portaria 765/2010), the authorised investments for new 3.20 GW CCGT were considered to have been implemented in all scenarios. Half of this installed capacity is currently being built, so in the CUR and SUP scenarios, 1.6 GW of new CCGT was assumed to function at least at 37% of its capacity, which is the minimum activity threshold to justify investment in such plants, based on information supplied by the DGEG. In the DEM and S&D scenarios, the new CCGT are installed but are not forced to operate, since the objective is to assess to what extent demand-side measures can reduce the need for electricity generation. Note that this approach means that no national RES-e target was implemented in any of the scenarios. Instead, our goal was to assess what level of RES-e can be achieved with the planned investment and policies.

Regarding the **promotion of end-use energy efficiency and small-scale renewable equipments**, both CUR and SUP scenarios use the same upper bounds reflecting the limited penetration of new equipments for residential, commercial and industry uses, based on 2000-2005 trends and on the estimated evolution until 2015 (assumed to be maintained until 2020) as stated in the NEEAP (RCM 80/2008). The transport sector is not analysed here. The DEM and S&D scenarios are identical to the CUR and SUP scenarios, respectively, but *do not involve any limits on the degree of penetration of end-use efficient and renewable equipments*. In these two scenarios, the TIMES_PT model is allowed to deploy these types of equipments in accordance with cost-effectiveness criteria. Thus, DEM and S&D reflect the maximum gains obtained by the full realisation of the national demand-side technological potential for the specific technological options studied in this paper. Therefore, this paper only addresses savings resulting from technological replacement and does not assess energy savings resulting from reduced demand for energy services, such as reduced thermal comfort requirements motivated by environmental awareness.

As mentioned above, TIMES_PT is an optimisation model with the ultimate objective of cost reduction. Thus, the model does not consider barriers to the penetration of cost-saving new equipments, such as resistance to change, imperfect information, and aesthetics or other subjective preferences. In order to reflect these "realistic" constraints, the CUR and SUP scenarios consider exogenous inertia factors that delay the penetration rate of new technologies and fuels in the residential, commercial and industry sectors. These factors were defined, based on past trends, for the replacement of existing lighting and other electric appliances, for penetration of insulation, and for replacement of existing biomass, LPG and diesel technologies for cooking, space heating and water heating by new, more efficient alternatives using the same fuels. The main differences in the scenarios regarding renewable energy and efficient equipments are presented in Table 4.3.

- Finally, all scenarios include the following assumptions reflecting the most relevant Portuguese energy policies in place:
- A ban on nuclear power due to the political unacceptability of this option in the modelled time horizon.
- "Conventional" coal power plants without CO_2 capture and sequestration are assumed not to be implemented from 2015 onwards, following expected GHG control policies.

- Taxes on oil products, differentiated according to energy carriers, are included.

- Power trade under the liberalised Iberian electricity market is not considered in the modelling exercise. Estimates of upper limits were used for 2000 to 2020, up to a maximum import and export of 46 and 20 PJ in 2020, respectively. The estimates are in line with the national transmission operator studies (REN, 2008), and correspond to a growth of 255% for imports and 121% for exports.

Table 4.3. Major differences between scenarios for 2020 used as exogenous inputs into the TIMES_PT model. The RES-e installed capacity for the CUR/DEM scenario reflects current and in-the-pipeline investments, whereas for SUP/S&D these values are taken from national policy commitments as stated in the 2010 NREAP.

Measure/Scenario	Unit	2010	CUR	DEM	SUP	S&D
Biofuel consumption target	% consumption of gasoline and diesel for transport	Gasoline: 0.0% & Diesel: 0.08%[a]	5.75%		10%	
Underlying implicit RES-e target – not implemented in the model	% RES-e in gross electricity consumption	52%[b]	39%		45%	
RES-e installed capacity	GW	9.41	10.42 (ongoing investments)		13.43 (national policies)	
Hydro	*GW*	*4.84*	*5.58*		*6.86*	
Wind-onshore	*GW*	*3.87*	*4.50*		*5.70*	
Biogas	*GW*	*0.01*	*0.05*		*0.10*	
Solar	*GW*	*0.13*[c]	*0.10*		*0.15*	
Waste	*GW*	*0.09*	*0.12*		*0.12*	
Biomass (non-CHP)	*GW*	*0.11*[c]	*0.05*		*0.25*	
Waves	*GW*	*0.00*	*0.03*		*0.25*	
CCGT installed capacity	GW	3.04	4.38 (3.2 new)			
Minimum new CCGT activity level	% of capacity	34%[d]	37%	n.a.	37%	n.a.
Maximum solar thermal water heating (part of scRES)	% of households	n.a.	8%[e]	–	8%[e]	–
	% of commercial building area	n.a.	1.2%[e]	–	1.2%[e]	–
Maximum heat pumps and efficient biomass heating (part of scRES)	% of households and of commercial building area	n.a.	8%[e]	–	8%[e]	–
Maximum insulation in existing buildings	% of households and of commercial building area	n.a.	9%[e]	50%	9%[e]	50%

Measure/Scenario	Unit	2010	CUR	DEM	SUP	S&D
Maximum double-glazed windows in existing buildings	% of households and of commercial building area	n.a.	18% [e]	50%	18% [e]	50%
Maximum efficient lighting (CFL)	% of efficient lamps in total lighting	15%	61% [e]	–	61% [e]	–
Maximum efficient refrigeration (A+ and A++)	% efficient freezers and refrigerators	1% freezers 8% refrigerators	37% freezers 25% refrigerators [e]	–	37% freezers [e] 25% refrigerators [e]	–
Maximum efficient dishwashers and cloth washing appliances (A+ and A++)	% efficient dishwashers and cloth washing machines	1%	25% [e]	–	25% [e]	–

n.a. – not available; [a] values for 2009; [b] 2010 was a wet year, hence the 52% value. In dry years this percentage can be 17% (as in 2005); [c] for solar and biomass, the ongoing investments at the time when the results were generated totalled 0.10 GW and 0.05 GW for 2020, respectively, which were the minimum capacities introduced in the model. However, the most recent data for 2010 (available in 2011) show that the figure was exceeded in 2011; [d] values for 2005; [e] Portuguese NEEAP objectives for 2015, assumed identical for 2020

4.3 Results and discussion

This section outlines the differences between the four scenarios regarding the effects of end-use energy-efficiency and renewable applications in terms of (i) avoided electricity generation in terms of installed capacity and costs, (ii) final energy consumption, (iii) share of renewables in final energy and (iv) reduction of GHG emissions.

4.3.1 Avoided electricity generation installed capacity and costs in 2020

Most of the installed capacity for electricity generation in the four scenarios was pre-defined, as explained in the previous section, in order to integrate the existing policy incentives for renewable electricity and the new CCGT plants. Thus, installed fossil power capacity for gas, coal and oil is the same in all scenarios (Table 4.4). In SUP and S&D, the hydro, wind and other renewables capacities are higher than in CUR since they replicate model inputs reflecting major investments on the supply side, particularly on RES-e (Table 4.3). In all scenarios there is an increase in total installed capacity by 2020 of at least 49% of 2005 values, and existing oil power plants are replaced by RES, especially hydro and wind, and to some extent by gas (CCGT).

The design of the scenarios makes it impossible to directly derive from Table 4.4 the reductions in installed capacity due to end-use energy efficiency. However, the activity level of the installed capacity varies, depending on the interactions between energy supply options such as (i) investing in large RES-e plants (in SUP and S&D) and (ii) forcing operation of new CCGT plants (in CUR and SUP), and between higher level of demand options (in DEM and S&D). This can be assessed by looking at the estimated operation times for the aggregated power generation technologies in Table 4.4, particularly for gas. Our assessment of avoided capacity focuses on gas, as for other electricity generation plants, the difference between the estimated operation time and the availability factors (AF) derived from the literature is always below 30 percentage points, whereas for gas it is 52 to 68 percentage points.

Table 4.4. Installed capacity for electricity generation (GW) in 2005 and 2020, estimated operation time (%) and literature availability factor (%) in 2020

		Installed capacity in 2020 (GW)				Estimated operation time in 2020 [b] (%)				Maximum literature availability factor [b] (%)
			Difference from CUR[a]							
	2005	**CUR**	**DEM**	**SUP**	**S&D**	**CUR**	**DEM**	**SUP**	**S&D**	
Gas (non CHP)	2.17	5.37	0.00	0.00	0.00	33	26	30	16	85
Coal (non CHP)	1.78	1.78	0.00	0.00	0.00	89	89	89	89	90
Oil (non CHP)	3.06	0.40	0.00	0.00	0.00	8	8	8	8	26 [c]
Hydro	4.75	5.58	0.00	1.28	1.28	33	33	33	33	43-46
Wind	1.05	4.61	1.42	1.09	1.09	27	27	27	27	28-29
Other Renewables	0.12	0.64	0.00	0.60	0.60	57	57	50	50	59-51
CHP[d]	1.11	1.62	0.10	-0.28	0.08	57	56	41	54	72-75
TOTAL	**14.04**	**20.00**	**1.52**	**2.68**	**3.04**					

[a] Positive values represent higher values than in the CUR scenario. [b] The availability factor (AF) indicates the percentage of the year in which the technology is functional (i.e. without required maintenance stops and/or stoppage due to low availability of variable RES). This parameter is a model input (maximum AF from the literature) that can be directly compared with the estimated operation time from model outputs (also represented here as a percentage of the year). The maximum literature-derived AF is the model input specific for each particular electricity generation technology, as found in the literature. Since, for the sake of simplicity, we have grouped electricity generation technologies according to energy carrier in this table, the theoretical AF is in some cases shown as a range in the table. The estimated operation time is computed using the model outputs of installed capacity and generated electricity in each scenario, and the "literature" AF. Thus the literature-derived AF is the maximum at which a technology can operate and not necessarily identical to its optimal deployment as identified by the model. [c] This very low AF for oil power plants differs from technical data for new oil power plants because this is applicable only to plants already in existence in 2000, which typically operate at a low capacity. The plants are assumed to continue to do so until 2020 for security of supply reasons, since they are situated in the remote

Azores and Madeira Islands. [d] The CHP installed capacity in 2005 was approximately 21% natural gas; 54% heavy fuel oil; 0% biogas and 24% biomass. The corresponding figures for 2020 are approximately 27-46% natural gas; 35-45% heavy fuel oil; 3-7% biogas and 10-30% biomass.

The maximum literature-derived AF for gas-fuelled CCGT power plants is typically 85%. Nonetheless, the installed power plants (both new CCGT and older) never operate above 33% and are much lower in the DEM and S&D scenarios, which have higher end-use energy efficiency and no forced new CCGT activity. This low use of installed capacity in the four scenarios was translated into avoided or "not in use" capacity. We estimated what gas capacity would be required to generate the TWh in Table 4.5 if the plants operated at 85% capacity (the maximum literature-derived AF) and subtracted this from the installed capacity generated by the model. This resulted in an avoided capacity in 2020 of 3.63 GW in both CUR and SUP (forced new CCGT activity and moderate level of energy efficiency measures). With more aggressive end-use energy efficiency measures on the demand side, and not forcing CCGT activity, the avoided gas capacity in 2020 could rise further to 4.20-4.84 GW in the DEM and S&D scenarios, respectively. In terms of investment costs in gas CCGT, this would represent savings of 1595 to 2129 Meuros_{2000}[43], roughly.

In terms of electricity generated from gas (Table 4.5), operating times ranging from 16-33% correspond roughly to less than 4.28-9.00 TWh in 2020, respectively, for DEM and S&D when compared to CUR and SUP. Although we have so far focussed on gas, we must mention that although these savings can be achieved for this energy carrier, the fact that gas power plants operate suboptimally in DEM and S&D is not entirely due to excess overall capacity of the power sector, but also to higher cost-effectiveness of other power plants. Thus, the savings of electricity generated from gas do not directly lead to identical reductions of total generated electricity (only 0.56-5.79 TWh). In both DEM and S&D, it is cheaper to compensate the lower activity level of gas-fuelled CCGT by installing new onshore wind and CHP to satisfy the increased demand for energy services (despite the more aggressive technology substitution on the demand side). In DEM, an additional 1.42 GW of new onshore wind power and an additional 0.10 GW of gas-fuelled CHP are installed, compared to CUR, whereas in S&D only an additional 0.08 GW

[43] Assuming investment costs of 440 Meuros 2000/GW in 2020 for the new gas-fuelled CCGT power plants. These costs were validated in 2008 and 2010 with Portuguese electricity companies and TSO.

of CHP is installed (Table 4.4). It should be noted that in both the SUP and S&D scenarios, the extra 1.09 GW of wind power compared to CUR was forced, in order to comply with the higher RES-e target for wind (i.e. GW pre-defined as a model input as in Table 4.3) and is not due to competitiveness. By contrast, the extra wind power in the DEM scenario is simply more cost-effective. This is detailed below, with an estimate of electricity generation costs (Table 4.6).

Table 4.5. Generated electricity per energy carrier (TWh) in 2005 and 2020 and difference in TWh due to implementation of end-use energy efficiency measures between DEM and CUR and S&D and SUP scenarios (both DEM and CUR have moderate level of RES-e whereas S&D and SUP have higher RES-e level)

		2020					
TWh	**2005**	**CUR**	**DEM**	**SUP**	**S&D**	**DEM-CUR**	**S&D-SUP**
Gas (non CHP)	11.49	12.90	8.62	12.90	3.90	-4.28	-9.00
Coal (non CHP)	14.29	13.82	13.82	13.82	13.82	0.00	0.00
Oil (non CHP)	6.24	0.30	0.30	0.30	0.30	0.00	0.00
Hydro	5.00	16.13	16.13	19.91	19.91	0.00	0.00
Wind	1.74	11.07	14.49	13.68	13.68	3.42	0.00
Other Renewables	0.72	1.63	1.63	3.80	3.80	-0.01	0.00
CHP	4.43	8.11	8.42	4.85	8.06	0.31	3.21
TOTAL	**43.90**	**63.96**	**63.40**	**69.26**	**63.47**	**-0.56**	**-5.79**

Table 4.6 presents an overview of the more relevant input parameters used in TIMES_PT to estimate the costs of electricity generated by the new CCGT, new onshore wind turbines and new hydro plants, as well as the estimated electricity costs. For the sake of validation, we have included, where possible, similar data from the SETIS Energy Calculator (SETIS 2011). Although the size of the technologies is not exactly the same, it is fairly similar and there seems to be a relatively good compatibility between TIMES_PT and SETIS input parameters and electricity costs, particularly regarding the ratio between the total costs of electricity generated by gas and hydro/wind. Wind-generated electricity comes cheaper than CCGT, mostly due to the high gas costs (Table 4.6). Whereas in TIMES_PT, the total cost of electricity generated by a CCGT in 2020 is approximately 50.75 $€_{2000}$/MWh, that of wind-generated electricity is only 42.79 $€_{2000}$/MWh. It can be argued that the total costs of electricity generated by gas and wind from TIMES_PT should

not be compared, because investing in new gas CCGT was forced as an exogenous model assumption (Table 4.3). We therefore also present electricity costs without investment costs in 2020: 46.97 $€_{2000}$/MWh for gas and 13.39 $€_{2000}$/MWh for wind. Electricity generated from installed CCGT in 2020 will cost 46.97 $€_{2000}$/MWh (without investment costs) whereas electricity generated from new onshore wind turbines (including investment costs) will still be cheaper (42.79 $€_{2000}$/MWh).

It appears that energy efficiency measures on the demand side (replacing equipments by more efficient and renewable-based ones in buildings and transport) make the new CCGT plants non-competitive in the Portuguese energy system. If CCGT electricity prices are competitive enough in the Iberian electricity market, there will be an interest in operating these plants for export. However, according to the national transmission operator (REN), the current expectations are for zero net import in 2020, as massive electricity generation investments are also being made in Spain.

Regarding avoided costs, we have estimated avoidedcosts corresponding to the avoided CCGT capacity of 4.20-4.84 GW in the DEM and S&D scenarios, respectively (1595 to 2129 Meuros_{2000} gas investment costs for DEM and S&D). To obtain a more complete picture, however, it is also necessary to consider the investment for the extra 1.42 GW onshore wind power in the DEM scenario compared to CUR, as discussed above. For this we roughly estimate a cost of 1395 Meuros_{2000} for wind investments, using the 2020 investment cost for wind for TIMES_PT in Table 4.6. To obtain a more correct avoided costs figure, we subtract the investment costs for this extra wind power from the avoided costs for gas CCGT estimated for the DEM scenario. Thus, the final cost savings figure based on more aggressive end-use energy efficiency measures and removal of antagonistic policy support to the supply side of the energy system[44] is 454 to 2129 Meuros_{2000} for the DEM and S&D scenarios, respectively. To give a rough idea of the order of magnitude of these amounts we point out that these savings correspond to approximately 0.34% and 1.57% of the 2010 Portuguese GDP. It is important to note that

[44] Strictly speaking, the operation and maintenance costs of the onshore wind plants should also be considered here, but since these represent a minor fraction of the total electricity cost (1% of investment for fixed costs) they were left out for the sake of simplicity.

these costs savings relate only to the electricity generation sector. In section 4.3.3 we discuss total system cost implications.

4.3.2 Impact of end-use energy efficiency on final energy consumption and share of renewables

The introduction of more aggressive technology substitution on the demand side (DEM and S&D) leads to a decrease in 2020 final energy consumption in commercial buildings and in industry (Table 4.7). The demand for energy services is identical in all scenarios, but when no upper bound is set for the technology replacement in the industry and buildings, it is possible to satisfy the demand using less final energy (except for the residential sector). Although this reduction in final energy consumption is marginal for industry and does not occur for the residential sector, it is relevant for commercial buildings, whose final energy consumption falls by 11%-14% respectively, in the DEM and S&D scenarios, relative to the CUR and SUP scenarios. In terms of total figures for the three sectors we studied, the reduction in final energy consumption is counteracted by the increased final energy consumption in the residential sector (13% more in DEM than in CUR and 11% more in S&D than in SUP) due to increased deployment of solar and biomass power for heating and cooling, which were in fact considered in this exercise as end-use energy efficiency measures (see Table 4.3). The SUP scenario has the highest electricity consumption, since it involves a higher capacity of renewable electricity power plants and a minimum CCGT activity level combined with limited possibilities for demand-side specific technologies substitution. Because the CCGT plants' capacity and activity are forced in SUP, their investment costs are not accounted for in the model's solution, causing electricity to be cheaper in SUP than in CUR (with less RES electricity). The upper bound on demand-side technology substitution does not allow for electrical appliances to be extensively replaced by biomass and solar thermal devices as in DEM and S&D.

Table 4.6. Comparison of model input parameters and estimated electricity costs between TIMES_PT and SETIS Energy Calculator for CCGT gas, hydro and onshore wind

		CCGT GAS				**Hydro**				**Wind onshore**			
		TIMES_PT		**SETIS**		**TIMES_PT**		**SETIS**		**TIMES_PT**		**SETIS**	
	Unit	**2010**	**2020**	**2007**	**2020**	**2010**	**2020**	**2007**	**2020**	**2010**	**2020**	**2007**	**2020**
Input parameters													
Net capacity	MW	400		645		50		75		1.5		2	
Lifetime	years	25		25		80		50		20		22	
Availability factor	%.	85		85		44		38		28		23	
Efficiency	n.a.	0.59		0.63		n.a.				n.a.			
Investment costs	€$_{2000}$/ kW	440		504	484	3500		1473	1457	1000	980	928	749
Variable O&M costs	€$_{2000}$/GJ	0.19	0.19	0.00	0.00	0.00	0.00	n.a.	n.a.	2.36	2.36	0.00	0.00
Fixed O&M costs	% of inv. costs	4	4	3	3	1	1	2	2	1	1	2.1	2.1
Fuel costs	€$_{2000}$/GJ	6.5	6.0	4.8	5.8	n.a.				n.a.			
Estimated electricity costs													
Total	€$_{2000}$/ MWh	54.86	50.75	51.46	53.34	36.41	49.64	32.13	31.89	43.39	42.79	34.84	43.12
Without investment costs	€$_{2000}$/ MWh	51.07	46.97	46.69	48.75	8.56	11.67	11.59	11.52	13.39	13.39	7.46	9.24
Ratio full electricity cost gas/renewable		n.a.				1.51	1.39	1.71	1.59	1.51	1.02	1.71	1.59

Notes: n.a. – not applicable; For the comparison with the SETIS Energy Calculator, we have used the same assumptions used in the TIMES_PT modelling exercise, where possible. Thus, in SETIS we used the Low Price scenario from DG TREN, a 4% nominal discount rate and a project lifetime of 25 years, and did not make any other assumptions about interest rates, inflation, escalation rate and learning effect. Although SETIS has net efficiencies for hydro and wind power, we did not compare them with TIMES_PT, since this parameter is not represented in the same way in the TIMES_PT model.

In DEM and S&D, the main technology substitutions in *industry* are more efficient clinker and ceramic kilns and cement mills, more efficient ammonia production technologies, and more new CHP and renewables equipments for process heat in all industry sub-sectors. In the case of the *commercial and residential* sectors, as expected, there is almost complete substitution of electric appliances and of space-heating, water-heating and cooling technologies by more efficient and renewable-based ones, especially insulation, biomass boilers, heat pumps and solar thermal systems. In the particular case of residential buildings, the installed heat pumps have an LPG and gas backup which leads to increased consumption of fossil fuels (by an additional 25 to 73%) compared to CUR and SUP. The model's technology database also includes alternative heat pumps with electrical backup, but these are costlier than the ones backed up by fossil fuels (investment cost for the former in apartment buildings is 730 $€_{2000}$/kW, while it ranges from 429-541 $€_{2000}$/kW for the fossil ones. The references for these technologies are the ones in the technology database used in the NEEDS EU project, including several sources, from manufacturers to the EFDA model[45]).

None of the four scenarios achieves the 2020 target of 31% share of RES in total final energy consumption, as defined in the EC "Climate action and renewable energy package" (Table 4.8). The positive effect of the more aggressive demand-side measures is slight (three percentage points increase from CUR to DEM and two percentage points increase from SUP to S&D) but still relevant for target compliance. Since both CUR/DEM and SUP/S&D have the same amount of installed large RES supply technologies, this difference is due to more efficient appliances and small-scale RES technologies, combined with not forcing the activity of new CCGT power plants. In both DEM and S&D, this leads to a decrease in the contribution of renewable electricity to the overall target, which is compensated by the increase in renewable heating and cooling.

The difference between the CUR and DEM scenarios in the relative contributions of electricity and heating and cooling to final renewable energy

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[45] More information on the NEEDS project can be found at http://www.needs-project.org/. EFDA is the European Fusion Development Agreement. More information on EFDA can be found at: http://www.efda.org/fusion/.

use is marginal (1%) (see Table 4.8) because the consumption of RES in industry is actually reduced by the introduction of more efficient equipments and unforced CCGT. In DEM, these same more efficient equipments make the limited amounts of available biomass more competitive for buildings than for industry. By contrast, in the scenarios with higher RES-e installed capacity (SUP/S&D), not forcing the new CCGT and allowing for more options on the demand side increases the consumption of biomass in industry. Although biomass consumption in buildings also increases in S&D, this increase is smaller than in DEM, as more solar thermal energy is consumed in that scenario (Table 4.7). This difference in RES deployment structure between DEM and S&D is due to the fact that the latter is more energy efficient, that is, it requires less final energy is required &D in buildings and industry to satisfy the identical demand for energy services in 2020.

Table 4.7. Final energy consumption in 2005 and 2020 in PJ in buildings and industry

		PJ						% variation	
	2005	CUR	DEM	SUP	S&D	DEM-CUR [a]	S&D-SUP [a]	DEM/CUR	S&D/SUP
Industry									
Fossil fuels	108.7	125.3	126.6	139.2	127.8	1.3	-11.4	1%	-8%
Electricity	55.7	61.9	66.7	70.4	66.8	4.9	-3.7	8%	-5%
Biomass	23.3	20.7	8.8	2.7	8.8	-11.8	6.1	-57%	227%
Other renewables & heat	47.7	12.3	16.6	11.3	16.1	4.2	4.8	34%	42%
Total Industry	235.3	220.1	218.7	223.7	219.6	-1.4	-4.1	-1%	-2%
Industry/Total (%)	*50%*	*46%*	*45%*	*47%*	*47%*				
Commercial									
Fossil fuels	49.6	35.2	13.8	35.2	11.7	-21.4	-23.5	-61%	-67%
Electricity	54.3	82.2	83.0	82.2	83.0	0.8	0.8	1%	1%
Biomass	0.0	0.0	2.5	0.0	1.6	2.5	1.6	100%	100%
Other renewables & heat [b]	0.5	1.4	5.9	1.3	5.9	4.6	4.7	334%	372%
Total Commercial	104.4	118.8	105.2	118.7	102.2	-13.6	-16.4	-11%	-14%
Commercial/Total (%)	*22%*	*25%*	*22%*	*25%*	*22%*				
Residential									
Fossil fuels	38.4	34.1	42.8	31.2	54.1	8.7	22.9	25%	73%
Electricity	47.7	72.4	64.7	80.0	64.7	-7.7	-15.3	-11%	-19%
Biomass	48.8	23.0	38.7	11.8	16.7	15.7	4.9	68%	41%
Other renewables & heat [b]	0.1	10.9	12.3	11.0	13.0	1.4	2.0	13%	18%
Total Residential	134.9	140.3	158.4	134.0	148.5	18.1	14.5	13%	11%
Residential/Total (%)	*28%*	*29%*	*33%*	*28%*	*32%*				
TOTAL (Industry & buildings)	474.6	479.3	482.4	476.4	470.3	3.10	-6.09	1%	-1%

[a] Positive values represent higher values than in CUR/SUP scenarios.

Table 4.8. RES share of final national energy consumption in 2020 and weight of each energy carrier and sector in final renewable energy

RES Energy Consumption (PJ)	2020 renewable final energy consumption (PJ)				% over final renewable energy			
	CUR	**DEM**	**SUP**	**S&D**	**CUR**	**DEM**	**SUP**	**S&D**
Electricity	110	122	142	142	51%	50%	61%	56%
Heating & cooling	91	105	64	86	42%	43%	28%	34%
Residential	34	51	23	30	16%	21%	10%	12%
Commercial	12	17	11	18	5%	7%	5%	7%
Industry	46	37	31	38	21%	15%	13%	15%
Transport	16	16	27	27	7%	6%	12%	11%
Final Renewable Energy	217	243	234	255	-	-	-	-
Total Final Energy (b)	854	856	835	847	-	-	-	-
% Renewables (a/b)	**25%**	**28%**	**28%**	**30%**	-	-	-	-

Although it seems that aggressive energy efficiency measures and demand-side RES alone cannot guarantee compliance with the EU RES target for Portugal, their role in achieving compliance clearly should not be overlooked. This is especially the case for heating and cooling in the residential and commercial sectors, which seems to have been overlooked in the past by policy makers. Finally, it should be pointed out that the NEEAP targets for the residential and commercial sectors modelled in the CUR and SUP scenarios seem to be somewhat modest, in view of the potential of demand-side measures modelled in the two more "end-use efficient" scenarios DEM and S&D.

4.3.3 Impact on greenhouse gases emissions

On the demand side of the energy system, the technology substitution in the residential, commercial and industry sectors in DEM and S&D, including the introduction of more efficient equipments and small-scale renewable-based ones, will lead to an additional reduction of total national GHG emissions by 2020 of 2520 to 2949 GgCO2e, compared with the CUR and SUP scenarios (Table 4.9). These emission reductions are mainly achieved in the commercial sectors (64-68% reduction in DEM and S&D compared to CUR and SUP) and in energy supply (6-8%), with a negligible reduction in the industry sector (0.02-3%). The other sectors are either not included in this analysis (i.e. there is no difference in 2020 emissions between CUR and Dem and SUP and S&D regarding transport) or increase emissions, as in the residential sector.

The residential sector emissions in 2020 in DEM and S&D are 32-73% higher than in the CUR and SUP scenarios, which is due to the fact that in the "end-use efficient" scenarios of DEM and S&D, a larger share of inefficient electric heating is replaced by heat-pumps which require LPG backups, as discussed in section 4.3.2. The reduction of emissions in the commercial sector is mainly due to the replacement of inefficient oil-based heating equipments by insulation, biomass boilers and geothermal heat exchangers. In the energy supply sector, the emission reduction in the DEM scenario compared to CUR is due to the replacement of CCGT power plants by new wind plants. In the S&D scenario, as installed wind capacity is already high, smaller gas-fuelled CHP plants are more competitive than using the full CCGT capacity.

The emission differences are quite significant for meeting the GHG target for Non-EU ETS emissions established in the energy-climate policy package. Whereas in the CUR scenario it is not possible to comply with the 1% increase in emissions from 2005 values, all other scenarios enable the target to be achieved. Considering that there is always a degree of uncertainty associated with the actual time of implementation of the RES-e plants considered in the SUP scenario, it seems sensible to promote technology substitution on the demand side to ensure compliance.

It can be argued that even in the CUR scenario, GHG compliance is partially achieved thanks to investment in large RES wind power plants and not necessarily via technologies on the demand side. Nonetheless, it should be stressed that the commercial sector plays a major role, with 25% reduction compared with 2005.

Table 4.9. GHG emission estimates for 2020 for the four scenarios

Gg CO2e	2005	2020 CUR	DEM	SUP	S&D
Energy supply	26 546	26 699	25 132	25 214	23 233
Industry & Solvents	17 701	23 743	23 738	24 413	23 775
Transport	19 861	16 554	16 554	15 866	15 866
Commercial	3 437	2 594	937	2 594	832
Residential	2 652	2 230	2 939	1 978	3 410
F-Gases[a]	799	3 618	3 618	3 618	3 618
Agriculture[a]	9 059	9 074	9 074	9 074	9 074
Waste[a]	7 151	5 679	5 679	5 679	5 679
National Total	**87 205**	**90 191**	**87 670**	**88 436**	**85 487**
Total Non EU ETS	50 780	52 317	50 760	51 269	50 695
Total EU ETS	36 426	37 874	36 910	37 167	34 792
% Variation from 2005					
EU ETS		4	1	2	-4
Non-EU ETS		3	0	1	0
Total		3	1	1	-2

[a] Emissions not derived from the modelling exercise but from Seixas, et al. (2008).

Finally, the major argument for investment in measures promoting efficient and renewables-based systems in the end-use sectors is still cost savings. Apart from cost savings, it is only in the power sector that replacing equipments in the DEM and S&D scenarios leads to reductions in the total energy system costs to satisfy the demand for energy services from 2000 to 2030, viz. 2693 to 2873 M€$_{2000}$, respectively. This was estimated as the difference between the total energy system costs for the four scenarios, including investment, maintenance and fuel costs from 2000 until 2030. These figures correspond to approximately 2.0 and 2.1% of the 2010 GDP, which is quite significant. This should not be read as directly indicating GDP losses or gains, as there are more mechanisms involved here, but these cost estimates constitute a useful first approximation.

4.3.4 Sensitivity analysis

Since the primary energy prices considered in the model runs are very low relative to current prices, we performed a sensitivity analysis for higher oil, coal and gas prices (Table 4.10). The analysis showed that the increase in primary energy fossil prices will lead to a small variation in 2020 Non-EU ETS GHG emissions, viz. -1% to -2%, and +2% to +4% for the 2020 EU ETS emissions. In terms of compliance with the 31% RES target, the increase in prices leads to an increase of 2-3 percentage points in the % RES in the total final energy (i.e. from 25-30% RES in 2020 to 27-33% RES in 2020), enabling Portugal to comply with the 31% RES target. This is due to the reduction in natural gas consumption for electricity generation (5 to 25% less than with the lower prices) in new CHP power plants and in industry boilers and kilns, which is compensated by an increased use of existing oil CHP and new biomass CHP. Natural gas consumption in buildings is also reduced, and compensated by more electricity, geothermal and solar thermal water. The results of the sensitivity analysis seem to strengthen the point made above, that a higher deployment of end-use efficient equipments and small-scale RES creates cost savings and makes at least part of the large-scale new CCGT power plants avoidable.

Although we did not perform a dedicated sensitivity analysis for the discount rate for this paper, this was done in previous work with this model. As reported in Simões et al. (2008), we found that using a discount rate of 2% (instead of 4%) led to large variations in hydropower deployment and total system costs, but not in CO_2 emissions or final energy consumption (less than 2% variation). The 2% discount rate led to higher penetration of hydropower, replacing less capital-intensive coal power plants. Using a discount rate of 6% had practically no effects, except for a reduction of 16% in total system costs, which is simply the result of higher returns on invested capital.

Table 4.10. Primary energy prices considered in the sensitivity analysis

	Oil ($2007/bbl)		**Natural Gas ($2007/m³)**		**Coal ($2007/ton)**	
Year	**Base case**	**High prices**	**Base case**	**High prices**	**Base case**	**High prices**
2000	35.84	35.84	0.21	0.21	35.25	35.25
2005	57.15	57.15	0.27	0.27	65.82	65.82
2010	53.53	93.28	0.22	0.39	50.85	85.04
2015	56.08	97.13	0.24	0.41	55.68	86.02
2020	58.75	101.15	0.25	0.43	58.21	87.01

4.4 Discussion and Limitations

The results of our analysis show that our case study offers substantial room for improvement in the coordination of supply-side and demand-side policies. It seems to be the lack of coordination in policy objectives (end-use energy efficiency targets, RES targets and energy security targets via liberalisation of electricity markets) that leads to an apparently intriguingly high number of permits for new power plants being issued by the authorities. Even considering that roughly 10% of the large-scale centralised electricity installed capacity in 2005 will achieve the end of its life by 2020, it is not clear why it would be necessary to increase the total electricity capacity as it was in 2005 by 42-64% by 2020. If these plants function according to their technical potential, this would correspond to an increase in per capita electricity consumption of more than 100% compared with 2005[46]. Thus it seems that neither the current moderate energy efficiency targets of the NEEAP nor the potential role of more demanding ones have been fully considered in terms of achieving the 31% RES targets and ensuring security of supply.

Based on the cost savings identified in this article, it might have been better if the permits for two of the new 800 MW CCGT plants had not been issued. Current developments seem to support this conclusion, as in the current national economic context, the investors seem no longer interested in building and operating them[47]. Another possible policy development based on the results we have presented is to review the NEEAP targets in order to increase their level of ambition, particularly regarding buildings. This view is also shared by Schüle et al. (2009). However, enforcing the NEEAP targets could be a major challenge, as TIMES models tend to oversimplify efficient technology deployment. A further interesting option would be to assess to what extent “strict” energy efficiency measures such as more efficient appliances and/or demand reduction could replace small-scale RES technologies. Finally, on the topic of policy development and to promote better policy coordination, specific policy instruments should be developed to

[46] We have considered a per capita electricity consumption for 2005 of 4.157 GWh/1000 inhabitants and have estimated the electricity generated in 2020 with the installed capacity in Table 3 (plus oil, coal and gas plants existing in 2010) and the literature-derived AF presented in Table 4. We did not include CHP here.

[47] In 2011, Endesa and GALP no longer had plans in place to build the CCGT plants at Lavos and Sines.

promote energy efficiency by energy suppliers, as suggested by Schüle (2011). Wuppertal and Ecofys (2009) also suggest that these should be developed coherently as packages of instruments such as energy performance contracting, voluntary agreements, frameworks for securing funding and education, etc.

The major limitation of this study is inherent to the model used. TIMES_PT, like most bottom-up models, addresses the very real and significant barriers to energy efficiency in a highly simplified way, as it assumes perfect foresight and perfect knowledge, that is, rational agents with unlimited time and access to complete information operating in perfect markets. Hence, the constraints on more cost-effective technology adoption can only be expressed as a combination of the following: (i) the availability of new technology depending on stock turnover, (ii) the value of the discount rate used to account for uncertainty, and (iii) an exogenous limit for the diffusion speed of new technologies (Fleiter et al. 2011).

This oversimplification motivated the use of “exogenous inertia factors” to mimic barriers to technology penetration which have a decisive impact on the results, as shown in the previous section. The “exogenous inertia factors” were based on previous energy sector trends, which may change in the future. It would therefore be desirable to further assess the implications of variations in such factors in technology adoption. On the other hand, the lack of detailed data on real end-use energy technology adoption can only allow a “blind” variation of future “inertia factors”. This would clearly lead to significantly different results in terms of savings achieved by energy savings, but they would not necessarily be any more robust. The extremely high uncertainty of future end-use technology deployment invalidates any attempt to reasonably predict the future, even if only until 2020.

Another limitation has to do with the scenario design and the fact that the investment on new large power plants (renewable and natural gas) was exogenously introduced into the model, so it is impossible to assess whether it would be more cost-effective to avoid them altogether.

Another major exogenous input has to do with the socio-economic scenarios and energy and materials demand projections for 2020, which have a high degree of uncertainty and significantly affect results. However, other, more robust projections are unavailable. Since the time when these scenarios were developed, in 2009, the Portuguese economic situation has drastically changed. In fact, according to the Portuguese planning authorities of the Ministry of Economics and the Bank of Portugal, it is currently not possible to make reliable socio-economic projections beyond 2016. The same applies to another very relevant limitation: this article did not model the Iberian electricity market. If the CCGT electricity prices are competitive enough compared to those of the Spanish suppliers, there will be an interest in operating these plants for export. Nonetheless, neither the Portuguese nor the Spanish Transmission System Operators have any estimates for this at the moment.

On a slightly different note, it should be mentioned that the overall energy supply and demand issue has a broader ramification not covered in this paper, regarding the elasticity of supply of different energy sources and demand. Krichene (2002) estimated the long-term demand elasticity for oil and gas to be around 1, which softens the effects of demand reduction and of shifts to non-fossil. This works at a mainly global level for fossil energy (with short-term price differences between regions). Whatever the exact elasticities, the effects will be more or less proportional to the reduction in fossil fuel use in Portugal, not influencing our conclusions here.

All the sources of uncertainty and limitations discussed above affect the cost estimates made in sections 4.3.1 and 4.3.3. Nonetheless, it should be mentioned that the purpose of this article is not to obtain an irrefutable value for the savings achieved by energy savings but is instead to present a first, but valuable, attempt to quantify the effects of uncoordinated supply-side and demand-side policies. The approach we have used can be generalised to other countries. Improving the robustness of the results will entail significant developments in the TIMES family of models in order to better reproduce the full realisation of the potential of demand-side measures, which depends to a large extent on individuals and their preferences. An overview of several approaches to this is presented in Fleiter et al. (2011).

4.5 Conclusions

This model-based paper has first specified the effects of demand-side options for greenhouse gas reduction and energy use reduction in the commercial, residential and industry sectors, i.e. replacement of existing equipment with more efficient and renewable-based equipment. The supply side was modelled to reflect reduced demand, including options for non-fossil based large-scale production. The effects were quantified in terms of: (i) reduced installed capacity for electricity generation, (ii) final energy consumption, (iii) share of renewables in final energy and (iv) reduction of GHG emissions. This was done using the Portuguese energy system as a case study and comparing four scenarios for 2020 using the TIMES_PT model: Current policy (CUR), focus on Supply with major investment in renewable electricity (SUP), focus on Demand with higher deployment of end-use efficient equipments (DEM), and simultaneous focus on Supply and Demand (S&D). The major differences between these scenarios are: (i) the degree of incentives for production of renewable electricity combined with forcing the activity level of new CCGT plants and (ii) the level of penetration of small-scale renewable and end-use efficient equipment in industry and buildings.

The results show that for Portugal, the specific demand-side measures significantly reduce the competitiveness of the new 1.6 GW of CCGT currently being built. In the DEM and S&D scenarios, these plants have a reduced activity level, below the minimum threshold of 37% capacity use. Due to the high costs of natural gas, and since there are significant policy incentives in place for renewable electricity, the implementation of the demand-side measures makes it cheaper to use RES-e power plants instead of the new CCGT. We estimate that avoiding this excess gas-fuelled capacity in 2020 could lead to cost savings of 454 to 2129 Meuros_{2000} referring only to the investment costs in the power sector. These correspond to approximately 0.34% and 1.57% of the 2010 Portuguese GDP. It should be noted that one of the motives for investing in CCGT in Portugal in the 1990s was the need to diversify primary energy sources. Since then, the gas and RES generation capacity has grown to an extent that makes us believe that the adequacy of investing in CCGT to achieve energy diversification should be reassessed.

Even so, none of the four scenarios enables the target of 31% share of RES in total final energy consumption to be achieved. However, the demand-side options do make a significant contribution, especially for RES heating and cooling in the residential and commercial sectors. Thus, it appears that the current NEEAP targets for the residential and commercial sectors modelled in the CUR and SUP scenarios seem somewhat modest, considering the gains that can be achieved by realising the potential of demand-side measures. Moreover, the Road-Map for Renewables being developed by the General

Energy Directorate aims to further increase RES-e capacity in 2020 by 4.70 GW additional to what is already integrated in the SUP and S&D scenarios. It seems that implementing all these new investments might be excessive, as the full potential of demand-side measures does not seem to have been taken into account.

Regarding the Non-EU ETS GHG emission targets, the demand-side measures are quite significant. Whereas in the CUR scenario it is not possible to comply with the 1% increase in emissions from 2005 values, the DEM scenario enables this target to be achieved. Although the Non-EU ETS emissions in the SUP scenarios are exactly 1% of 2005 values, in the S&D they are identical to the 2005 values. Considering that there is a degree of uncertainty associated with the actual time of implementation of the RES-e plants considered in the SUP scenario, it is sensible to promote demand-side measures to ensure compliance.

The major argument for investment in measures promoting efficient and renewable equipments in the end-use sectors is cost savings. Replacing equipments in the DEM and S&D scenarios leads to reductions in the costs of satisfying the demand for energy services from 2000 to 2030 amounting to 2693 to 2873 M€$_{2000}$, respectively, which corresponds to approximately 2.0 and 2.1% of the 2010 GDP. Our overall conclusion is therefore that balanced policy development can lead to substantial cost reductions in climate and energy policy. Although the results are specific to Portugal, the main mechanisms involved are very similar in most other countries, though quantitative outcomes may differ due to different circumstances. For example, more wind potential with more connected grid systems with hydro power reserve capacity, as in north-western Europe, would probably lead to even more favourable results. A further step could be to quantify the EU-wide savings achieved by energy savings and to identify ways to achieve them. Such a balanced policy development can lead to substantial cost reductions for climate and energy policy.

4.6 Appendix – National Primary Energy Potentials

Primary energy	2000	2020	Reference
Wood products (PJ)	74,53	48,40	GPPAA-MADRP (2005) and extrapolation of National Climate Change Waste Management Scenarios (APA, 2006)
Agriculture waste (PJ)		16,30	Ibid
Biogas (PJ)	0,10	23,21 (+75%)	Ibid
Crops for biofuel production (PJ)	0,00	9,99	GPPAA-MADRP (2005)
Edible oil for biodiesel production (PJ)	0,00	0,59	Extrapolation based on Gonçalves, H., Joyce, A., Silva, L. (eds) (2002c)
Crops for ethanol production (PJ)	0,00	19,5	GPPAA-MADRP (2005)
Municipal solid waste (PJ)	7,30	10,00	Extrapolation of National Climate Change Waste Management Scenarios (APA, 2006)
Industrial waste (PJ)	0,00	2,00	Expert guess
Solar – water and space heating (PJ)	0,75	38,01	Gonçalves, H., Joyce, A., Silva, L. (eds), 2002b
Hydro (GW)	4,52	6,96	INAG, DGEG and REN, 2007
On-shore wind (GW)	0,08	7,60	Sá da Costa, A. APREN in van de Toorn, G. (2007)
Offshore wind(GW)	0,00	1,00	Estimate based on study by INETI - National Engineering and Industrial Technology Institute - Wind & Ocean Energy Unit (unpublished)
Concentrated solar for electricity generation (GW)	0,00	2,40	REN and ISR (2007 and 2005)
Geothermal (GW)	0,01	0,05 (+75%)	Extrapolation based on Gonçalves, H., Joyce, A., Silva, L. (eds), 2002a
Waves (GW)	0,00	1,20	REN and ISR (2005 and 2007)
Photovoltaic (GW)	0,0	9,30	REN and ISR (2005 and 2007)

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5 Effects of exogenous assumptions in GHG emissions models - A 2020 scenario study for Portugal using the Times model*

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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 4th 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. 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. 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. 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). 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). 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). 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). 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. 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. 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

Parameter	Unit	2000	2005	BASE, EFF, low RES-e, LowH, HighH, 100$ 2010	2015	2020	DEM 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).

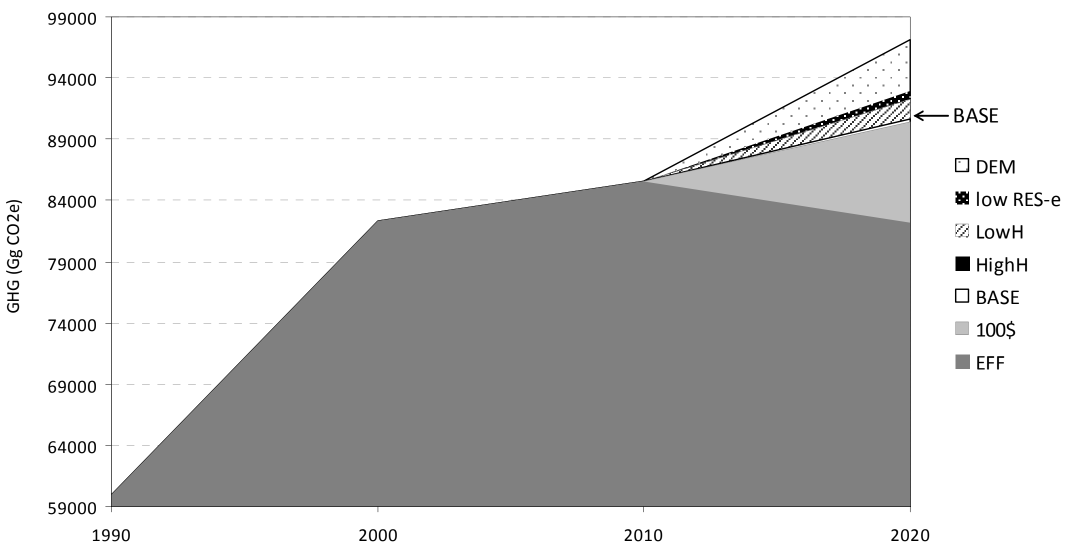

Figure5.1 – Variation in GHG emissions from 1990 to 2020 for the modelled scenarios

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) +1% for passenger transport and +8% for freight transport -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.

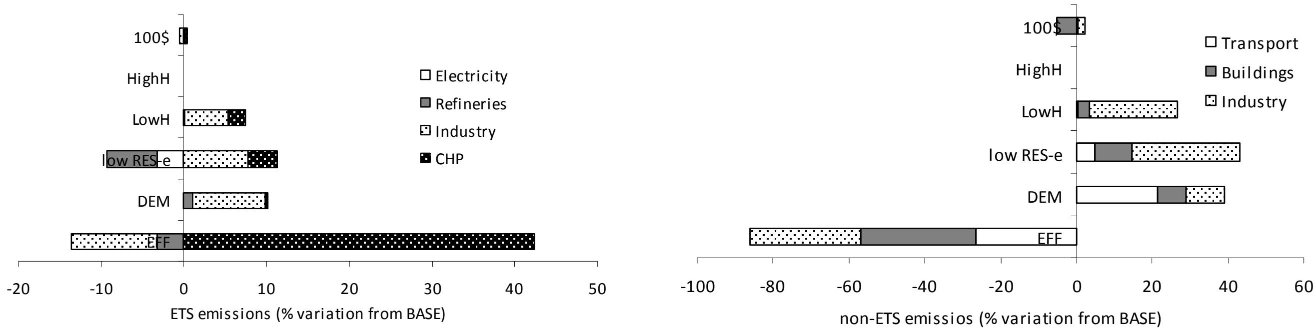

Figure 5.2 ETS and Non-ETS GHG emission estimates for 2020 represented as % variation from the BASE scenario

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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6 Top-down and bottom-up modelling to support low carbon scenarios: climate policy implications*

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Abstract

Bottom-up (BU) and top-down (TD) models have been supporting climate policies, identifying the options required to meet greenhouse gases (GHG) abatement targets and evaluating its economic impact. Some studies have shown that GHG mitigation options from economic TD and technology BU models tend to vary, being different baseline scenarios one recognised divergence factors. This article explores the use of TIMES_PT (BU) and the general equilibrium GEM-E3_PT (TD), assessing the extent of their differences in mitigation options when calibrated to a common baseline scenario and how different outcomes are relevant for domestic climate policy making. Three low carbon scenarios were generated until 2050, with different GHG reduction targets for the case study of Portugal.

The models present close mitigation options, allocating the larger mitigation potential to energy supply. However, they suggest different in mitigation options for end-use sectors. GEM-E3_PT focuses more on energy efficiency, while TIMES_PT relies on carbon intensity decrease by shifting to electricity. Common baseline scenario cannot be ignored but the models inherent characteristics' are the key factor for different outcomes, highlighting different mitigation recommendations.

6.1 Introduction

The need to limit the negative impacts of climate change has motivated several countries and regions to set greenhouse gases (GHG) emissions reduction pledges in the medium (UNFCCC, 2011) and long term (e.g. EC, 2011; HMG, 2008; MFE, 2011). Many studies have been conducted to design decarbonization scenarios (see Hughes and Strachan, 2011 and Söderholm et al., 2011 for a review on low carbon scenarios). Energy-economic-environmental models are extensively used to outline how the transition to a low carbon economy can be achieved and to evaluate its economic impacts.

E.g. macro-economic top-down and technological bottom-up frameworks are the two main modelling approaches, differing in the emphasis placed on energy technologies and the comprehensiveness of endogenous market adjustments (Böhringer and Rutherford, 2008). Conventional bottom-up (BU) models follow a partial equilibrium representation of the energy system, describing it with high technological detail. They solve optimization problems, computing the least-cost combination of energy technologies to meet energy services demand. BU models often ignore the macro-economic feedbacks of different energy system pathways or consider them partially through energy services demand adjustments, dependent on their endogenous energy costs and exogenous price-elasticities. Although some studies evidence that price elasticities capture a relevant part of the feedback effects from economy to energy system (Bataille, 2005; Labriet et al., 2010), BU models do not include the full macro-economic feedback, being unable to assess all the economic impacts of climate and energy policies such as on GDP, production, labour.

Conventional top-down (TD) models, namely Computable General Equilibrium (CGE) models, describe the interaction between the energy system and the economy as a whole, following the Arrow-Debreu economic equilibrium paradigm. They represent the energy sector in an aggregated form by production functions, capturing substitution possibilities through elasticities of substitution (Böhringer, 1998) and setting energy savings through an autonomous energy efficiency index (AEEI). These are usually estimated from aggregated historical data, with no guarantee that they will remain valid in the future (Grubb et al., 2002). Therefore, CGE models suggest that efforts to change the energy system away from a specific form, namely as response to GHG abatement, tend to be costly (Grubb et al., 1993; Hourcade et al. 2006; IPCC, 2001; Rivers and Jaccard, 2005; Wilson and Swisher, 1993).

Some efforts to integrate the two modelling paradigms in hybrid models (Hourcade et al., 2006) have been made, assuming a soft-link between two independent TD and BU models, complement one model to a reduce form of the other, introduce discrete technologies (mostly electricity generation) in CGE models through a mixed complementary problem, or integrate the two models through a decomposition algorithm which employs an iterative procedure (see Labriet, 2010 and Lanz and Rausch, 2011 for a detailed overview). The primary difficulty arising from most of these methods lies in the inherent computational challenges, being assumed simplified forms of the models which do not allow capturing the global strengths of both approaches. Thus, conventional use of CGE and BU models continues to support extensively climate policy studies.

Some earlier studies have confronted the results of both approaches under carbon mitigation targets, comparing abatement costs (Grubb et al., 1993; IPCC, 2001; Wilson and Swisher, 1993). More recent analysis, as from Intergovernmental Panel on Climate Change (2007) and Van Vuuren et al. (2009) assessed also the sectoral reduction potential from both approaches, finding considerable differences in the level of sector abatement from BU and TD models, with TD indicating higher reductions for energy supply and industry. However, the studied models used different baseline scenarios and, in some cases, even different assumptions. Dissimilar baseline scenarios can limit the results' comparison, since In climate mitigation modelling besides the structural characteristics of the models and the climate policy regime considered, base case emissions represent one of the factors that can drive model outcomes (Fischer and Morgenstern, 2006). Most of multi-models comparison studies (e.g. ACROPOLIS (Das et al., 2007) and ADAM (Edenhofer, et al., 2010) projects and the Energy Modeling Forum (Clarke et al., 2009)) do not consider however common baseline emissions, focus primarily on analysing the modelling tools and results. Harmonised baseline scenarios include energy consumption and emissions, plus other exogenous assumptions (e.g. GDP, population, energy import prices). By setting a common baseline, it is possible to conclude that different TD and BU outcomes, under similar climate policy regime, are a result only of the models structure and characteristics (e.g. energy substitution elasticities, technology data).

This article aims to explore the relevance of the modelling approach used to support climate policy mitigation, by: (1) identifying to what extend the BU TIMES and the CGE GEM-E3 models, applied for the case study of Portugal and considering a common baseline, lead to different abatement strategies and (2) how possible dissimilar outcomes could result in different domestic climate policy recommendations. To achieve these objectives we compare the models strategies to reduce sector emission using modified Kaya identity.

The paper is organized as follows: Section 6.2 summarizes the modelling framework, the baseline calibration process and outlines the low carbon scenarios. Section 6.3 presents models results, comparing the GHG reductions per sector, carbon mitigation strategies and marginal abatement costs. Section 6.4 discusses the impact on domestic climate policy and Section 6.5 concludes.

6.2 Modelling Framework

The BU TIMES_PT and the CGE GEM-E3_PT were used to generate the baseline and three low carbon scenarios for Portugal up to 2050. TIMES and GEM-E3 models have been broadly used to assess the impact of European Union (EU) or EU countries climate policies (Blesl, 2012; Criqui et al., 2003; EC, 2008; Proost et al., 2009; Russ et al., 2009), but mitigation options from these models have never been compared. In this paper, to ensure that possible divergences between models' results are not due to different reference state and assumptions, the models were initially calibrated to a common baseline scenario. This section, presents a brief characterization of the two models, as well as, the calibration process for setting a similar baseline scenario and the low carbon scenarios developed.

6.2.1 GEM-E3_PT Model

GEM-E3 (General Equilibrium Model for Economy, Energy, Environment) is a multi-region, multi-sector, recursive dynamic computable general equilibrium model (E3M Lab, 2010). Adopting the quantitative application of the Arrow-Debreu economic paradigm, GEM-E3 computes the equilibrium prices of goods, services, labour and capital that simultaneously clear all markets and optimize the behaviour of economic agents. Its production technology is represented by constant substitution elasticity (CES) production function. The CES function combines primary factors with intermediate consumption of materials, services and energy in a four-level nested structure.

GHG emissions abatement by the production sectors results from three strategies available: i) fuel switch to low carbon options (i.e. decrease of carbon intensity), driven by substitution elasticities between energy carriers: electricity, oil, natural gas and coal (E3M Lab, 2010); ii) increase of energy efficiency (i.e. decrease energy intensity), by substituting energy for other production factors, i.e. materials, labour or capital (this can also translate a shift to renewables, which cannot be differentiated in this model), and iii) reduction of activity levels (i.e. reduction of domestic production). On the consumer side, the mitigation options are mainly driven by energy saving through the energy demand price elasticities.

GEM-E3_PT corresponds to a single country version of GEM-E3 for Portugal, assuming eighteen productive sectors (Appendix A). The 2005 benchmark Social Accounting Matrix was built from Use and Supply IO tables, published by Eurostat (Eurostat, 2009) and for the transfers between sectors from the Portuguese National Accounts of the National Statistics Institute (INE, 2008). The calibration of the energy consumption was made by crossing the national energy balances (DGGE, 2007) with the energy prices published by the International Energy Agency (IEA, 2008). Through the use of aggregated CO_2, CH_4 and N_2O emissions factors for coal, oil and natural gas, supported by the 2005 energy balance, the GHG generated by each productive sector and category of consumption were computed and calibrated with the national GHG inventories (APA, 2012).GEM-E3_PT CES nesting structure differs from the standard GEM-E3 (E3M LAB, 2010) in the second level where the composite factor labour, energy, and materials (LEM) is split by the three components. At the third level CES functions defines the substitution between materials types, as defines (separately) energy substitution between electricity and a fossil fuel aggregate (coal, oil and natural), which is divided at the succeeding level. The substitution possibilities are set through constant elasticities derived from international econometric studies and literature review as explain in detail in E3M LAB (2010). CES varies between 0.4 and 0.5 up to LEM factors, being the range of elasticities values between the energy sources higher (0.5 between fossil fuels aggregate and electricity and from 0.4 to 0.9 between fossil types for transports and energy intensive industries, respectively). TIMES_PT model

TIMES (The Integrated MARKAL-EFOM system) is a dynamic linear optimization model generator, which simulates regional or multiregional energy systems (Loulou et al., 2005). Based on a technology database and external constraints (e.g. GHG emissions caps, fossil fuels import prices and energy sources potential), TIMES computes the energy supply/demand equilibrium, where both supply and demand are adjusted to changes in prices under perfect foresight. The ultimate goal of TIMES is to satisfy energy services demand at the minimum system cost, making simultaneous decisions about equipment investment and operation, primary energy supply and energy trade (Loulou et al., 2005).

TIMES-PT maps the Portuguese energy system, modelling in detail energy supply (petroleum refining) and power sector, as well as final energy consumption sectors, namely, industry, residential, commercial, agriculture and transport, which are disaggregated in several subsectors (Appendix A).

The technology database in the model includes the characteristics of the existing and future energy technologies, as efficiency, capacity factor, availability, technical lifetime, investment, operation and maintenance costs. The data has been updated within European Projects and international bibliography, and validated by national stakeholders. TIMES_PT is calibrated to 2005 national energy balances (DGEG, 2007) and includes CO_2, CH_4 and N_2O combustion and process emissions, which are calculated and calibrated through emissions factors per energy carrier and/or sector from the national GHG inventories (APA, 2012). Like GEM-E3_PT, TIMES_PT assumes the same strategies to reduce GHG abatement: i) carbon intensity decrease, by choosing technologies that provide the same service with a less carbon intensive fuel (i.e. substitution of a boiler on coal with a boiler on gas); ii) energy intensity reduction through more efficient technologies; and iii) the reduction of activity levels (i.e. reduction of energy services demand or mobility) via exogenous demand-price elasticities. TIMES_PT assumes a price elasticity of -0.3 for almost all demands categories, supplied by Katholieke Universiteit Leuven, and assumed as a generic value valid for the EU countries. Although TIMES can also reduce GHG emission through carbon capture and storage technologies, this mechanism was not considered as explained in the next section.

6.2.2 Calibration methodology for a common baseline scenario

GEM-E3 and TIMES have been applied together in several European projects, (e.g. NEEDS, RES2020, REALISEGRID), following a specific sequence: GEM-E3 computes demand drivers, such as GDP and sector domestic production growth that are used to determine energy services and materials demand evolution, used as TIMES inputs (see Step I of the calibration process). No further feedback of any kind has been considered.

To guarantee that both models are benchmark to a common Baseline scenario, without considering any climate mitigation target, we developed a calibration process based on a soft-link between the two models. The link follows an approach close to de one used by Labriet et al. (2010), exchanging prices and quantity variables (e.g. energy, emissions) between the models and solving them iteratively until reaching similar results (less than 10% difference). The overall calibration framework is presented in Figure 6.1 and explained in detail in this section.

The main assumptions of the Baseline Scenario in both models include: (i) annual real interest rate of 4%; (ii) fossil fuel import prices up to 2035 adopted from Current Policies Scenario of World Energy Outlook 2010 (IEA, 2010) and extended till 2050, namely $162.0/barrel for crude oil, $176.9/BTU for natural gas and $124.5/ton for coal in 2050 (in year-2009 dollars); (iii) socio-economic scenario assuming an annual average GDP and population growth of 2.3% and 0.3%, respectively, between 2010 and 2050 (Seixas et al., 2010); (iv) technological assumptions: nuclear electricity generation ban and unavailability of carbon capture and storage technologies for the analysed time period, justified by the absence of this option in GEM-E3_PT.

The calibration process between the two models, as represented in Figure 6.1, followed the three steps described below.

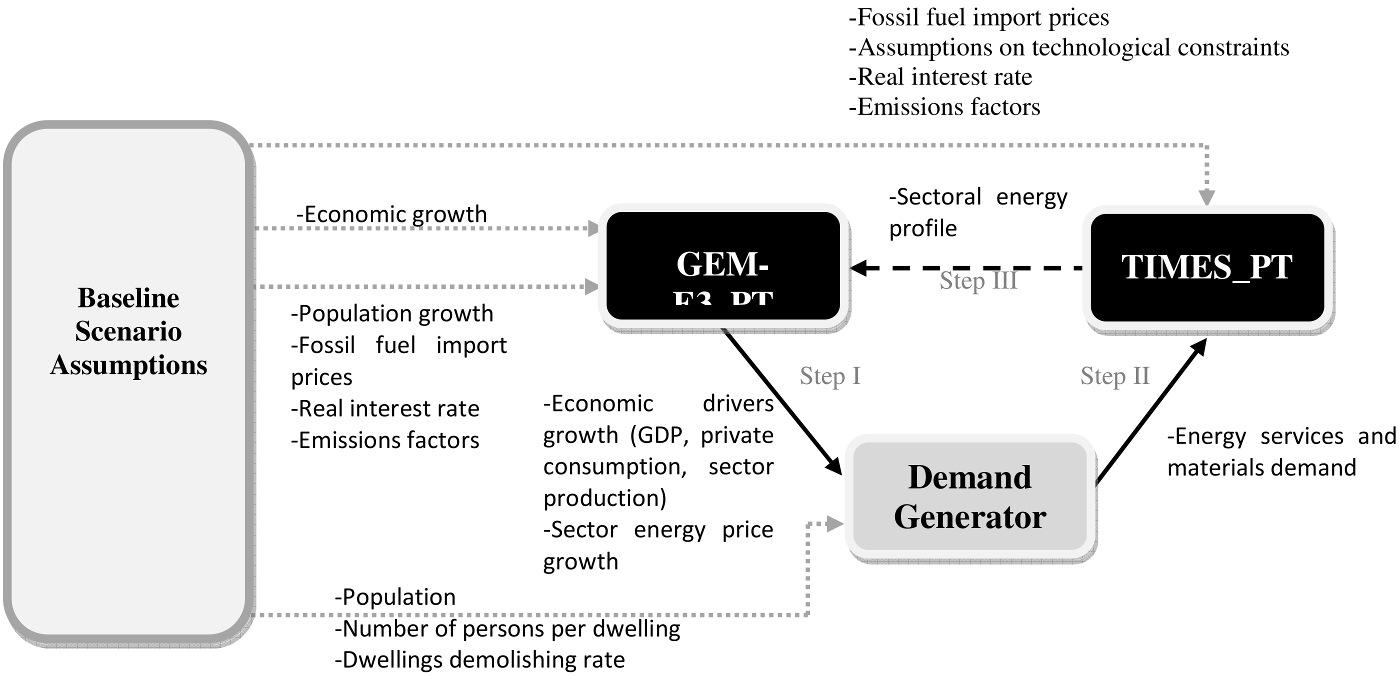


Figure 6.1 – GEM-E3_PT and TIMES_PT calibration framework. The dotted grey lines represent Baseline scenario assumptions (e.g. economic and population growth, fossil fuel import prices) or calibration parameters (e.g. real interest rate, emission factor); the black lines represent the iteration process: full black lines are direct inputs/outputs and the black dashed lines represent indirect inputs.

Step I: The economic drivers and total energy prices by sector generated by GEM-E3_PT through the optimization behaviour of the economic agents were used to produce energy services and materials demand evolution according to the equation of the demand generator from Van Regemorter and Kanudia, (2006) in Simões et al. (2008). The computation assumes a relation between the economic drivers and the total energy price growth with the evolution of energy services demand, given and autonomous efficiency improvement in industry.

Step II: The energy service and materials demand generated in step I are inputted into TIMES_PT, and the model is run to compute the least cost technological profile of the energy system, as energy consumption (quantities per sector per energy source) and corresponding GHG emissions.

Step III: The sectoral energy profile from TIMES_PT (both final and primary energy) for the time horizon is included in GEM-E3_PT where the energy efficiency evolution is associated with an exogenous AEEI. In most uses of GEM-E3 this variable is a fixed value derived from the literature and identical for all energy carriers and for all end-use energy sectors. In GEM-E3_PT, to ensure consistency between the two models, the parameter was disaggregated per energy carrier and per sector and adjusted according to TIMES_PT technological choices. Appendix A presents the eleven sectors considered in the calibration process and its correspondence with the models categories.. The goal of step III is to align in Baseline the models energy consumption and GHG emissions per sector..

Since modifications in sector energy consumption can induce changes on domestic production and consequently on energy services and materials demand, these three steps were repeated until each of the eleven sector's energy consumption per energy carriers from TIMES_PT and GEM-E3_PT converged, i.e. achieved a minor difference between them and relative to the previous iterative process (less than 10% or 1 PJ).

6.2.3 Low Carbon Scenarios

Three low carbon scenarios, differing from Baseline only in the level of GHG emission cap up to 2050 were imposed in GEM-E3_PT and TIMES_PT: +27% above 1990 energy-related emissions **(+27S)** (corresponds to maintaining the Portuguese commitment to Kyoto Protocol until 2050); -20% **(-20S)** and -60% **(-60S)**, with a constant annual decrease rate from 2015 onwards (Figure 6.2). From 2010 to 2015 the three scenarios assume the Portuguese commitment under the Kyoto Protocol: an increase of 27% of 1990 emissions. The total GHG caps consider only energy combustion emissions, corresponding to around 97% of the total energy GHG emissions in 2010 (APA, 2012) and no trade among sectors was modelled.

6.3 Results

This section presents the results of the Baseline (BS) scenario, and compares the mitigation options adopted by TIMES-PT and GEM-E3_PT for the low carbon scenarios, regarding the allocation of total GHG abatement effort across economic sectors, the strategies to achieve it, and the marginal abatement costs.

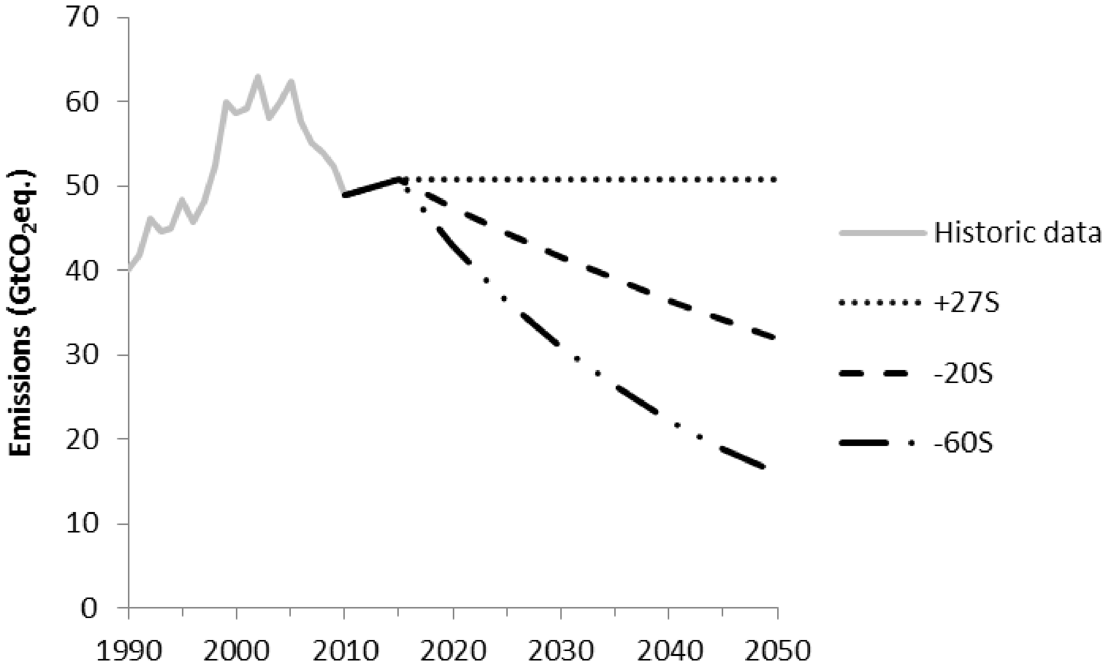


Figure 6.2 – Low carbon scenarios (+27S, -20S, -60S) (Note: High variability of historical GHG emissions data refers to the variability of hydrologic year. The modelling results relies on an average hydrologic year)

6.3.1 Baseline scenario

The models achieve high convergence in BS results regarding the consumption of energy and GHG emissions, with differences below 10% as set in the calibration process (Table 6.1). From 2005 to 2050, the final energy consumption in BS will increase more than 20%. Industry (ferrous and non-ferrous metals, chemical, energy intensive and other industries) has the biggest increase (27% for GEM-E3_PT and 29% to TIMES_PT), and buildings (services and residential) the smallest (13% to 18%). In BS without a GHG cap, power sector will rely on coal, increasing its relative share from 46% in 2005 to around 82% in 2050, since this is the cheapest technology/fuel. The consumption of renewable energy was not included in this estimate since it is not an explicit output of GEM-E3_PT, as mentioned in section 6.2.1. For both models, the energy supply (power sector and refinery) is the leading emitter followed by transport and industry. The main

GHG emissions reduction from 2005-2050 occurs in buildings (-14%) while transports are responsible for the main increase (22 to 27% for GEM-E3_PT to TIMES_PT, respectively).

6.3.2 Low Carbon Scenarios

6.3.2.1 GHG emissions reduction per sector

For the sake of simplicity, the following results are assessed by comparing with BS. The two models indicate that energy supply has the highest GHG abatement potential, as shown in Figure 6.3. Compared to BS, GEM-E3 reduces GHG emissions from 24% (in 2020 for +27S) to 90% (in 2050 for -60S), while TIMES_PT reduces from 35% to 82% for the same years and scenarios. In both models energy supply has the highest contribution for total abatement, but as the cap's stringency increases over time and scenario, its relative importance on total abatement decreases, as higher abatement is required from all other sectors. For the -60S in 2050, TIMES_PT allocates the biggest abatement to transport (43% of total abatement) due to a shift to biofuels and electricity based technologies. GEM-E3_PT presents lower substitution possibilities for this sector. In fact for private cars is not possible to substitute oil with electricity or natural gas, explaining the lower abatement level.

Industry has the second highest abatement potential (in percentage of reduction) in both models, except for -60S and -20S in 2050, when TIMES_PT places industry after transports and energy supply as these two sectors have considerable renewable and electricity technologies available, respectively.

In TIMES_PT, buildings have one of the least cost-efficient reduction options, with an abatement effort below 55% for -60S in 2050, while in GEM-E3_PT the reduction reaches 65%

Table 6.1 – Modelling results for Baseline scenario from GEM-E3_PT and TIMES_PT following the calibration process (renewable energy consumption not included)

	2005		2020		2030		2050		Difference between the models (%)			
	GEM-E3	TIMES	GEM-E3	TIMES	GEM-E3	TIMES	GEM-E3	TIMES	'05	'20	'30	'50
Final Energy consumption (PJ)	654	665	665	684	700	699	802	813	2	3	0	1
Agriculture	16	16	17	18	18	18	20	19	0	3	-1	-8
Industry	191	191	202	199	202	210	243	245	0	-2	4	1
Buildings	184	189	167	170	165	170	217	214	3	2	3	-1
Transport	264	269	278	297	314	301	322	335	2	7	-4	4
Energy consumption in power sector (PJ)	294	299	232	234	229	225	241	235	1	1	-2	-3
Coal	136	138	164	166	169	170	196	192	2	2	1	-2
Oil	69	70	5	5	0	0	0	0	2	-6	0	0
Natural Gas	90	90	63	63	60	55	45	43	1	0	-9	-5
GHG emissions (Gg CO2eq)	62923	63562	57484	59801	60009	60548	65467	67870	1	4	1	4
Agriculture	950	951	1048	1080	1096	1085	1093	1114	0	3	-1	2
Industry	9193	9311	9041	9008	9211	9590	11113	11251	1	0	4	1
Energy Supply	27025	27087	22046	22971	22238	23232	23995	24765	0	4	4	3
Transport	19820	20021	20841	22067	23598	22455	24159	25428	1	6	-5	5
Buildings	5936	6192	4509	4676	3867	4187	5107	5312	4	4	8	4

In general, in the long term GEM-E3_PT systematically shows higher emissions reductions than TIMES_PT for agriculture, industry and buildings. For energy supply and transports it is not as easy to highlight major trends between models as results vary across scenario, but mostly TIMES_PT results in higher reductions for energy supply than GEM-E3_PT. The differences in the models' sector abatement allocation are associated with their abatement possibilities represented by the technological database in TIMES_PT and by the CES function in GEM-E3_PT. Moreover, TIMES_PT results are based on an optimistic perspective about the future, where current immature technologies will become marketable in the long term. The model assumes that economic agents have perfect knowledge about the future and their choices are strictly rational. Thus, their investment decisions are not postponed by uncertain long term climate policies, by resistance to change due to imperfect information, or by subjective preferences. In opposition GEM-E3_PT has an imperfect knowledge of the future and its technological decisions are driven by exogenous substitution elasticities, based on historical data that integrate the above mentioned aspects.

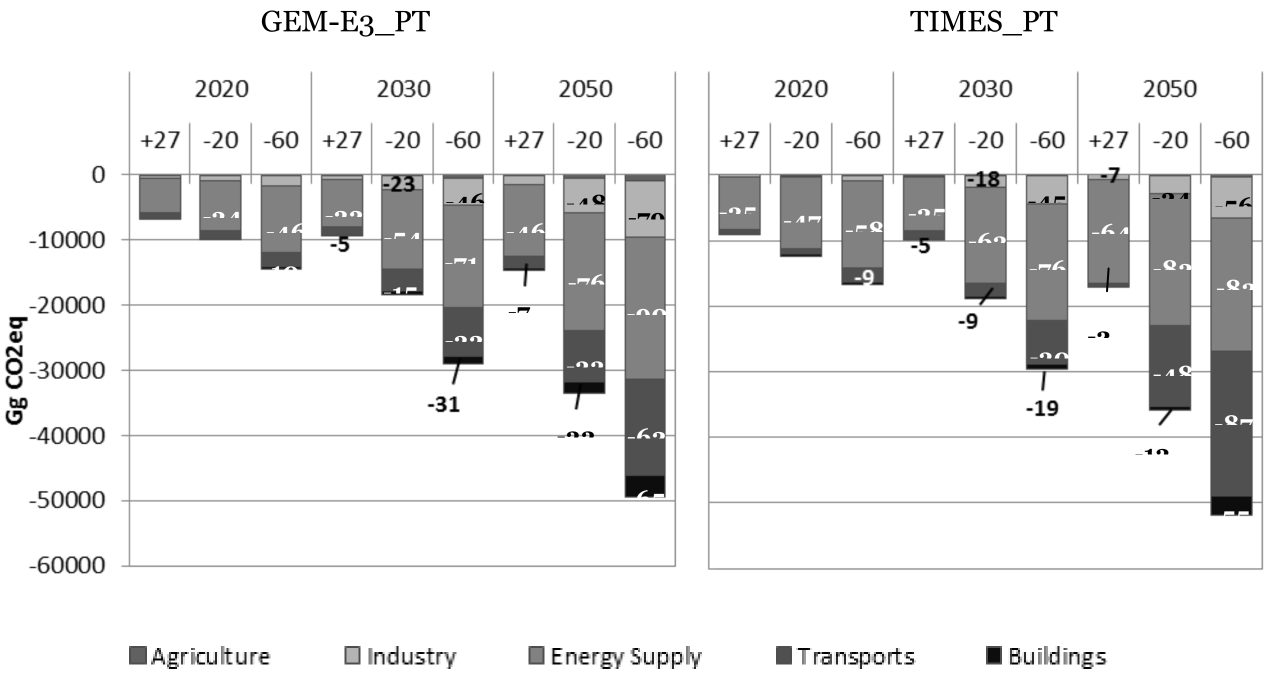


Figure 6.3– GHG emissions reduction (Gg CO2 eq. and percentage inside the bars) for the low carbon scenarios comparing to Baseline scenario (slightly differences in the total GHG emissions abated from the models are a result of the small divergences identify in Baseline).

To illustrate the policy significance of differences between model results regarding GHG reduction, we present the abatement effort using the EU climate and energy package metrics, i.e. comparing 2020 results with 2005 emissions included in the European Union GHG Emission Trading System (EU-ETS), and the energy component of the effort-sharing decision (non EU-ETS) (Table 6.2).

For simplification, it is assumed that the whole energy supply and energy intensive industry sectors are included in EU-ETS. Non EU-ETS includes emissions from agriculture, commercial, residential, transport sectors (including domestic aviation) and non-energy intensive industry.

For all scenarios TIMES_PT achieves a reduction effort for EU-ETS higher than GEM-E3_PT (five to seven percentage points), while the CGE model defines a higher abatement for non EU-ETS emissions (three to five percentage points) comparing to the BU model.

Both models suggest that decarbonization is foremost in EU-ETS sectors, as energy supply and energy intensive industry have the cheapest abatement options. Although there is no national target for EU-ETS emissions, both models found cost-effective to achieve a reduction above the EU target of 21% (EC, 2009a) even in +27S. However, in this scenario only for TIMES_PT is cost-efficient to achieve a -34% reduction target within the conditional increase of EU's total GHG emissions reduction from 20% to 30% in 2020 (EC, 2010).

Table 6.2 - Percentage of GHG emissions reduction in 2020 compared to 2005 disaggregated in EU ETS and non EU-ETS for the Low Carbon scenarios.

Scenario	Sector	GEM-E3_PT	TIMES_PT
+27% Scen.	EU-ETS	-32	-37
	Non EU-ETS	-6	-3
-20% Scen.	EU-ETS	-41	-48
	Non EU-ETS	-8	-3
-60% Scen.	EU-ETS	-50	-57
	Non EU-ETS	-12	-8

Under the EU Effort Sharing Decision, Portugal has a national target of 1% increase in 2020 from 2005 values (EC, 2009b). Still, the EU working paper about the analysis of options beyond 20% GHG emission reductions (EC, 2012) indicates that the Portuguese non EU-ETS emissions have a higher reduction potential, between 11 to 19%. Results show that the 11% reduction is only reached by GEM-E3_PT in -60S. This is relevant for policy-making and negotiations and demonstrates how important it is to understand the range of modelling tools used.

6.3.2.2 Abatement strategy

The Kaya Identity (Kaya, 1990) is widely used to assess the main drivers responsible for GHG emissions or for its abatement. By comparing the evolution of the factors of a modified Kaya identity (eq. 1) for each low carbon scenario with BS, it is possible to understand the strategy used by the two models to reduce GHG emissions. The original Kaya identity is associated to the whole economy, defining activity in terms of GDP and population. In this modified Kaya identity, the activity is associated with the respective sector, which can generally be expressed in domestic production for GEM-E3_PT or energy service demand for TIMES_PT. Although for end-use sectors it is not possible to establish a direct comparison between the models activity reduction (and consequently energy efficiency), as they assume different activity indicators, the factors evolution allows understanding the models abatement strategy for each sector. The three Kaya factors correspond to three main strategies for reducing GHG emissions mentioned in the models characterization (sections 6.2.1. and 6.2.2): reducing activity, energy intensity, and carbon intensity.

$$CO2\ emissions_s = activity_s{}^{*} \cdot \frac{Energy\ Consumption_s}{activity_s *} \cdot \frac{CO2\ emissions_s}{Energy\ consumption_s} \quad \text{(eq. 1)}$$

$\forall s = buildings, industry, transport, power\ sector \ldots$

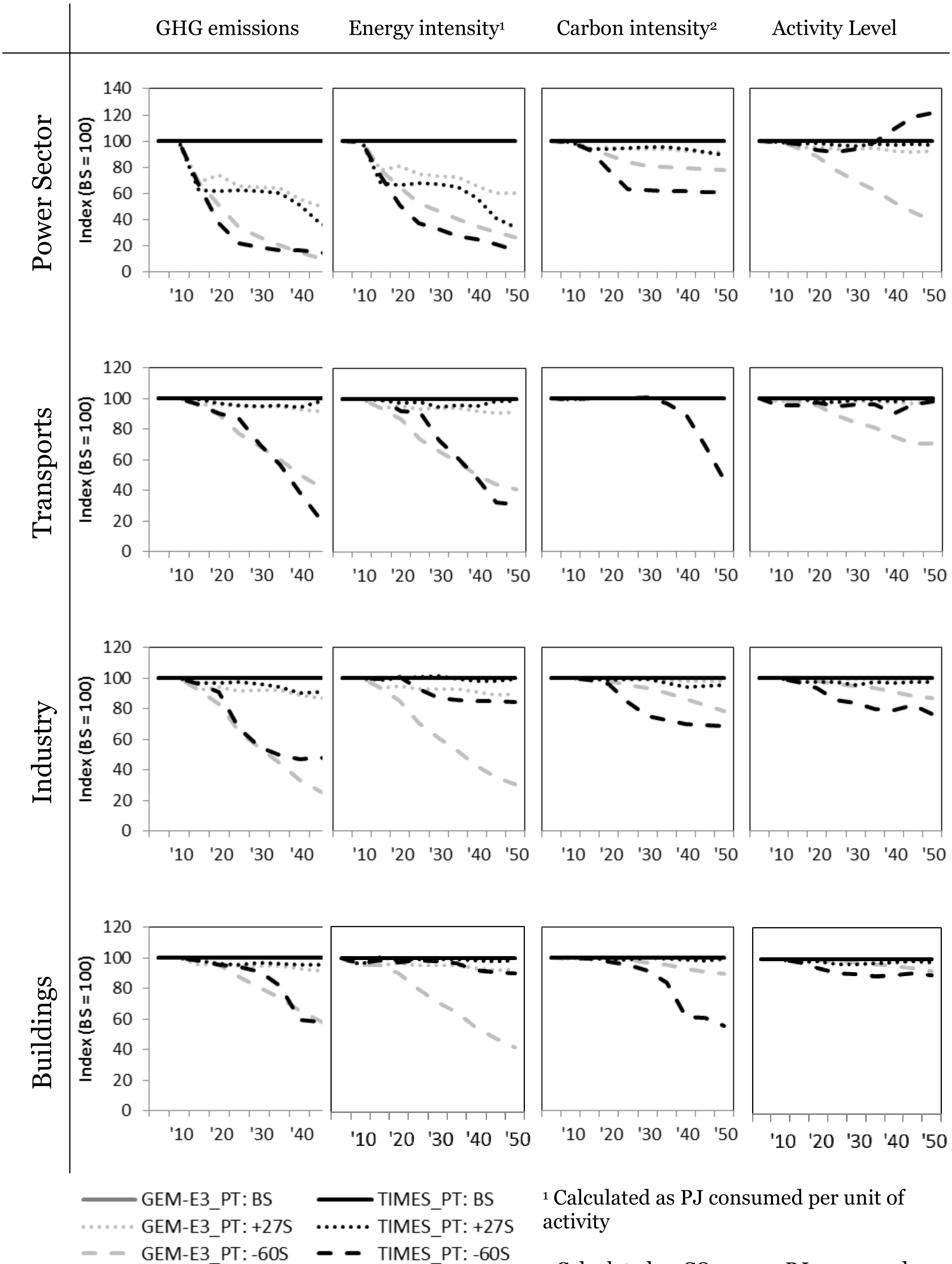
* In GEM-E3_PT activity refers to: sector domestic production in volume (M€'05) for industry, services, agriculture and transport services (i.e. freight and public transport), as well as private consumption (except fuels and power demand) (M€'05) for the residential and private transport sectors. In TIMES activity refers to: sector energy service demand (PJ) for buildings (residential and services) and agriculture, mobility (pkm, tkm) for

transport and materials and energy demand (ton and PJ) for industry. For both models the power sector activity corresponds to electricity production (PJ).

Figure 6.4 illustrates GHG pathways by sector and the respective Kaya drivers' evolution comparing with BS. For simplification the intermediate -20S and agriculture sector are not shown. In power sector, both models have a close emissions path and energy and carbon intensity reduction range. TIMES_PT shifts from coal to renewables decreasing fuel carbon intensity from around 10% to 39% (+27S to -60S) in 2050 compared to BS. GEM-E3_PT moves from energy consumption to other production factors (labour, materials and capital), representing investment in renewable energy, as well as more efficient equipment, decreasing the carbon intensity from 8% to 29% for the same year and scenarios. Although GEM-E3_PT reduces significantly the consumption of coal (37% to 66% compared to BS) it keeps using it, causing a lower carbon intensity reduction than TIMES_PT. In the more stringent target, and contrary to the CGE model, TIMES_PT increases the electricity production so the end use sectors can reduce its carbon emissions.

In general, GEM-E3_PT strategy to reduce end-use sectors is associated with a reduction of energy intensity, while TIMES_PT decreases mostly the carbon intensity and sector activity. GEM-E3_PT reduces more the total final energy than the share of fossil fuels (Figure 6.5). In 2050, for -60S, the final energy is reduced around 65% compared to BS, while the share of fossil fuel use just reduces 4 percentage points (from 73% in BS to 68%). On the contrary, TIMES_PT reduces more significantly the consumption of fossil fuels, less 34 percentage points (from 73% in BS to 39% in -60S in 2050), replacing them by electricity, and decrease less the final energy consumption (46% decrease in 2050 for -60S compared to BS).

Due to its technological database TIMES_PT has considerable options to reduce power sector emissions (supported by renewable technologies) and to substitute fossil energy consumption by electricity in end-use sectors. The CGE model focus more on demand side measures, as pointed by Van Vuuren et al., (2009), increasing the energy efficiency of end-use sectors through the substitution of energy for other production factors in the CES nest. Although electricity consumption is reduced in industry and buildings, its share in the sectors energy consumption increases, which can be associated to a shift from fossil to more efficient electric technologies.



[1] Calculated as PJ consumed per unit of activity

[2].Calculated as CO2eq per PJ consumed

Figure 6.4 - Comparison between GHG emissions, energy intensity, carbon intensity and activity level across models and scenarios (Baseline scenario (BS) = 100 over time) (excluding renewable energy).

In -60S, when a higher effort is necessary from end-use sectors, transport becomes the exception of these clearly different strategies. Besides carbon intensity TIMES_PT also reduces significantly its energy intensity, deploying high efficient electricity and hybrid plug-in vehicles. In GEM-E3_PT, the reduction of transports energy intensity is also accompanied by a reduction of its activity, decreasing -30% in 2050 in -60S. For the CGE model, transport is the end use sector that reduces less its energy consumption, maintaining always a high share of oil demand, regardless the scenario or year, which is reflected in its constant carbon intensity and represents a limitations of its substitution possibilities. .

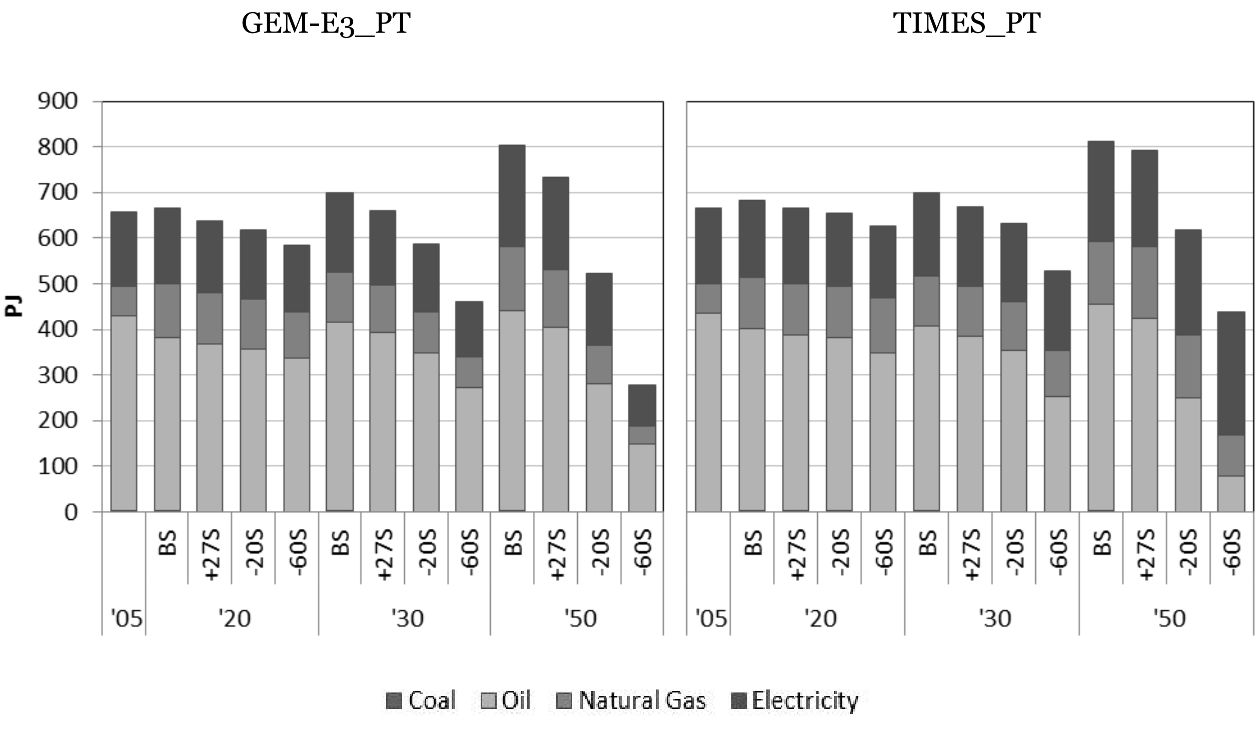


Figure 6.5– Final energy consumption by fuel (2005, 2020, 2030 and 2050) under Baseline and Climate Policy scenarios (Renewable energy not included)

6.3.2.3 Marginal Abatement Cost

The GHG emission reduction potential and abatement strategy defined by each model has a direct impact on abatement costs. Marginal abatement cost

(MAC) curves have been extensively used to assess the cost of a certain carbon abatement strategy, representing the shadow price of mitigation in a certain period. As mentioned by Kesicki and Ekins, (2010), the MAC curves are also in the focus of the climate policy debate, influencing decision making, namely by ranking abatement policies.

To plot the MAC curve for 2050 from both models results (Figure 6.6), additional GHG caps were run, representing a linear GHG emissions pathway from 2015 to 2050 until achieving in 2050: 0% (OS), -40% (-40S) and -50% (-50S) of GHG emissions vis-à-vis 1990 levels. All other assumptions of the three original low carbon scenarios and BS were maintained.

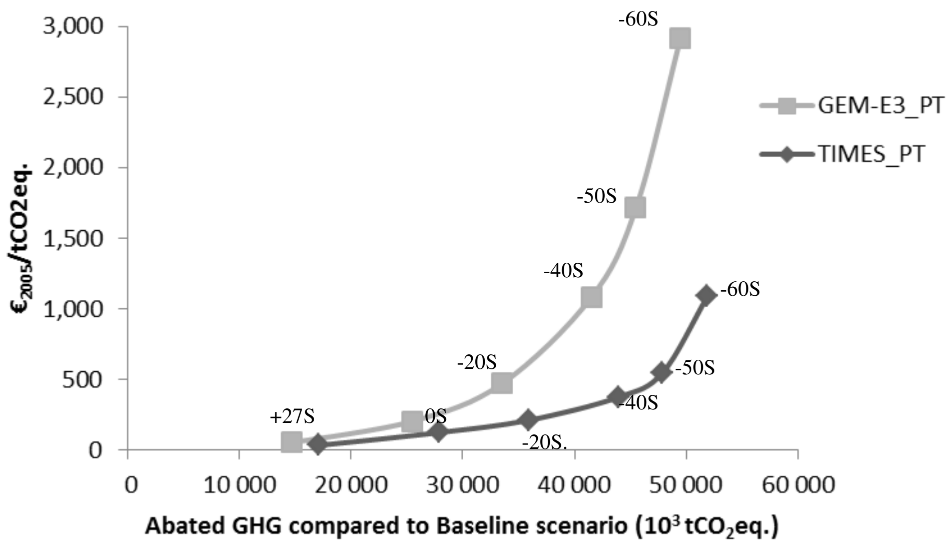


Figure 6.6 – Marginal abatement cost curve for the year 2050

As already observed by some authors (e.g. Jaccard et al., 2003; Hourcade et al., 2006, IPCC, 2001; Rivers and Jaccard, 2005), for the same level of reduction, the MAC from the CGE model is higher than from the BU models. The increase of the carbon reduction target from +27% to -60% denotes a corresponding increase of the carbon price from 54 to 2915€'05/t CO2eq from GEM-E3_PT, and only from 34 to 1075 €'05/t CO2eq from TIMES_PT. For higher GHG abatement levels, the relative difference between the MACs is higher, justified by different reduction strategies and sector potential. Historical substitution elasticities (as in GEM-E3_PT) make the economy's willingness to change the energy system away from GHG intensive technologies lower, (Jaccard et al., 2003) resulting in higher abatement costs. On the contrary, in BU models when technology costs are converted into present value through a social discount rate (e.g. 4% used), many technologies providing the same energy service and reducing GHG emissions appear to be profitable (Bataille et al., 2006), as the widespread use of electric and hybrid plug-in vehicles observed in TIMES_PT for -60S. The greater financial risk of new technologies, the fact that they may not be perfect substitutes to consumers and the availability of capital are usually not considered, resulting in lower mitigation costs from BU models. Moreover, TIMES_PT does not include the fully economic feedback represented in GEM-E3_PT (e.g. impact of the change in economic activity due to the GHG policies).

6.4 Discussion on policy considerations

BU and TD models are two of the most common tools used to support climate policy design, giving indications on the strategy required to meet GHG emissions caps. However, they are mostly used independently and without assuming harmonized baselines. Previous runs, without considering a common baseline scenario and without any cap were made. They present significant differences between the models outcomes (GEM-E3_PT GHG emissions were 13% to 48% higher than in TIMES_PT for 2020 and 2050, respectively). Thus, the abatement effort computed by each model to accomplish the GHG emission caps will be different. For -60S, and assuming the abatement effort comparing to base year, the results with and without common baseline have also shown relevant differences, especially for GEM-E3_PT buildings, agriculture and industry sectors. For industry for example, the difference in the abatement effort from non-harmonized GEM-E3_PT and TIMES_PT are higher (maximum of 38% in 2050) than the one considered with baseline harmonization (28% in 2050). These results show that although common baseline emissions are not the decisive driver for different outcomes they cannot be ignored.

By assuming the same baseline emissions, the models present close results regarding sector abatement, for moderate emission caps. However, as the stringency of the cap increases, the abatement effort and the strategy to reduce emissions differ more.

Although the relevance and usefulness of the models' findings does not rely as much on the accuracy of the numbers as on the insights on how and where climate policies should be applied to meet a GHG cap, the directions pointed out by the two modelling approaches seem to suggest different policy pathways (e.g. allocate higher abatement effort to transport or to industry, or invest more on electricity consumption). By allocating significant emission reductions in one sector instead of other, the models indicate where are the cost-efficient mitigation policy opportunities, influencing for instance the potential for emissions trading. For example, the higher emissions reduction set by TIMES_PT in transports than in industry suggest that is less cost-efficient to reduce industry emissions than transport emissions, which is not the case pointed by GEM-E3_PT.

TIMES_PT main strategy to reduce GHG emissions comparing with BS is to decarbonize the power sector through renewable based technologies, and to shift the end-use sectors' consumption to electricity. These outcomes suggest that the most cost-efficient solution is the adoption of low carbon technologies, which are typically promoted by carbon taxes, financial incentives or regulations..

For GEM-E3_PT the strategy to reduce end-use sectors emissions, rely mainly on energy savings, which is also reflected in the decline of electricity production. This indicates the relevance of demand-side energy efficiency policies as technology or buildings efficiency standards and incentives.

The main difference between the models is related with the transport sector, which currently is responsible for 30% of the GHG emissions in Portugal (APA, 2012). Based on TIMES_PT, transport can play an important role in the economy decarbonization, reducing around 87% from its BS emissions in 2050 for the -60S, thanks to biofuels and high efficient electricity based technologies (electric and hybrid plug-in vehicles). Technology choices are the main driver to GHG abatement, while behaviour changes have a modest contribution, as it is shown in the lower reduction of activity level (Figure 6.4). For GEM-E3_PT, the key driver to transport emissions reduction is the decrease of its energy intensity, achieved by both efficient oil technology options and activity reduction. Therefore, if on one hand policy-makers have results pointing to develop technology oriented policies as incentives for purchasing for example electric vehicles, on the other hand, the conservative vision of the CGE model suggests that road transports will not move away from oil and policies that reduce this activity may be necessary.

Confronted with different results, decision-makers should consider ranges of abatement potentials and costs rather than focus in just one model outcome. It might be reasonable for the policy makers to create incentives for promoting the technological shifts suggested by the BU while taking into account the macroeconomic impacts defined by the TD model(s). However, they are simply tools to explore which technologies and policies could make a specific scenario attainable, and at what possible cost. The model results are just one of the inputs informing the policy decision process, being factors like technology public acceptance as important as its cost-effectiveness. Thus, model outcomes adequacy should be discussed with industry stakeholders, consumer associations, among other.

6.5 Conclusions

This paper aims to assess to what extent two different models (TD and BU) lead to different abatement strategies, while assuming a common Baseline scenario, and how these can result in different domestic climate policy making options. Results show that TIMES_PT and GEM-E3_PT models present close outputs when harmonized to a common Baseline scenario, assigning in general the larger mitigation potential to energy supply. However, the effort level required for each sector, especially for more stringent caps, and the strategy to reduce GHG emissions present dissimilarities which could lead to different policy design. GEM-E3_PT privileges energy efficiency, as it tends to focus more on the demand side, while TIMES_PT relies on the reduction of carbon intensity by shifting energy consumption in end use sectors to electricity and promoting renewable electricity, thus pointing towards incentives to promote low carbon technologies.

Common baseline assumptions cannot be ignored for defining an equal reduction global abatement effort. However, the models characteristics and implicit substitution possibilities are the decisive factor for its different results. The CES function and consumer demand equations in GEM-E3_PT result in a smoother reduction path, while the TIMES-PT reduction path reflects the explicit penetration of technologies ignoring its financial risks or the available capital. These aspects, allied to the fact that TIMES_PT does not include the full economic feedback of GEM-E3_PT also cause the differences in the two models' MAC curves. As described in the literature, the BU TIMES_PT estimates lower costs than the CGE GEM-E3_PT.

The fact that GEM-E3_PT does not include directly renewable energy as TIMES_PT is one of the limitations of this study, although renewable energy consumption is excluded from the results comparison. It should also be underlined that the CGE model can indirectly choose renewable technologies when increasing capital to reduce fossil and electricity consumption. Moreover, as a perfect forecasting model, TIMES_PT anticipate decisions regarding GHG reduction, while, due its recursive dynamic character, the economic agents in GEM-E3 are surprised by the GHG caps. These observations and the fact that the models do not consider the same activity indicators tend to limit its comparison. However, the goal of this paper is not to assess divergences of perfectly comparable models, but rather compare the outcomes of two "real-life" models extensively used in EU climate policy analysis.

Despite its limitations the outcomes from this paper suggest that decision makers should carefully consider which modelling tool is used to support their policies. Climate policy design would ideally be supported by the two modelling approaches, clearly stating the assumptions and limitations associated to each modelling tool. The complementary use of both models could bring added value and result in more robust climate policy making once its specificities make them more appropriate to address certain policy questions. Thus, the CGE model handles better questions on the choice of policy instruments (economic instruments, standards, recycling strategy) while BU models such as TIMES, is more appropriate to evaluate where is more cost efficient to reduce the emissions and which technologies to promote.

Considering the relevance of integrate both modelling approaches in climate policy design, further work is being undertaken to developed a hybrid modelling platform supported by a soft-link between TIMES_PT and GEM-E3_PT, ensuring consistency between its implicit substitution possibilities. This approach has the advantage of being a transparent process, maintaining the integrity of each model and their respective strengths. Assuming the calibration process presented in this paper as a starting point and based on the methodology presented by Labriet et al., (2011), GEM-E3_PT CES function structure will be changed to introduce new energy carriers, and to replicate the energy system profile defined by TIMES_PT, not just for a Baseline scenario but also under different policy scenarios.

6.6 Appendix A

Table A provides a characterization of the models sectors and its correspondence to sectors considered in the calibration process.

Table A – GEM-E3_PT and TIMES_PT sectors and its respective correspondence in the calibration process

GEM-E3_PT productive sectors	TIMES_PT sectors	Calibration sectors
Agriculture	Agriculture	Agriculture
Oil	Oil Refinery	Non electricity energy supply
Coal	Other energy supply	
Natural Gas		
Electricity	Electricity	Electricity
Ferrous and non-ferrous metals	Iron and Steel; Non-ferrous metals	Ferrous and non-ferrous metals
Chemical	Ammonia; Chlorine; Other chemicals	Chemical
Energy intensive sector	Cement; lime; glass; other non-metallic minerals; paper	Energy intensive industries
Electric and Other equipment goods; Transport equipment; Other Industries; Consumer Goods Industries; Food and textile; Construction	Other industries	Other industries
Land transport; Other transport; Households operation of transport associated with Operation of transport (consumption expenditure category)	Transports (road freight, rail freight; buses, Intercity coaches, heavy rail passengers, subway, road car, moto, aviation, navigation)	Transports
Services of credit and insurances; Other Market Services; Non Market Services	Services (space heating and cooling, water heating, cooking, refrigeration, electric appliances, public lighting)	Services
Households Fuels and power associated with Heating and cooking appliances (consumption expenditure category)	Residential (space heating and cooling and water heating, refrigeration, cooking, electric appliances)	Households

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7 Overarching Conclusions

In this dissertation the necessity and benefits of developing integrated policy approaches to the energy systems in general, and power systems in particular were assessed. The research work covers not only the integration of energy and environment policy objectives, but also the integration of different policy instruments along the power system. In order to do so, the dissertation focussed on developing an applied policy evaluation methodology to assess the relevance of divergences between the objectives of current energy and environment policies and its instruments.

In order to further assess the interactions between energy and environment policies and instruments a two part methodology was developed:

- a simple framework to map and qualitatively assess the most relevant interactions between the energy and environment policy instruments currently in place along European power systems, not considering the other components of the policy process (e.g. structures and procedures), and

- a complementary methodology to quantify the effects of the most relevant interactions (as identified in i) using an optimisation bottom-up energy system model (TIMES model, implemented for Portugal as a case-study).

Naturally, the methodology has limitations since the framework has to be simplified in order to be able to implement it to the whole power system and thus obtaining a full view of the tangled web of policy instruments. Also, bottom-up optimisation energy system models depict a simplified reality without fully including aspects as stakeholder behaviour, among many other. Nonetheless, the dissertation defends that this is still an acceptable trade-off in order to achieve quantified insights that can easily be communicated to policy-makers.

It is concluded that there are relevant interactions between current energy and environment policies instruments & measures along the power system.

These are named co-effects and can be either synergetic or antagonistic. In this dissertation emphasis was placed in assessing the latter. It was found that antagonistic co-effects affect effectiveness and cost-effectiveness of the policy instruments and measures and can represent a significant cost for the overall energy system. For the case-study of Portugal used in this dissertation, antagonistic interactions between policies were estimated to representing roughly up to 2% of the 2010 Portuguese GDP.

7.1 Answers to the four main research questions

This section presents more detailed conclusions for each of the research questions addressed in this dissertation.

7.1.1 What divergences exist between the objectives of energy and environment policies and how relevant are these?

We conclude in Chapter 2 that there are significant divergences between the objectives of environment and policy instruments, although at EU level the "(...) central goals for energy policy [are] (security of supply, competitiveness, and sustainability)". However in practical terms the minimisation or mitigation of caused environmental impacts is a secondary goal of energy policy, but of course a main goal of environment policy. Because the ultimate goal of environmental policies is to protect natural resources, the difference in policy goals (implemented by different agencies and organizations) is an important cause for non-coordination between energy and environment policy instruments.

Moreover, because both concern natural resources, environment and energy policy instruments are partly overlapping in terms of targeted stakeholders. Consequently, a large number of overlapping energy and environment policy instruments is targeting the various stakeholders in the power system. Although there are synergies between different policy instruments exist, there are also some whose effects counter each other, not only within different environment policy instruments but also with energy policy instruments.

The seemingly most relevant conflicts found are between hidden subsidies provided to energy supply infrastructures and environment command-and-control regulation. Although there are policy instruments acting both on the supply and the demand side, these do not necessarily lead to integration of supply and demand-side policy instruments.

7.1.2 How well can we assess the interactions between energy and environment policies and instruments? In particular, how can they be quantified?

Although several applied policy evaluation studies have looked into interactions of policy instruments they are mostly limited to specific pairs or limited groups of instruments from the field of energy policy and/or climate policy. This dissertation proposes both a qualitative framework and a qualitative methodology to assess these interactions.

1. Qualitative framework to assess interactions

The qualitative framework in Chapter 2 considers both the energy policy instruments and those from the broad field of environment policy. The concept of overlaps of policy instruments is used to measure the extent to which: 1) target stakeholders are shared, and 2) their steering effects occur within the empirical domains related to the different policy goals. If there are relevant overlaps in policy instruments co-effects between them will occur, i.e. effects on each other are felt at the level of their intended steering effects. These can be complementary, synergetic or counteracting.

The framework systematically assesses overlaps and co-effects of policy instruments looking into their objectives, mechanisms and targeted stakeholders. The first step of the framework is the screening of the objectives of the different policy instruments to assess to what extent they steer related behavior of the same stakeholders, followed by the identification of the type of overlap (complementary, synergetic or counteracting). The coordination of the policy instruments' mechanisms is then analyzed and classified in two straightforward levels: a) no-coordination - the instruments do not touch and are complementary or b) some overlap exists, synergetic or counteracting. Finally, divergences in the target stakeholder's steering effect are assessed. Then coordination between the instruments is due, like derogations or alterations in scope.

2. Quantitative methodology to assess interactions

Besides the qualitative approach this dissertation develops a quantitative bottom-up approach that estimates the losses or gains on effectiveness and cost-effectiveness of interacting policy instruments. This quantitative approach (presented in Chapter 3) is essential to support successful policy assessment and integration. Such a methodology is most useful to assess the relevance of counteracting effects between policy instruments, to set priorities for their integration, and to test more integrated policy designs. For this purpose TIMES_PT is used, a bottom-up technology optimization model, here exemplary implemented for Portugal.

Economy-Energy-Environment models, such as MARKAL, PRIMES, TIMES, RAINS or GEM-E3 have been widely used for the analysis of policy effects and to support decision-making. However, these models have not yet been used to assess how different policy instruments interact with each other. This dissertation brings such a modeled approach use one step further by illustrating how they can be used in energy and environment policy integration. The effects of the implementation of the policy instruments are transformed into technology changes (e.g. alterations in stock, costs, emission factors) into TIMES_PT, reflecting the impact of the policy instruments to be analyzed. This is followed by simulations of the implementation of different combinations of policy instruments. The analysis of the different optimum solutions achieved by the model in the different situations, e.g. the different CO_2 emissions and total costs allow a quantification of the counteracting (and possibly also synergetic) effects between instruments (Chapters 3 and 4).

3. Limitations of the quantitative methodology to assess interactions

The outcomes of Economy-Energy-Environment models (and thus the proposed quantitative methodology) depend on the assumptions implemented in the model as exogenous parameters. The main causes for uncertainty in such models are the different assumptions on exogenous parameters such as demographic and economic evolution, technology deployment, energy resources availability and the implementation and effectiveness of policy instruments. The contribution of different exogenous parameters for the case study was assessed in Chapter 5.

The greenhouse gas (GHG) emission estimates of the studied scenarios related to costs and availability of primary energy lead to variations in 2020 total national GHG emissions that are less than 2% different from baseline. The high promotion of end-use efficient equipment results in a higher difference in 2020 emissions from baseline (less 9%), followed by assumptions of macro-economic growth (roughly 7% higher). The delayed or slower implementation of policy incentives & investments to renewable electricity leads to an increase in emissions of only 2.5%. Thus, in overall terms it seems that the emission changes are not significant. Nonetheless, these relatively small differences in GHG emission scenarios have an impact in compliance with the energy-climate policy package, especially regarding the RES target of 31% for 2020.

The scenarios' comparison concluded that the most relevant assumptions for overall uncertainty are the ones related to the socio-economic assumptions, followed by the assumptions on technology deployment. Contrary to what is commonly assumed by policy makers, the availability of energy resources presents minor variations on GHG emission (less than 2%).

When further comparing the results of the bottom-up technology TIMES_PT model with the alternative economic GEM-E3_PT top-down model (Chapter 6) we found that although there are differences in model outcomes with relevance for climate policy making these differences are not substantial which confirms the robustness of the quantitative methodology using TIMES_PT.

7.1.3 How do the different energy and environment policies instruments & measures along the power energy system interact with each other and how does that interaction affect their effectiveness and cost-effectiveness?

1. Quantitatively assessing interactions for the whole of the energy system

The quantitative methodology using the TIMES_PT model was implemented in Chapter 3 to estimate CO2 Marginal Abatement Costs (MAC) for Portugal for 2020 for a set of policy scenarios including one or more of the following policies: ban on nuclear power; ban on new coal power plants without carbon sequestration and storage; incentives to natural gas power plants, and a cap on biomass use. The different MAC were used to show the policies' effects in the potential for CO_2 abatement and thus as a measure of interaction between the policy options. From a CO_2 emission mitigation perspective it was found that the existing policies introduce significant inefficiencies, possibly related to other policy goals. The total energy system costs are 10-13% higher if all policies are implemented – 76 to 101 B€ - roughly the equivalent to 2.0-2.6% of the 2005 GDP.

2. Quantitatively assessing interactions between policies targeting the supply side and the demand side of the power system

From the qualitative framework depicting the tangled web of policy instruments in place it was found that policies seem to be developed either focussing on the supply side or on the demand side of the power systems, not always in a coordinated way (Chapter 2).

The impact of interacting end-use energy-efficiency & renewables applications policies for Portugal in 2020 was estimated in Chapter 4 in terms of (i) reduced electricity generation capacity, (ii) final energy consumption, (iii) share of renewables in final energy and, (iv) reduction of GHG emissions.

Results showed that aggressive industry and buildings demand-side measures can make the increase in renewable electricity capacity with approximately 4.7 GW, as discussed by policy-makers, superfluous. These measures represent savings in total energy system costs of approximately 3000 M€2000 - roughly the equivalent to 2% of the 2010 GDP.

Specifically for electricity generation, it appears that energy efficiency demand-side measures make the new combined cycle gas turbines (CCGT) plants non-competitive in the Portuguese energy system. By removing antagonistic policy support on the supply side of the energy system it is possible to avoid costs of 454 to 2129 Meuros$_{2000}$, corresponding approximately to 0.34% and 1.57% of the 2010 Portuguese GDP.

These results show that there is substantial room for improvement in coordination of supply-side and demand-side policies for the example of Portugal. It seems to be the lack of coordination in policy objectives (namely end-use energy efficiency targets, RES targets and energy security targets via liberalisation of electricity markets) that leads to issuing of permits for new power plants by authorities. Even considering that the roughly 10% of the centralised electricity installed capacity in 2005 will achieve its end of life by 2020 it is not clear why it would be necessary to increase the total electricity 2005 capacity by 42-64% by 2020. Thus it seems that the neither the current moderate energy efficiency targets of the NEEAP nor the potential role of more demanding ones are fully considered for achieving the 31% RES targets and for ensuring security of supply.

7.1.4 How can energy and environment policy instruments be better integrated in order to improve their overall effectiveness and cost-effectiveness?

It might be unrealistic to aim for fully coordinated policy instrumentation. Given the severe limitations on policy development and implementation sparse instruments are difficult to develop. Therefore, coherent policy packages can be more effective, as long as co-effects are assessed and dealt with. When governments develop and implement such packages it is fundamental to make sure that clear signals are sent out to stakeholders. While doing so governments should pay attention to minimise distortion of policy goals due to lobbying in developing on specific policies, easily disregarding their interrelations, development level and ensuring stability at policy implementation level (Chapter 2).

The integration of policy instruments inevitably brings out the issue of trade-offs. Not only is it necessary to assess the trade-offs between two different policy instruments, but also between having them separate versus their integration. For simplification it is necessary to reduce the analysis to two things to be traded at one time. But even if it is possible to isolate just two policy goals and two costs of these policies involved, with two simple policy instruments; there is not one *numeraire* available to express different non-market effects, as in trading security of supply against CO2 reduction. Reflecting this, the approaches to structure trade-offs in policy integration are mostly quite vague and generic. For further structuring of trade-offs it is necessary to increase the objectivity of the criteria to use, which can only be done if there is more information on the functioning of co-effects of policy instruments and on their quantitative impacts on overall effectiveness and efficiency (Chapter 2).

7.2 Insights gained

This dissertation has used the Portuguese energy system as an example for developing and applying the methodology. However, not only the methodology for assessing interactions can be easily implemented for other countries, but also most of the findings (naturally, not the specific quantification of interactions) can constitute learned lessons for other countries. This is the case of the identified antagonisms between supply-side and demand-side policies or between policies aiming to promote renewable energy and cheap fossil fuels. Although there are obviously differences in configuration of each energy and power system across countries, in particular for the European Union (EU), member states use broadly the same energy and environmental policies, stemming from EU wide common policies and targets as specified in EU Directives.

As in any research work focusing on policy aspects, a most critical question is: what is the actual policy appropriateness of the methodology for assessing interactions here presented? To what extent will it ever be implemented by policy makers affecting "real life" policy making? These questions cannot be replied easily or perhaps cannot even be replied at all. As discussed throughout the dissertation, the policy making process includes many non-rational and unclear elements that cannot be fully captured and modeled. This brings to other underlying questions throughout the dissertation: Is integrated policy evaluation really feasible? Or even further, to what extent is policy integration feasible?

The approach to assess interactions between policies presented in this dissertation concerns the interactions between policy instruments and therefore is limited to only two of the components of the policy process (the policy instruments and actors or stakeholders). The other components - objects, goals and structures and procedures – are not approached. To achieve policy integration it is not enough to simply secure the integration of its instruments, as the effects of the policy instruments are dependent of the context and thus of all the other components of the policy process.

Nonetheless, integration at the level of the policy instruments is a good starting point towards the next challenge, the integration of the policy processes in all its components. This dissertation argues that although it is desirable to have full policy integration in all policy components, in practical terms this is unfeasible, due to its high complexity. Despite well-intentioned claims to achieve policy integration, practice shows that there is still a long way to go. Energy and environment policy integration so far seems to have been done mostly at the broadest level by including vague mentions to sustainability in overarching energy policy goals. These intentions and claims have not yet trickled down to the level of the policy makers and their policy instruments. This dissertation has suggested that the approach to policy evaluation and integration should be supported in more practical terms with a bottom-up evaluation of concrete policy instruments in place. Despite the limitations of the suggested methodology and modeling tools, a simple quantified measure of antagonisms and synergies between policy instruments is tangible result that can more easily be grasped by our limited human minds.

In order to do so more work is needed on methodologies for the assessment of interactions of policy instruments and case application. Due to the systematic lack of analysis of existing policy instruments it is not possible at this stage to assess the relevance of interactions and co-effects between them regarding overall cost-effectiveness, effectiveness and equity. This entails significant effort and costs. In complement, a possible more simplistic way forward to untangle the web of policy instruments is reducing complexity as defended by Tinbergen (1956) by having one instrument per goal. However, political and administrative impediments make this approach not feasible in many domains; It then is perhaps a more realistic strategy to reduce the stakeholder-technology-behavior specificity of policy instruments as much as possible, as defended by several authors (Huppes, 2011). Examples are carbon taxes applying to all stakeholders leaving technology choices open instead of technology specific subsidies. Policy instruments should focus on supporting the removal or mending of market imperfections such as lack of investment funds, access to information, reducing inertia and resistance to change, among other.

The work involved in better policy development and alignment is worthwhile as we have made highly probable that currently substantial losses are made in the tangled web of fuzzy policy mixes.

7.3 References

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8 Summary

In this dissertation a qualitative framework and a quantitative methodology are developed and implemented to assess interactions, in particular antagonisms, between energy and environment policy instruments.

Section 1 General introduction

This section introduces the research problem. The section includes an overview on the need for environment and energy policy integration, the approaches that have been used to do so, the several available methods used for policy evaluation and assessment, and a short description of the Portuguese case-study. The following main research questions are introduced:

- A) What divergences exist between the objectives of energy and environment policies and how relevant are these?
- B) How well can we assess the interactions between energy and environment policies and instruments? In particular, how can they be quantified?
- C) How do the different energy and environment policies instruments & measures along the power energy system interact with each other and how does that interaction affect their effectiveness and cost-effectiveness?
- D) How can energy and environment policy instruments be better integrated in order to improve their overall effectiveness and cost-effectiveness?

Section 2 A tangled web: assessing overlaps between energy and environmental policy instruments along the electricity supply chain

This section presents the background for non-coordination in environment and energy policies, characterizes most of the energy and environment policy instruments along the electricity supply chain, and presents a qualitative framework to assess interactions between policy instruments in place along the electricity supply chain.

The electricity supply chain was considered not only in this section but also throughout this dissertation because the use of electricity for provision of energy services is pervasive throughout the economy. Therefore, policies affecting the electricity system might significantly condition wellbeing.

Presently there is a large number of energy and environmental policy instruments in place which overlap with each other in as much as they share the same targets for policy. A total of 27 different generic types of instruments are or will be in place along electricity systems, creating quite a complex picture which in this dissertation is named "a tangled web".

Some of these policy instruments' overlaps are synergistic, but quite a few steer the behaviour of stakeholders in opposite directions, compromising the overall policy effectiveness. Each of these policy instruments aims to steer stakeholder behaviour in a particular direction. In most cases the steering effects of the policy instruments are also affected by the other instruments in place, i.e. the policy instruments have co-effects. These co-effects occur not only within the same policy field, but also between instruments of different policy fields.

Although several studies have looked into such interactions of policy instruments they are limited to specific pairs or groups of instruments from the field of energy policy and/or climate policy. In this section is presented a framework in which to consider both the energy policy instruments as well as those from the broad field of environmental policy (climate policy is seen as a segment of the wider field of environmental policy).

The framework looks into the extent to what the policy instruments overlap and how their steering effects affect each other. To understand this, the objectives of the instruments, its mechanisms and the targeted stakeholders have to be looked upon, as follows:

1. A **screening** of the objectives of the different policy instruments is made to assess as to what point they are **overlapping** (i.e. to what extent they either target the same stakeholder and/or they steer related behaviour of stakeholders or not.

2. Their respective **mechanisms** are analysed to understand how well the instruments are coordinated. At this stage this can be done at two levels: a) no-coordination - the instruments do not acknowledge the existence of other or b) some coordination in the instruments (expressed as derogations or alterations in scope, among other).

3. The **steering effects** of the different instruments are analysed to identify if they are complementary (the objectives of the instruments steer the behaviour of the target stakeholders supplying mutual needs or offsetting mutual lacks), or counteracting (the objectives of at least one of the instruments steers the behaviour of the same stakeholders in a way that hampers the steering effect aimed by the other instruments).

The seemingly most relevant conflicts found in the tangled web are between hidden subsidies provided to energy supply infrastructures and environmental command-and-control regulation. Although there are policy instruments acting both on the supply and the demand side, these do not necessarily lead to integration of supply and demand-side policy instruments.

The section concludes with a discussion on how trade-offs can be structured, as well as some notes on issues to be considered towards policy integration.

Section 3 Cost of energy and environmental policy in Portuguese CO2 abatement – scenario analysis to 2020

In this section is presented how the interactions between energy and environment policies can be quantified by using an Economy-energy-environment model, in particular the TIMES model implemented for the Portuguese case-study. In the section the emphasis was placed on modelling different combinations of the existing energy and environment policy options in order to assess how these different combinations affect, in 2020, the CO2 marginal abatement costs, the total energy system costs, the primary and final energy demand, and the allocation of abatement effort throughout the different economic sectors.

The main emphasis was placed in CO2 abatement since climate change is currently one of the hot topics in energy and environment policy making. Multiple policy instruments are being developed to address the problem, aiming to coordinate the objectives of climate change mitigation with the ones of the European energy policy: security of supply, competitiveness and sustainability. Although it is clear that the way forward in European energy policy making includes climate change mitigation, it is not clear how policy options made in the past in a different context contribute to this objective.

The set of policy scenarios analysed including one or more of the following policies: ban on nuclear power; ban on new coal power plants without carbon sequestration and storage; incentives to natural gas power plants, and a cap on biomass use. It was found that the introduction of assumed policies significantly increases MAC: the policy scenario has 91 to 42% higher CO_2 MAC than the no policy scenario. The removal of the assumed policies leads to a significant decrease in total system costs of 10-13% (76-101 B€), roughly the equivalent to 2.01 to 2.65% of the 2005 Portuguese GDP.

The most general conclusion of this section is that even the limited set of policies in the energy domain assumed in this model exercise has a significant effect on the cost of CO_2 reduction. This interaction of policies therefore seems to be a prime subject for further analysis on cost-effective policy development in the energy and environmental policy domain, not only in Portugal.

Section 4 The Savings of Energy Saving: Interactions between energy supply and demand side options combined - quantification for Portugal

After looking on how the interactions in policies could be quantified using the TIMES_PT model in section 3, this section uses the same approach to quantify antagonism between policies implemented in the supply-side and on the demand-side of the energy system.

Although climate change policy brings together end-use energy efficiency, Renewable energy sources (RES) and other mitigation options, it is argued in the dissertation that policy makers often prefer supporting investments in the supply-side like in bio-energy and large scale hydro, wind and wave power or even centralised fossil power plants. Government subsidies to fossil fuels are typically maintained along with incentives to RES albeit in a more discrete manner. Thus, despite the fact that more recent energy strategies and programmes combine many policies and measures for tackling climate change, energy security, energy efficiency and promoting RES, there is still a need for quantified assessments of the contribution of the policies within each major policy objective, and of the synergies and antagonisms caused by different combinations of policy measures. This type of information is highly valuable for identifying the most cost-effective combination of policy measures and for reducing the overall cost of policies.

Taking Portugal as a case study, in this section is assessed the effect of specific uncoordinated supply-side and selected demand-side policies, namely of end-use energy-efficiency & small renewable applications. These effects are quantified in terms of reduced investments in large scale energy supply and contribution for compliance with energy and environmental policy targets. The bottom-up model TIMES_PT was used generate four scenarios till 2020 corresponding to different levels of efficiency of equipment in buildings, transport and industry. In the current policy scenario, the deployment of end-use equipments follows the 2000-2005 trends and the National Energy Efficiency Action Plan targets. In the efficient scenarios, all equipments can be replaced with more efficient ones.

Results show that aggressive industry and buildings demand-side options can make superfluous the increase in renewable electricity capacity of 4.7 GW currently discussed by policy makers. These measures reduce only 0-2% of total final energy, but this represents reductions of 11-14% in the commercial sector, with savings in total energy system costs of approximately 3000 M€$_{2000}$ - roughly the equivalent to 2% of the 2010 GDP.

The section concludes that there is substantial room for improvement in coordination of supply-side and demand-side policies for the case-study. It seems to be the lack of coordination in policy objectives (namely end-use energy efficiency targets, RES targets and energy security targets via liberalisation of electricity markets) that leads to an apparent intriguing sky-high issuing of permits for new power plants by authorities. The cost-effectiveness of policy measures should guide choices between supply shifts and demand reduction. Such balanced policy development can lead to substantial cost reductions in climate and energy policy.

Section 5 Effects of exogenous assumptions in GHG emissions models - A 2020 scenario study for Portugal using the Times model

In this dissertation it is argued that the Energy-economic-environment TIMES model should be used to quantify interactions between policy instruments. However, these models have a number of limitations, discussed in detail throughout the thesis. In this section the emphasis is on assessing one of these limitations: to what extent model outputs are dependant on the exogenous assumptions they have to integrate. In the section it is looked in particular to the assumptions that typically are used for climate policy making, reflecting the perception of policy makers on what is relevant.

Models such as TIMES (and PRIMES, POLES, etc.) are frequently used to support policy makers in climate change policy decisions, particularly to develop greenhouse gas (GHG) emission scenarios, as conditional forecasts. Examples of the required exogenous model assumptions are 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 which affects the uncertainty of the resulting GHG forecast. 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. There is good reason to combine different pathways into feasible 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 section is set out to fill this gap in knowledge, highly relevant in interpreting modelling outcomes for policy purposes.

The TIMES_PT model 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 results show 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). 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).

Therefore it seems 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.

Section 6 Top-down and bottom-up modelling to support low carbon scenarios: climate policy implications

Most of the research work in this dissertation relies on the use of the TIMES_PT model. Whereas the previous section assessed how different assumptions affect TIMES_PT outputs, in this section is assessed what are the differences in model results when using a different modelling tool (GEM-E3_PT).

Bottom-up (BU) and top-down (TD) models have been supporting climate policies, identifying the options required to meet greenhouse gases (GHG) abatement targets and evaluating its economic impact. Some studies have shown that GHG mitigation options from economic TD and technology BU models tend to vary, based on different baseline scenarios regarding divergence factors.

This section explores the relevance of the modelling approach used to support climate policy mitigation, by: (1) identifying to what extend the BU TIMES and the TD GEM-E3 models, applied for the case study of Portugal and considering a common baseline, lead to different abatement strategies and (2) how possible dissimilar outcomes could result in different domestic climate policy recommendations. To achieve these objectives we compare the models strategies to reduce sector emissions using a modified Kaya identity.

Three low carbon scenarios were generated until 2050, with different GHG reduction targets for the case study of Portugal. Results show that TIMES_PT and GEM-E3_PT models present close outputs when harmonized to a common Baseline scenario, assigning in general the larger mitigation potential to energy supply. However, the effort level required for each sector, especially for more stringent caps, and the strategy to reduce GHG emissions present dissimilarities which could lead to different policy design. GEM-E3_PT privileges energy efficiency, as it tends to focus more on the demand side, while TIMES_PT relies on the reduction of carbon intensity by shifting energy consumption in end use sectors to electricity and promoting renewable electricity, thus pointing towards incentives to promote low carbon technologies.

The approach suggested to deal with the different outcomes of the models would be for decision-makers to consider ranges of abatement potentials and costs rather than focus in just one model outcome. The two outcomes can actually be combined as it might be reasonable for the policy makers to create incentives for promoting the technological shifts suggested by the BU while taking into account the macroeconomic impacts defined by the TD model(s). In any case, both TD and BU models are simply tools to explore which technologies and policies could make a specific scenario attainable, and at what possible cost, and only one of the inputs informing the policy decision process. Thus, model outcomes adequacy should be discussed with industry stakeholders, consumer associations, among other.

Section 7 Overarching conclusions

In this section the results are presented in the form of a set of replies to each of the four main research questions. The main conclusion is that energy and environment policy integration at the level of its respective policy instruments is a good starting point towards the integration of the policy processes in all its components. Policy evaluation and integration should be supported in more practical and concrete terms with a bottom-up evaluation of concrete policy instruments in place. The approach developed in this dissertation allows obtaining a simple quantified measure of antagonisms and synergies between policy instruments which can more easily be communicated to policy makers. This dissertation concludes with a general discussion on the insights gained.

9 Samenvatting

In dit proefschrift is een kwalitatief raamwerk en een kwantitatieve methode ontwikkeld en geïmplementeerd om de interacties tussen beleidsinstrumenten op het gebied van energie- en klimaatbeleid te analyseren en evalueren, met nadruk op de antagonistische relaties.

Hoofdstuk 1 Algemene inleiding

Dit hoofdstuk geeft de inleiding op de onderzoeksvraag. Het geeft een overzicht van het belang van de integratie van milieu- en energiebeleid; de benaderingen die hiervoor gebruikt zijn, de verschillende methoden die gebruikt worden voor beleidsanalyse en beleidsevaluatie, en een korte beschrijving van de Portugese case studie die in verschillende hoofdstukken wordt gebruikt. De volgende onderzoeksvragen worden behandeld:

1. Welke divergenties bestaan er tussen de doelstellingen van energie- en milieubeleid, en hoe relevant zijn dergelijke divergenties?

2. Hoe kunnen de interacties tussen beleid en beleidsinstrumenten op het gebied van energie en milieu geanalyseerd worden, en met name hoe kunnen deze gekwantificeerd worden?

3. Wat is de wisselwerking tussen energie- en milieubeleid, met de daarbij behorende instrumenten en maatregelen, in de in het elektriciteitsproductieketen, en welke invloed heeft deze wisselwerking op effectiviteit en kosteneffectiviteit?

4. Hoe kunnen instrumenten voor energie- en milieubeleid beter geïntegreerd worden om zodoende hun effectiviteit en kosten-effectiviteit te verbeteren?

Hoofdstuk 2. De beleidskluwen: De analyse van de overlap tussen energie- en milieubeleidsinstrumenten in de aanbodsketen van elektriciteit

Dit hoofdstuk schetst de achtergrond van de het niet gecoördineerd zijn van het milieu- en energiebeleid; geeft een beeld van de instrumenten van energie- en milieubeleid de elektriciteitsproductieketen; en ontwikkelt het kwalitatieve raamwerk voor de analyse van de interacties tussen de beleidsinstrumenten die operationeel zijn in de aanbodsketen van elektriciteit.

De aanbodsketen van elektriciteit fungeert niet alleen in dit hoofdstuk maar vormt ook de basis van analyse in de andere hoofdstukken omdat elektriciteit als bron van energiediensten het meest geïntegreerd is in het economisch systeem. Door deze omvattende invloed heeft beleid in deze energieketen ook substantiële invloed op het welzijn.

Er is op dit moment een groot aantal beleidsinstrumenten operationeel op het gebied van energie- en klimaatbeleid, die met elkaar overlappen in die zin dat ze dezelfde aangrijpingspunten voor beleid delen. In totaal zijn er 27 verschillende algemene beleidsinstrumenten operationeel of worden binnenkort ingevoerd in binnen in het elektriciteitssysteem, die samen een complex beleidsbeeld vormen: een “beleidskluwen”.

De overlap tussen beleidsinstrumenten is deels synergistisch. Maar een groot aantal stuurt het gedrag van geaddresseerden in tegengestelde richting, waardoor afbreuk gedaan wordt aan de effectiviteit van het beleid als geheel. Elk van de beleidsinstrumenten heeft als doel het gedrag van geaddresseerden in een bepaalde richting te sturen. Meestal zal het sturingseffect mede door andere beleidsinstrumenten bepaald worden, dat wil zeggen dat voor de overlappende beleidsinstrumenten co-effecten zijn. Deze co-effecten treden niet alleen op binnen een bepaald beleidsdomein maar ook tussen verschillend beleidsdomeinen.

Hoewel verschillende studies de interacties tussen beleidsinstrument als onderwerp hebben gehad zijn deze in het algemeen beperkt gebleven tot een paarwijze vergelijking van groepen instrumenten in het energie- en/of klimaatbeleid. In dit hoofdstuk is een raamwerk ontwikkeld voor de gecombineerde analyse van zowel het energiebeleid en het milieubeleid (waarbij klimaatbeleid gezien wordt als een onderdeel van het bredere domein van milieubeleid).

Dit raamwerk beziet in hoeverre beleidsinstrumenten overlappen en hoe de sturingseffecten elkaar wederzijds beïnvloeden. Om het benodigde inzicht te krijgen wordt een onderscheid gemaakt tussen de doelstellingen van instrumenten; de mechanismen die door instrumenten in werking worden gezet; en de geadresseerden van de beleidsinstrumenten, als volgt gestructureerd:

1. Een **screening** van de doelstellingen van de verschillende beleidsinstrumenten geeft aan waar zij overlappen (dat wil zeggen hoe zij zich richten op dezelfde gereguleerde en /of zij het gedrag van de gereguleerde sturen).

2. De respectieve **mechanismen** worden geanalyseerd om te begrijpen hoe goed de instrumenten op elkaar zijn afgestemd. In deze fase kan dit op twee niveaus gedaan worden: a) non-coördinatie – de instrumenten refereren niet aan elkaar of b) enigerlei coördinatie – er is bij voorbeeld sprake van derogatie of afbakening van respectievelijke toepassingsdomeinen.

3. De **effecten van sturing** van de betrokken beleidsinstrumenten worden geanalyseerd om vast te stellen of zij complementair zijn (de doelstellingen van de instrumenten sturen het gedrag van de geadresseerden door voorwaarden te versterken of beperkingen wederzijds te verminderen), of zijn elkaar tegenwerkend (de doelstellingen van tenminste één van de instrumenten stuurt het gedrag van de betrokkenen zodanig dat het sturingseffect op doelstellingen van andere beleidsinstrumenten beperkt wordt).

Het conflict tussen instrumenten in een beleidskluwen lijkt het meest relevant voor te komen tussen subsidies op energie-infrastructuur en fysieke regulering (‘command-and-control’) in het milieubeleid. Hoewel er instrumenten zijn die zich zowel op de vraag- als aanbodzijde richten leidt dit niet noodzakelijkerwijze tot integratie van vraag- en aanbodszijde in de beleidsinstrumentatie.

Dit hoofdstuk sluit af met een discussie over hoe afwegingen gestructureerd zouden kunnen worden, waarbij een aantal onderwerpen wordt geponeerd die in aanmerking genomen moeten worden om tot beter beleidsintegratie te komen.

Hoofdstuk 3 De kosten van energie- en milieubeleid bij de emissiebeperking van CO2 – een scenarioanalyse tot 2020

Dit hoofdstuk geeft aan hoe de interacties tussen energie- en milieubeleid gekwantificeerd kunnen worden, gebruikmakend van een economie-energie-milieumodel, te weten het TIMES model, geïmplementeerd voor Portugal ten behoeve van de Portugese case studie. In dit hoofdstuk ligt de nadruk op het modelleren van de verschillende combinaties van bestaand energie en milieubeleid. Het doel daarbij is vast te stellen hoe deze combinaties in 2020 uit zullen werken op de marginale reductiekosten van CO2; de totale kosten van het energiesysteem; de primaire en finale vraag naar energie; en de verdeling van reductie inspanning over de verschillende economische sectoren.

De nadruk is gelegd op CO2 reductie omdat klimaatbeleid een hot topic is in de ontwikkeling van het energie en milieubeleid. Een groot aantal beleidsinstrumenten is in ontwikkeling voor dit beleidsdomein, gericht op het coordineren van de doelstelling van emissiereductie met die van het Europese energiebeleid: aanbodszekerheid, concurrentievermogen en duurzaamheid. Hoewel het zeker zo is dat de ontwikkeling van het Europese energiebeleid mede op klimaatdoelstellingen is gericht, is het niet duidelijk hoe in het verleden ontwikkeld beleid zich tot deze doelstellingen verhoudt.

De te analyseren verzameling beleidsscenario's omvat steeds een van de volgende elementen: een verbod op kernenergie; een verbod op nieuwe kolencentrales zonder koolstof opslag (CCS); prikkels voor de bouw van gasgestookte centrales; en maximering van het gebruik van biomassa. Het blijkt dat elke van deze beleidsopties tot een substantiële stijging leidt van de marginale emissiereductiekosten (MAC) van CO2. Deze beleidsscenario's leiden tot een 42 tot 91 procent hogere MAC voor CO2 dan het geen-beleid scenario. Het verwijderen van deze beleidsscenario's leidt tot een substantiële daling van de totale kosten van het energiesysteem, met 10 tot 13 % (76 tot 101 miljard Euro). Dat komt overeen met 2,01 tot 2,65 van het Portugese nationaal inkomen (GDP) in 2005.

De meest algemene conclusie in dit hoofdstuk is dat slechts een beperkte inzet van beleid zoals in de modelstudies verondersteld reeds een substantiële invloed op de kosten van CO2 emissiereductie kan hebben. Deze interactie van beleidsinstrumenten is daarom een essentieel onderwerp voor verdere analyse voor een kosteneffectief energie- en milieubeleid, en dit niet alleen in Portugal.

Hoofdstuk 4 De Besparingen van Energiebesparing: Interacties tussen gecombineerde opties voor aanbodbeleid en vraagzijde beleid, met een kwantificering voor Portugal

Na de beschouwing over hoe interacties van beleidsinstrumenten gekwantificeerd kunnen worden met behulp van het TIMES_PT model, in hoofdstuk 3, wordt in dit hoofdstuk bezien hoe vraag aanbod gericht beleid in het energiesystem zich tot elkaar verhouden.

Hoewel klimaatbeleid in principe energie efficiëntie, hernieuwbare energiebronnen en andere opties voor mitigatie omvat, komt hier naar voren dat beleidsmakers veelal opties ondersteunen gericht op het ondersteuning van investeringen aan de aanbodszijde. Het gaat daarbij met name om bio-energie, grootschalige water- wind- en golfenergie, en zelfs grootschalige fossiele energie. Daarbij blijven subsidies voor fossiele brandstoffen bestaan naast incentives voor hernieuwbare energie, hoewel vaak niet direct als zodanig herkenbaar. Hoewel er nu strategieën programma's zijn die verschillende beleidsinstrumenten voor klimaatbeleid, energiezekerheid, energie-efficiëntie, en duurzame energie samenbrengen blijft er derhalve toch behoefte aan een gekwantificeerde analyse van de bijdrage van verschillend beleid op elk van de hoofddoelstellingsgebieden. Die analyse dient de synergieën en antagonismen aan te geven tussen de verschillende combinaties van beleidsmaatregelen. Dit soort informatie is van groot belang voor het bepalen van kosteneffectieve combinaties van beleidsinstrumenten en daarmee het reduceren van de totale kosten van beleid.

Portugal vormt in deze analyse een voorbeeld, als case studie. Beginpunt is de studie naar de effecten van niet gecoördineerde beleidsopties aan de aanbodszijde met die aan de vraagzijde, te weten energie-efficiëntie van eindgebruik met kleinschalige toepassingen van hernieuwbare energie. Deze effecten worden gekwantificeerd in termen van verminderde investeringen in grootschalige energieproductie en hun bijdrage aan het voldoen aan de doelstellingen van het energie- en milieubeleid. Met het bottom-up TIMES_PT model zijn vier scenario's tot 2020 gegenereerd die aansluiten bij verschillende niveaus van energie-efficiëntie in gebouwen, transport en industrie. Het scenario voor het huidige beleid volgt de trends in de toepassing van eindgebruik installaties en sluit aan bij de doelstellingen van het Nationale Energie-Efficiëntie ActiePlan in Portugal. In het efficiënte scenario wordt aangenomen dat alle eindgebruiksinstallaties vervangen worden door de meest efficiënte.

De resultaten laten zien dat meer doortastende beleidsopties aan de vraagzijde – zoals nu in discussie bij beleidsmakers - de capaciteitstoename van dure grootschalige hernieuwbare elektriciteitsproductie met 4,7 GW overbodig maken. Deze beleidsopties leiden slechts tot een vermindering van de totale finale vraag met 0-2%, maar dat is wel 11-14% van het gebruik in de commerciële sector. Daarbij wordt een bedrag van 3 miljard Euro op de totale energiekosten bespaard, ruwweg 2% van het nationaal inkomen van 2010.

De conclusie van het hoofdstuk is dat er in deze case studie ruimte blijkt te bestaan voor substantiële verbeteringen in de afstemming tussen beleidsopties aan de vraagzijde en de aanbodszijde. Het gebrek aan afstemming op het niveau van beleidsdoelstellingen – tussen doelstellingen op het gebied van energie-efficiëntie; hernieuwbare energie doelstellingen; aanbodszekerheid door het liberaliseren van energiemarkten – lijkt te leiden tot een intrigerende vergunningverlening voor torenhoge investeringen in de bouw van elektriciteitscentrales. Het zou echter beter zijn als dergelijke keuzen tussen aanbodsverschuivingen en vraagvermindering gemaakt werden op basis van overall kosteneffectiviteit. Een dergelijke afgewogen beleidsontwikkeling kan tot een substantiële daling leiden van het klimaat-energiebeleid.

Hoofdstuk 5 De effecten van exogene vooronderstellingen in emissiemodellen voor klimaatgassen - Een scenariostudie 2020 voor Portugal met het TIMES model

In dit proefschrift wordt het gebruik van het energie-economie-milieumodel TIMES aangewezen als middel om de interacties tussen beleidsinstrumenten te kwantificeren. Dergelijke modellen hebben echter beperkingen, die in voorafgaande hoofdstukken reeds in detail aan de orde zijn geweest. In dit hoofdstuk wordt dieper ingegaan op een van deze beperkingen, in hoeverre de modeluitkomsten afhangen van de exogene assumpties die die in het model geïntegreerd worden. Daarbij wordt met name gekeken naar de vooronderstellingen die gebruikelijk zijn bij de ontwikkeling van het klimaatbeleid, die de opvattingen weerspiegelen van wat beleidsmakers als meest relevant percipiëren.

Modellen zoals TIMES (en ook PRIMES, POLES, etc.) worden vaak gebruikt om beleidskeuzen te ondersteunen in het klimaatbeleid, met name bij het ontwikkelen van emissiescenario's, als voorwaardelijke voorspellingen. Voorbeelden van de benodigde exogene vooronderstellingen zijn de groeivoet van de bevolking en de economie; de snelheid van ontwikkeling en implementatie van energie-efficiënte technologie; de beschikbaarheid en prijs van energiebronnen; en de snelheid van implementatie van beleidsbesluiten en de effectiviteit ervan.

Elk van deze veronderstellingen bergt noodzakelijkerwijze een bepaalde mate van onzekerheid in zich, die resulteert in een onzekerheid van de emissievoorspellingen. Het is daarbij gebruikelijk om een aantal vooronderstellingen te combineren tot interessante scenariopaden. De scenariopaden combineren daarbij elk twee of meer reeksen van samenhangende veronderstellingen, met zinvol vergelijkbare scenarioresultaten. In dat combinatieproces gaat echter het inzicht verloren in de bijdrage die individuele veronderstellingen leveren in het resultaat. Het is daarbij ook lastig en tijdrovend om de bijdrage van elk van de vooronderstellingen aan de overall onzekerheid in het scenario resultaat. Dit hoofdstuk vult het ontbrekende onderdeel van de analyse, essentieel voor het interpreteren van modeluitkomsten in een beleidscontext.

Het TIMES_PT model wordt hier gebruikt bij het ontwikkelen van zeven emissiescenario's voor klimaatbeleid voor 2020, niet als beleidsscenario's maar als technische scenario's. Het Baseline Scenario wordt gevormd door een combinatie van alle exogene parameters. De andere zes scenario's variëren steeds één veronderstelling. De vergelijking tussen de scenario's geeft aan hoe de betreffende veronderstelling de uitkomsten beïnvloedt.

Het resultaat laat zien dat de meest relevante vooronderstellingen in het TIMES-model die zijn betreffende de sociaaleconomische ontwikkeling, macro-economisch en bevolkingsgroei. De volgende in belangrijkheid is die over de ontwikkeling van de energie-efficiëntie van technologie in het eindgebruik. In tegenstelling tot wat beleidsmakers veronderstellen speelt de prijs van fossiele energie slechts een beperkte rol bij het ontstaan van klimaatemissies, evenmin als de beschikbaarheid van hernieuwbare energiebronnen, samen minder dan 2% variatie op de Baseline.

Het lijkt er daarom sterk op dat de focus in het energie-aanbodbeleid in Portugal, te weten de beschikbaarheid van water voor waterkracht en de prijs van geïmporteerde olie, nauwelijks van belang zijn voor de omvang van de klimaatemissies in 2020. De emissies van klimaatgassen zoals geschat in de scenario's waar de vooronderstellingen per stuk werden gevarieerd verschilden minder dan 9% met het Baseline Scenario. Dit heeft gevolgen in twee richtingen. Modelverbetering zou niet op deze onderwerpen gericht dienen te zijn; en beleid zou niet op deze elementen gebaseerd moeten zijn. Een verder liggende consequentie zou zijn dat de stijging van olieprijzen zoals door beleidsmaatregelen geïnduceerd, een beperkte invloed zal hebben op de totale emissieomvang van klimaatgassen.

Hoofdstuk 6 Top-down en bottom-up modelering ter onderbouwing van low carbon scenario's; implicaties voor klimaatbeleid.

Een groot deel van het onderzoek voor deze promotie is gebaseerd op het gebruik van het TIMES_PT model. In het voorafgaande hoofdstuk is aangegeven hoe modeluitkomsten in TIMES_PT afhangen van verschillende vooronderstellingen. In dit hoofdstuk wordt een andere benadering gevolgd, door te laten zien hoe uitkomsten verschillen wanneer verschillende modelinstrumenten worden gebruikt, naast TIMES_PT nu ook GEM-E3_PT.

Bottom-Up (BU) en Top-Down (TD) modellen worden in het klimaatbeleid beide gebruikt om opties voor het realiseren emissiereductiedoelstellingen te bepalen en hun economische gevolgen te evalueren. Er zijn studies die aangetoond hebben dat dergelijke opties variëren bij het gebruik van economische TD modellen of van technologische BU modellen, aangezien zij gebaseerd zijn op divergente factoren in hun Baseline Scenario's.

Dit hoofdstuk onderzoekt hoe relevant de keuze van modelbenadering is voor de ontwikkeling van emissiereductie in het klimaatbeleid. Specifiek gaat het daarbij om:

1. Het identificeren van de verschillen in emissiereductiestrategieën die voortkomen uit gebruik van het BU TIMES model of het TD GEM-E3 model, toegepast in de Portugese case studie en uitgaande van een gemeenschappelijke Baseline.
2. Het aangeven hoe mogelijk verschillende uitkomsten leiden tot verschillende adviezen voor klimaatbeleid zouden kunnen leiden.

Voor dit doel gebruiken we een aangepaste Kaya identiteit om de modelgebaseerde strategieën voor emissiereductie te vergelijken.

In de Case Studie voor Portugal zijn drie Low Carbon scenario's voor 2050 ontwikkeld, met verschillende emissiereductiedoelstellingen. De resultaten laten zien dat de uitkomsten van het TIMES_PT en het GEM-E3_PT model dicht bij elkaar liggen, uitgaande van een geharmoniseerd Baseline Scenario. Bij beide modellen ligt het reductiepotentieel met name aan de aanbodszijde. Echter, de inspanning die per sector vereist is om het emissieplafond te realiseren verschilt, met name bij stringente emissiedoelstellingen, zodat ook de emissiereductiestrategieën kunnen verschillen, leidend tot verschillende beleidsontwerpen. GEM-E3_PT geeft een nadruk op energie-efficiëntie, omdat in het model meer nadruk op de vraagzijde ligt, terwijl TIMES_PT meer nadruk legt op de koolstofintensiteit. Daarbij verschuift de energieconsumptie in het finale gebruik naar elektriciteit, met meer hernieuwbare grondstoffen in de elektriciteitsproductie, met meer nadruk op het stimuleren van low carbon technologieën.

Het lijkt voor beleidsmakers van belang om de breedte van verschillende modeluitkomsten in beschouwing te nemen, met variatie in emissiereductie opties en kosten, dan van slecht een model uit te gaan. De uitkomsten van beide modellen zouden zelf redelijkerwijze gecombineerd kunnen worden, door stimulansen te creëren voor de verschuivingen in technologie in lijn met BU modellen, daarbij rekening houdend met de macro-economische effecten zoals voortkomend uit TD modellen. Natuurlijk blijft het zo dat zowel TD als BU modellen slechts middelen zijn om te onderzoeken welke technologieën en beleidsopties bepaalde scenario's bereikbaar zouden kunnen maken, tegen welke kosten. Zij vormen slechts een deel van de input die het beleidsvormingsproces informeren. Dit houdt tevens in dat het zinvol is om onder andere met betrokkenen uit industrie en consumentenbeweging te bespreken hoe adequaat de modeluitkomsten zijn voor het besluitvormingsproces.

Hoofdstuk 7 Overkoepelende conclusies

In dit hoofdstuk worden de resultaten van het onderzoek gepresenteerd als antwoorden op de vier hoofdonderzoeksvragen zoals die in hoofdstuk 1 zijn geformuleerd. De hoofdconclusie is dat in het brede beleidsvormingsproces de integratie van energie- en milieubeleid het beste begonnen kan worden op het niveau van het beleidsinstrumentarium. Beleidsevaluatie en integratie kan ondersteund worden in praktische en concrete zin door een bottom-up evaluatie van de specifieke beleidsinstrumenten die al gebruikt worden. De benadering die in dit proefschrift is ontwikkeld maakt het dan mogelijk om op betrekkelijk eenvoudige wijze antagonismen en synergieën te bepalen, die vrij eenvoudig met beleidsmakers gecommuniceerd kan worden. Tenslotte volgt een algemene discussie over de inzichten die uit het onderzoek zijn voortgekomen.

10 List of Publications

Publication in peer-reviewed journals

- Simoes, S., Huppes, G. & Seixas, J. (2012). Effects of exogenous assumptions in GHG emissions models - A 2020 scenario study for Portugal using the Times model. Submitted to the Technological Forecasting and Social Change Journal in June 2013

- Simoes, S., Huppes, G. & Seixas, J. (2012). A tangled web: assessing overlaps between energy and environmental policy instruments along the electricity supply chain. Submitted to the Environmental Governance and Policy Journal in August 2012

- Fortes, P., Simoes, S., Seixas, J., Van Regemorter, D., Ferreira, F. (2013). Comparison of Top-Down and Bottom-Up Modeling to Support Low Carbon Scenarios: Implications for Climate Policy. Climate Policy Journal Vol. 13, No. 3, 1–20, http://dx.doi.org/10.1080/14693062.2013.768919

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- Seixas, M.J.; Martins, A.; Martinho, S.; Fernandes, M.; Moura, F.; Simões, S. (2003). Technical studies for the Portuguese Programme on Climate Change [Programa Nacional para as Alterações Climáticas]. GASA-DCEA, FCT-UNL, CEEETA. Study commissioned by the Portuguese Environment Institute of the Ministry of the Cities, Land Management and Environment. (in Portuguese). December 2003. Lisbon, Portugal. http://www.apambiente.pt/politicasambiente/AlteracoesClimaticas/PNAC/Paginas/default.aspx

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- Evaluation of the Technical, Socio-economical, Organisational and Legal implications of the IPPC EU Directive (96/61/EC) in Portugal. Study commissioned by the General Directorate of Industry of the Portuguese Ministry of Economy. SEIA, SA. September 2000. Lisbon, Portugal.

11 Curriculum Vitae

Sofia Simões was born on 17 September 1974 in Coimbra in Portugal. From 1992 to 1998 she has studied Environmental Engineering at the New University of Lisbon, Portugal.

After obtaining her bachelor degree she worked for Shell Portugal in 1998 on the development of an integrated strategy for industrial waste management. From 1998 to 2000 she worked with a SEIA, SA - a Portuguese consultancy - on a Study commissioned by the Portuguese Ministry of Economy, assessing of the technical and economic implications of the implementation of the IPPC EU Directive in Portugal.

In 2000 she was awarded a scholarship to continue her graduate studies on Environmental Management and Policy at the International Institute for Industrial Environmental Economics (IIIEE) – Lund University, Lund, Sweden. She obtained her Master degree in October 2001 with a dissertation entitled "Incentives for demand-side management initiatives promoted by electricity companies: case study of EDP -- Electricidade de Portugal".

After her MSc studies she worked as a research associate at the New University of Lisbon. She cooperated in several national and EU research projects on energy-economy-environment modelling. She has worked as a consultant for the Portuguese Ministries of Economy and of Environment on the National Programmes on Climate Change and on Emission Ceilings. In parallel she has started her PhD at Leiden University in September 2004.

Since November 2011 she works at the Institute for Energy and Transport of the Joint Research Centre of the European Commission. Her work focuses on assessing the role and potential of low carbon technologies in Europe.