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

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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

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[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%.

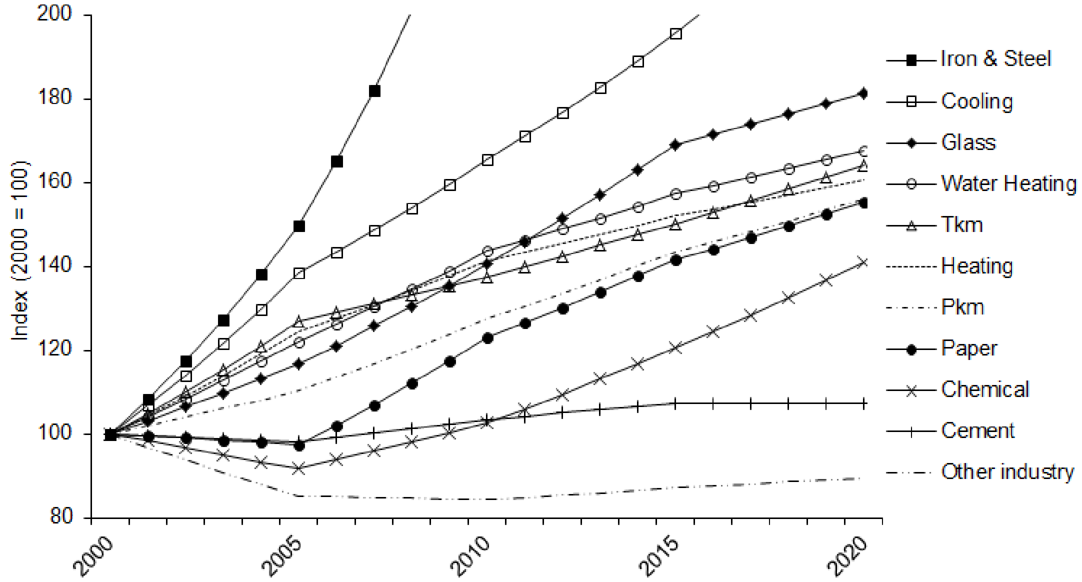

Figure 4.1. Evolution of the demand for materials and energy services. For the sake of simplicity, the demand for ammonia and chlorine was aggregated into "Chemical"; the demand for ceramics was aggregated with "Other industry" and from the useful energy demand of buildings we only depict here the demand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

[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

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[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)

4.7 References

ADENE. 2010. [NEEAP – 2009 Implementation report]. PNAEE – Relatório Nacional de Execução 2009. June 2010. Portuguese Energy Agency, Lisbon, Portugal (in Portuguese). Available at: [http://www.adene.pt/pt-pt/PNAEE/Documents/Relatrio_Impactos_PNAEE_2009_1_6_2010_2.pdf].

APA. 2006. PNAC. [National Climate Change Programme]. Programa Nacional para as Alterações Climáticas. January 2006. Portuguese Environment Agency, Lisbon, Portugal (in Portuguese).

APA. 2011. Portuguese National Inventory Report on Greenhouse Gases 1990-2009. Portuguese Environment Agency. Lisbon, Portugal. Available at: [http://www.apambiente.pt/politicasambiente/Ar/InventarioNacional/Documents/NIR_20110415_v20110515.pdf]

DGEG. 2010. [National Action Plan for Renewable Energy Within the Directive 2009/28/EC – Final version]. Plano Nacional de Acção Para as Energias Renováveis ao Abrigo da Directiva 2009/28/CE – Versão Final. Portuguese Republic. October 2010, Lisbon, Portugal.

EEA. 2004. Energy subsidies in the European Union: A brief overview. Technical Report No. 1/2004. Copenhagen: European Environment Agency. Available: [http://reports.eea.eu.int/technical_report_2004_1/en]. Accessed 10th June 2011.

ENE2020. [National Energy Strategy 2020]. Estratégia Nacional para a Energia 2020 (ENE2020). Resolution of the Council of Ministers nr.29/2010 of 15th April. DR 1st series, No 73. 15th April 2010.

EREC, Greenpeace. 2010. Energy Revolution –a sustainable world energy outlook. 3rd edition June 2010, Pp. 260. Available at: [http://www.greenpeace.org/international/Global/international/publications/climate/2010/fullreport.pdf], accessed September 7nd, 2011.

EU Commission COM(2008) 16 final. 2008. Proposal for a Directive of the European Parliament and of the Council COM(2008) 16 final amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the Community.

EU COM(2008) 17. EU Decision of the European Parliament and of the Council COM(2008) 17 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

EU Commission COM(2008) 19 final. 2008. Proposal for a Directive of the European Parliament and of the Council COM(2008) 19 final on the promotion of the use of energy from renewable sources.

EU Commission COM(2008) 30. 2008. 2020 by 2020—Europe's climate change opportunity, Communication from the European Commission to European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2008) 30.

Fleiter, T., Worrell, E., Heichhammer, W. 2011. Barriers to energy efficiency in industrial bottom-up energy demand models—A review. *Renewable and Sustainable Energy reviews*, Vol. 15, Issue 6: 3099-3111

Fortes, P., Simões, S., Cleto, J., Seixas, J. 2008. [Energy and other goods demand for Portugal until 2020 – Methodology] Procura de energia e outros bens para Portugal para o horizonte até 2020 – Metodologia, Departamento de Ciências e Engenharia do Ambiente, Science and Technology College of the New University of Lisbon. March 2008, Monte de Caparica, Portugal (in Portuguese).

GEOTA, FAPAS, LPN, Quercus, CEAI, Aldeia, COAGRET, Flamingo, SPEA, MCLT. 2011. Memorandum: The Portuguese dam program: economic, social and environmental disaster. Lisbon, Portugal. Available at: [http://www.geota.pt/xfiles/scContentDeployer_pt/docs/Doc2212.pdf], accessed September 2nd, 2011. April 2011.

Gonçalves, H., Joyce, A., Silva, L. (eds). 2002a. [Renewable Energy in Portugal Forum – a contribution towards the energy and environmental policy objectives – Geothermal]. Fórum Energias Renováveis em Portugal - Uma contribuição para os Objectivos de política Energética e Ambiental – Geotermia. ADENE/INETI, Lisbon.

Gonçalves, H., Joyce, A., Silva, L. (eds). 2002b. [Renewable Energy in Portugal Forum – a contribution towards the energy and environmental policy objectives – solar]. Fórum Energias Renováveis em Portugal - Uma contribuição para os Objectivos de política Energética e Ambiental – Solar. ADENE/INETI, Lisbon.

Gonçalves, H., Joyce, A., Silva, L. (eds). 2002c. [Renewable Energy in Portugal Forum – a contribution towards the energy and environmental policy objectives – Biofuels]. Fórum Energias Renováveis em Portugal - Uma contribuição para os Objectivos de política Energética e Ambiental – Biocombustíveis. ADENE/INETI, Lisbon.

GPPAA- MADRP, 2005. [Biomass and Renewable Energy in Agriculture, Fisheries and Forestry – Situation in 2005]. Biomassa e Energias Renováveis na Agricultura Pescas e Florestas- Ponto da Situação em 2005. Portuguese Ministry of Agriculture Rural Development and Fisheries, Lisbon.

de Groot, H., Verhoef, E., Nijkamp, P. 2001. Energy savings by firms: decision-making, barriers and policies. *Energy Economics*, Vol. 23: 717–740.

IEA. 2007. World Energy Outlook 2007 – China and India insights. International Energy Agency, Paris, France.

INAG, DGEG and REN. 2007. [National Programme for Dams with High Hydroelectric Potential] Programa Nacional de Barragens com Elevado Potencial Hidroeléctrico (PNBEPH). National Water Institute, General Directorate for Energy and Geology and National Transmission Operator. November 2007. Lisbon, Portugal (in Portuguese).

Jaffe, A., Stavins, R. 1994. The energy-efficiency gap – What does it mean? *Energy Policy*, Vol. 22, Issue 10: 804-810.

Krichene, N. 2002. World crude oil and natural gas: a demand and supply model. *Energy Economics*, Vol. 24, Issue 6: 557-576.

Lenard, T. 2009. Renewable electricity standards, energy efficiency, and cost-effective climate-change policy. *The Electricity Journal*, Vol. 22, Issue 8: 55-64.

Loulou, R., Remme, U., Kanudia, A., Lehtila, A. and Goldstein, G. 2005a. Documentation for the TIMES model - PART I. Energy Technology Systems Analysis Programme. Available: [www.etsap.org/tools.htm]

Loulou, R., Remme, U., Kanudia, A., Lehtila, A. and Goldstein, G. 2005b. Documentation for the TIMES model - PART II. Energy Technology Systems Analysis Programme. Available: [www.etsap.org/tools.htm]

MEI, 2007a. Renewable energy in Portugal. Ministry of Economy and Innovation, Lisbon, Portugal. Available at: [http://www.min-economia.pt/document/Energias_Renov_PT.pdf]

MEI, 2007b. Portuguese Energy Policy – Energy and Climate Change. Ministry of Economy and Innovation, Lisbon, Portugal. Available at: [http://www.min-economia.pt/document/policy.pdf]

OECD. 2005. Environmentally Harmful Subsidies: Challenges for Reform. OECD, Paris.

RCM 1/2008, January 4th. Resolução do Conselhos de Ministros 1/2008 relativa ao PNAC 2006 e Novas Metas 2007 [Resolution of Council of Ministers 1/2008 regarding the National Climate Change Programme 2006 and New Targets 2007]. DR 1st series, no. 3. (in Portuguese)

RCM 80/2008, May 20th. Resolução do Conselhos de Ministros 80/2008 relativa ao Plano Nacional de Acção para a Eficiência Energética [Resolution of Council of Ministers 80/2008 regarding the National Action Plan for Energy Efficiency]. DR 1st series, no. 97. (in Portuguese)

REN and ISR. 2005. [Characterization of Sustained Integration Solutions of High Intermittent Production Levels] CISEPI: Caracterização de Soluções de Integração Sustentada de Elevados Níveis de Produção Intermitente. ISR, Coimbra, Portugal (in Portuguese).

REN and ISR. 2007. [Energy efficiency and sustainable integration of special regimen production] EFIPRE - Eficiência energética e integração sustentada de PRE. ISR, Coimbra, Portugal (in Portuguese).

REN, 2005. [Investment Plan for the National Transmission Grid 2006-2011]. Plano de investimentos na rede nacional transporte 2006-2011. REN, Lisbon, Portugal (in Portuguese). Available at: [www.ren.pt]

REN. 2008. [PDIRT – Development and Investment Plan of the Transmission Grid 2009-2014 (2019)], PDIRT- Plano de Desenvolvimento e Investimento na Rede de Transporte 2009-2014 (2019). REN, Lisbon, Portugal (in Portuguese). Available at: [www.ren.pt].

Ribeiro, J. Félix, Dias, A. M., Lobo, A., Nunes, C., Lopes, E., Ponte da Silva, G., Escária, S. 2008a. [Scenarios for the Portuguese Economy in the Post-Kyoto Period] Cenários para a Economia Portuguesa no Período Pós-Quioto. DPP – Department of Prospective and Planning and International Relations of the Portuguese Ministry of the Environment. March 2008. Lisbon, Portugal (in Portuguese).

Russ P., Wiesenthal, T. Van Regemorter, D., Císcar, J.. 2007. Global Climate Policy Scenarios for 2030 and beyond - Analysis of greenhouse gases emission reduction pathway scenarios with the POLES and GEM-E3 models. October 2007. JRC Reference Reports. Report EUR 23032 EN.

Sá da Costa, A. APREN in van de Toorn, G. 2007. EU TradeWind Work Package 2: Wind Power Scenarios. W.P.2.1:Wind Power Capacity Data Collection. 27 April 2007

Seixas, J., Simões, S., Cleto, J., Fortes, P., Barroso, E., Alves, B., Dinis, R., Pisco, F., Faria, P., Finote, S. 2008. [Final Report: Portugal Climate 2020 – Impact Evaluation of the EU Energy-Climate Policy Package for Portugal] Relatório Final: Portugal Clima 2020 – Avaliação do Impacto da Proposta Energia-Clima da Comissão Europeia para Portugal, Evalue, S.A. and Science and Technology College of the New University of Lisbon. November 2008, Lisbon, Portugal (in Portuguese).

Seixas, J., Simões, S., Fortes, P., Dias, L., Gouveia, J., Alves, B., Maurício, B. 2010. New Energy Technologies: RoadMap Portugal 2050 - Analysis of new national energy technologies e impact scenarios on the national energy system - D3: Competitiveness Assessment of New Energy Technologies. Policy Report for the Portuguese Innovation Fund for Renewable Energy of the Ministry of Economy. Evalue, S.A. and Science and Technology College of the New University of Lisbon. December 2010, Lisbon, Portugal (in Portuguese). Available at: [http://www.evalue.pt/conteudo.php?mid=3010101212&id=4821].

SETIS. 2011. SETIS Energy Calculator. Institute for Energy and Transport, Joint Research Centre of The European Commission. Available at: [https://odin.jrc.ec.europa.eu/SETIS/SETIS1.html#], accessed December 20, 2011.

Schleich, J. 2009. Barriers to energy efficiency: A comparison across the German commercial and services sector

Ecological Economics, Vol. 68, Issue 7: 2150-2159.

Schüle, R., Arens, C., Becker, D., Fülöp, O.. 2009. Policy Learning and Innovation in National Energy Eficiency Action Plans. European Council for an Energy Efficient Economy Summer Study 2009. 1-6 June 2009. La Colle-sur-Loup, France.

Schüle, R., Höfele, V., Thomas, S., Becker, D. 2011. Improving the National Energy Efficiency Strategies in the EU Framework – Findings from Energy Efficiency Watch Analysis March 2011. Wuppertal Institut and Ecofys Germany. EEW-Publication Nr.

1/2011. Available at: [http://www.energy-efficiency-watch.org/fileadmin/eew_documents/EEW2/Improving_National_Energy_Efficiency_Strategies_in_the_EU_Framework_Findings_from_EEW1.pdf], accessed October 25, 2011.

Simões, S., Cleto, J., Fortes, P., Seixas, J., Huppes, G. 2008. Cost of energy and environmental policy in Portuguese CO_2 abatement - scenario analysis to 2020. *Energy Policy*, Vol. 36, Issue 9: 3598-3611.

Sorrell, S., O'Malley, E., Schleich, J., Scott, S. 2004. *The economics of energy efficiency: Barriers to cost-effective Investment*, Edward Elgar Publishing Ltd., Cheltenham, United Kingdom. pp. 368.

van Regemorter, D., Kanudia, A. Projections of the demand of energy services for NEEDS, 2006. Unpublished working paper from the NEEDS project.

Wade, J., Guertler, P., Croft, D., Sunderland, L. 2011. National energy efficiency and energy saving targets – further detail on Member States. ECEEE – European Council for an Energy Efficient Economy. Pp. 42. May 24th 2011. Available at: [http://www.eceee.org/Policy/Targets/Targets_Country_Specific_Information.pdf], accessed September 13, 2011.

WWF, n.d. To dam or not to dam? Five years on from the World Commission on Dams. WWF Global Freshwater Programme, The Netherlands. Pp 15. Available at: [http://wwf.panda.org/what_we_do/footprint/water/dams_initiative/], accessed September 15, 2011.

WWF, ECOFYS, OMA. 2011. WWF - The Energy Report. Pp 256. Available at: [http://wwf.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/renewable_energy/sustainable_energy_report/], accessed October 20, 2011.

WCD, 2000. Dams and Development – A new framework for decision making. The report of the World Commission on Dams. London and Sterling, VA: Elsevier.

Wuppertal Institut and Ecofys. 2009. Energy Efficiency Watch (EEW) - Final Report on the Evaluation of National Energy Efficiency Action Plans (NEEAPs), Wuppertal, Berlin.