Is economic optimism hampering long term energy efficiency goals? The role of energy system models

Sofia Simoes
CENSE, Faculdade Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal
FCT/UNL
Campus da Caparica
2829-516 Caparica
Portugal
+351 21 294 83 74
sgcs@fct.unl.pt

Luís Dias
CENSE, Faculdade Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal
FCT/UNL
Campus da Caparica
2829-516 Caparica
Portugal
+351 21 294 83 74
luisdias@fct.unl.pt

Patrícia Fortes
CENSE, Faculdade Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal
FCT/UNL
Campus da Caparica
2829-516 Caparica
Portugal
+351 21 294 83 74
p.fs@fct.unl.pt

João Pedro Gouveia
CENSE, Faculdade Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal
FCT/UNL
Campus da Caparica
2829-516 Caparica
Portugal
+351 21 294 83 74
jplg@fct.unl.pt

Júlia Seixas
CENSE, Faculdade Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal
FCT/UNL
Campus da Caparica
2829-516 Caparica
Portugal
+351 21 294 83 74
mjs@fct.unl.pt

Keywords

modelling, sufficiency, system, target, efficiency, energy systems, TIMES

Abstract

Energy system models as TIMES or PRIMES support policy makers in energy and climate change mitigation policies, as the EU-wide energy efficiency (EE) goal of 30 % by 2030. Model outputs are determined by assumptions, some of which are tested. However, the economic development assumptions considered in the models are less experimented with. Economic growth is present in all long-term energy scenarios as it might not be politically acceptable to consider otherwise. Thus, energy system models show an energy future with growing energy services demand.

We explore to what extent such economic optimism affects the definition of long term energy efficiency goals. We use the linear optimization bottom-up TIMES_PT energy system model implemented for Portugal. We model in TIMES_PT how six different macro-economic trajectories lead to different energy efficiency goal formulation. The Base scenario has a GDP growth of 1.5 % pa over the period 2020–2050, whereas the High scenario considers a GDP growth of 3.0 % pa. We then deviate from economic optimism with two scenarios with constant or decreasing energy services demand till 2050. The Sufficiency scenario has a constant energy services demand from 2014 till 2050. The Revolution scenario considers a decrease in energy services demand of 7 % every 5 years from 2014 till 2015. Additionally, we then model Base_Transport and Base_Industry, where we lower demand for mobility and for products from energy intensive industries.

With the traditional economic optimistic vision, the final end-use energy consumption in 2050 is 15 % lower (Base) or 31 % lower (High) compared to 2010. In the Sufficiency and Revolution scenarios the Final Energy Consumption (FEC) in 2050 is 42–65 % lower. We find a substantial difference for energy efficiency target setting depending on the considered economic scenario. Energy system models inherently consider all possible energy efficiency improvement due to deployment of more efficient technologies. We argue that this is not enough when looking into long-term energy futures requiring an open mind frame. One way to do so is, together with policy makers, explore futures where the demand for energy services is not necessarily growing. By doing so the importance of policies focused on the drivers affecting energy services demand can be made visible.

Introduction

Energy system models as TIMES or PRIMES support policy makers in energy and climate change mitigation policies, such as the EU-wide energy efficiency goal of 30 % by 2030 (European Communities, 2012). These models' outputs are determined by assumptions, some of which are tested. However, the economic development assumptions underlying the models use are less experimented with, perhaps as it might not be politically acceptable to consider an economy that is not growing (Simoes, Fortes, Seixas, & Huppes, 2014). In fact, long term economic growth is assumed in the energy scenarios used for policy support in the European Union (EU), as in the 2050 Energy Roadmap (European Communities, 2011) and the Roadmap for moving to a competitive low carbon economy in 2050 (European Commission, 2011).

Similarly to the policy support work, in the scientific literature most of the long-term energy scenarios studies rely on underlying macroeconomic assumptions that consider a growth of the GDP. Examples are the work of (Schulz, Kypreos, Barreto, & Wokaun, 2008) with the MARKAL technological model for Switzerland considering a GDP growth of approximately 50 % from the year 2000 to 2050; of (Patricia Fortes, Simões, Seixas, Regemorter, & Ferreira, 2013) for Portugal using both the TIMES_PT technological model and the general equilibrium model GEM-E3_PT where GDP is assumed to grow 2.3 % from 2010 till 2050; of (Gambhir, Napp, Emmott, & Anandarajah, 2014) using the technological model TIAM-UCL for India with a 7.7 % GDP annual growth till 2030; of (Bibas, Méjean, & Hamdi-Cherif, 2015) with a 12 % global GDP growth from 2010 till 2050 using the IMACLIM-R general equilibrium model; or of (Capros et al., 2014) that compares the outputs of four different models (NEMESIS, PRIMES; TIMES-PanEU and GEM-E3) for EU to assess decarbonisation pathways. In the latter for all these four models runs it is considered the GDP evolution from (European Commission, 2009) of 2.4 % in the period 2007–2020, followed by 1.6 % for 2021–2030 and 1.3 % in 2041–2060. Although the GDP growth rate is reduced from 2007 till 2050, it is nonetheless still growing.

In parallel with such optimistic assumptions on more or less eternal economic growth used in the energy modelling field, there is also a substantial body of work that challenges them. These stem from the degrowth economics literature (Bauhardt, 2014; Jackson, 2009; Kallis, Kerschner, & Martinez-Alier, 2012), with some more energy-focused analysis looking into the economic growth assumptions and their implications for energy systems and energy efficiency. An example is the work of (AYRES, TURTON, & CASTEN, 2007) that states that "if energy service costs begin to increase significantly as a fraction of GDP, economic growth is likely to decrease or even turn negative". (Victor, 2012) used the LowGrow simulation model for the Canadian economy to study how a 'degrowth' scenario affects the interplay of scale and intensity in determining greenhouse gas emissions. Moreover, a wide number of econometric studies analyse the interrelations between GDP and energy consumption. The authors seem to agree that there is a multitude of factors involved and that developed and developing countries show different causality relations between growth and energy efficiency policies (Belke, Dobnika, & Dreger, 2011; Chen, Chen, & Chen, 2012; Chontanawat, Huntb, & Pierse, 2008). However, to our knowledge in the current literature there are no studies combining degrowth assumptions with long-term energy system scenarios derived with energy system models.

This paper builds on this gap and seeks to add value to the literature by exploring the extent to which economic optimism affects the definition of long term EE goals. We use the linear optimization bottom-up TIMES_PT energy system model implemented for Portugal, which has been used for policy support for a decade. We model in TIMES_PT how six different macro-economic trajectories lead to different energy efficiency goal formulation and subsequent energy efficiency polices. The Base scenario follows the development pathway of the last years but with a GDP growth of 1.5 % pa over the period 2020–2050, whereas the High scenario considers a GDP growth of 3.0 % pa. We then deviate from traditional economic optimism with the Sufficiency and Revolution scenarios, respectively with a demand for energy services and materials evolution till 2050 constant from 2014 and a decrease by 7 % every 5 years (as it happened for the Portuguese GDP in the period 2007 till 2013). We then model two variants of Base, Base_Transport and Base_Industry. For these two, only the demand for mobility and for energy use for energy intensive industries was reduced by 7 % every 5 years, respectively. The paper is structured as follows: in the following section we present an overview of the current and past energy and economic context for Portugal and detail the methods and assumptions underlying the modelling. Section 3 presents and discusses the results, while Section 4 concludes the paper.

Making a case for less economic optimism – looking back into two decades of energy projections and scenarios for Portugal

Before delving into the modelling exercise where we studied the effect of a "pessimistic" economic scenario on outputs of a large energy system model and its implications for energy efficiency target setting, in this section we look into past energy scenarios made for Portugal and compare these with real values of Final Energy Consumption (FEC). The objective of this comparison is to highlight both the uncertainty associated to such long term scenarios and the importance of the macroeconomic assumptions in influencing the results.

Our statement is supported by the fact that the first publicly available energy projections for Portugal date from 1982 for the period 1990–2010 as part of the first National Energy Plan and were reviewed already in 1984 (PEN84 study) considering updated macro-economic projections, as well as in 1993 considering energy efficiency measures. In 1995 more scenarios were made for the period 1995–2015 (CCE study) and the first 2020 energy projections for Portugal were developed in 1999 for the period of 2000–2020 (ED20 study).

In all these studies energy projections and scenarios were based on simulation methodologies and tools. It was only from 2004 that optimization tools, in particular the TIMES_PT energy technology model (detailed in the following section), were used to build energy projections/scenarios for Portugal. We present an overview of the most relevant of these in Table 1 detailing the name of the policy support study that motivated the energy projections and its main goals and assumptions, including on GDP growth.

Considering both the simulation and the more recent optimisation based work, we have looked into the final energy consumption projections generated by a total of eight studies developed for energy and climate policy support in Portugal (Figure 1). Of these, four studies and their respective projections were developed based on energy simulation approaches and methods and cover the period from 1990 till 2020 (PEN84, .CCE and GHG) The other four studies (PT20, NETR, LCR and NCCP) were developed from 2008 onwards and delivered energy scenarios for the period 2020 till 2030 using the TIMES_PT energy technology model. As a common feature to most of these studies they typically rely on two distinct macroeconomic scenarios for the long term, a high growth and a low growth scenario, depicted with the letters H and L in front of the study name in the figure.

We observe that the different studies and projections made during the past two decades led to variations in final energy

Table 1. Overview of major energy scenarios for policy support performed with TIMES_PT including major economic assumptions.

Study name [Time horizon]	Goals of the study	Main TIMES_PT assumptions
Portugal Clima2020 (PT20) [2000–2020]	Assess impact of EU 20-20-20 policy package (Seixas et al., 2008)	Two macro-economic scenarios (2–3 % GDP growth), 84 USD2010/bbl in 2020. No GHG caps.
New Energy Technologies: Roadmap Portugal 2050 (NETR) [2005–2050]	Assess competitiveness of renewable technologies within the Portuguese energy system, identifying the critical drivers for their deployment (Seixas et al., 2010)	Two macro-economic scenarios (1–3 % GDP growth), 101 USD2010/bbl in 2020. -20 % GHG cap from 1990 in 2020. Cost reduction in specific renewable technologies.
Low Carbon Roadmap: Portugal (LCR) 2050 [2005–2050]	Assess the feasibility of achieving a low carbon scenario for Portugal in the long term. Identification of the energy drivers/technologies for achieving a reduction of -60 % and -70 % of energy related and process GHG emissions in 2050 (Seixas et al., 2012)	Two macro-economic scenarios (0.7–3 % GDP growth), 118 USD2010/bbl in 2020. +1 % GHG cap from 1990 in non-Emission Trading Schem (ETS) in 2020.
Portuguese National Action Plan on Climate Change (NCCP) – 2020 [2005–2030]	Develop cost-effective GHG mitigation policies and measures for 2020 (Seixas et al., 2014)	Two macro-economic scenarios (0.39–3 % GDP growth), 115 USD2010/bbl in 2020. +1 % GHG cap from 1990 in non-ETS in 2020. Explicit EU-ETS prices.

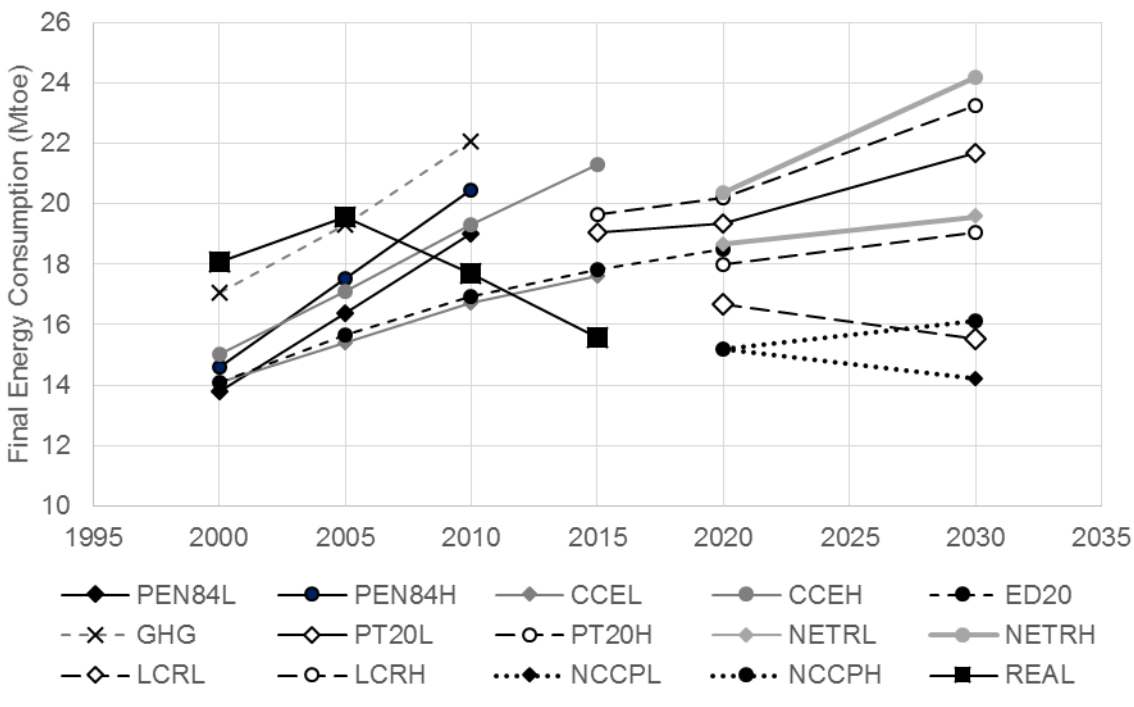

Figure 1. Different estimates for Final Energy Consumption in Mtoe for Portugal from past energy scenarios and projections studies. REAL refers to historical values reported by the National Statistics Office. The historical values for 2015 refer to 2012 values here included for better comparison.

consumption in 2010 of less 4 % to more 35 % than the real 2010 measured values. These differences increase with the age of the studies, the assumptions on expected macro-economic growth and other assumptions such as on considered sector discount rates. Besides assumptions on economic growth, typically energy projections and scenarios include assumptions on different levels of the structure of the GDP, on the level of implementation of policies and measures according to established policy goals (e.g. National Plan for Energy Efficiency), on primary energy prices (imports of coal, oil and natural gas), on electricity trade with Spain and on hydrological availability, and on availability and techno-economic aspects of energy supply and demand technologies.

Looking into the energy forecasts of final energy consumption for the years 2020 and 2030, it becomes clear that the more recent studies (NCCP made in 2014 and LCR made in 2012) are substantially more conservative than studies made in 2008 (PT20) and in 2010 (NETR). The more recent studies generated final energy consumption values for the country that are up to 25–31 % lower than in the 2008 study, respectively for 2020 and for 2030. Although, as we previously stated, there are several motives for these differences, we consider that the most influential one is the expectations on macro-economic growth, based on our previous work with the TIMES_PT model and the relative importance of its assumptions as described in (Simoes et al., 2014).

The development of energy scenarios relies on a continuous update of the data sources which in the recent years reflect more accurately the economic crisis felt in Portugal. Inevitably the expectations on future -macro-economic growth and associated demand for energy services even as far as 2030, 15 years from now, are affected by the current situation. In other words, before the economic crisis the macro-economic scenarios considered to develop the energy consumption projections were more optimistic than the ones developed after 2010. Before and after the crisis these scenarios for Portugal were developed by the same persons using a similar process involving active stakeholder participation, described in (Patrícia Fortes, Alvarenga, Seixas, & Rodrigues, 2015) and in (Seixas et al., 2010). The same stakeholders that, in 2007, were not open to consider a GDP growth rate from 2020 till 2050 lower than 1.5 %, were in 2012 and 2013 willing to consider a growth rate as low as 0.39 %, although always maintaining a "high growth" scenario.

As we stated before, the impressive changes in the economy and Portuguese energy system during the period 2007–2013 (Figure 2) made acceptable for stakeholders to be less economic optimistic. From 2007 to 2013 the Portuguese GDP was reduced by 7 % and the final energy consumption was reduced by 20 % (DGEG, 2013). Although the population was constant the final energy intensity of the GDP was in 2012 13 % lower than in 2007. The primary energy intensity of the GDP was 15 % lower in 2012 than in 2007. This was a case of degrowth for the worse possible motives: unemployment and significant loss of welfare and wellbeing, as described by some degrowth economic sceptics (van den Bergh, 2011). Nonetheless, it shows the possibility for rapid and drastic changes of energy systems, although with brutal costs. This leads us then to the question of how conservative optimistic assumptions on economic growth used by energy system models are blinding us or not for setting long term energy efficiency targets.

Using the TIMES-PT energy system model to study effects of economic optimism

THE TIMES_PT MODEL

TIMES_PT is a cost minimization linear optimization bottom-up model generated with the TIMES model generator of the IEA-ETSAP. More information on TIMES can be found at (Loulou, Remme, Kanudia, Lehtila, & Goldstein, 2005a, 2005b). TIMES_PT represents the Portuguese energy system from 2005 to 2065 and is disaggregated in: primary energy supply; electricity generation; industry; residential; commercial; agriculture; and transport. TIMES_PT represents the energy system of Portugal and its possible long-term developments. The actual system encompasses all the steps from primary resources in place to the supply of the energy services demanded by energy consumers, through the chain of processes which transform, transport, distribute and convert energy into services. Figure 3 presents an overall view of the structure of the energy system modelled in TIMES_PT.

The ultimate goal of the model is the satisfaction of the energy services demand at the minimum total system cost (i.e., net surplus maximization), subject to technological, physical and policy constraints. TIMES_PT defines an optimal combination of existing and emerging technologies, using different forms of energy, while respecting the framework of polices and measures imposed and the national potential of endogenous resources (hydro, wind, solar thermal, biomass, etc.) from (Seixas et al., 2010).

As a partial equilibrium model, TIMES_PT does not model the economic interactions outside of the energy sector. Furthermore, it does not consider in detail demand curves and non-rational aspects that condition investment in new and more efficient technologies. In fact, the model unrealistically assumes that stakeholders are rational with perfect market foresight. Thus, some of the most important barriers for the uptake of new energy technologies are absent in TIMES_PT. Therefore, all the scenarios and respective technology choices, are driven by the cost-effective criteria.

The energy services and materials demand projections drive the whole energy system modelled in TIMES_PT and are thus described in more detail in the next section.

MODELLED MACRO-ECONOMIC AND ENERGY SERVICES AND MATERIALS SCENARIOS

For this analysis we have modelled a total of six scenarios representing different macro-economic trajectories which lead to different energy services and materials demand to be input into TIMES_PT along the following categories:

- Industry: i) quantities (Mt) of steel, paper, glass, cement, lime, 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;

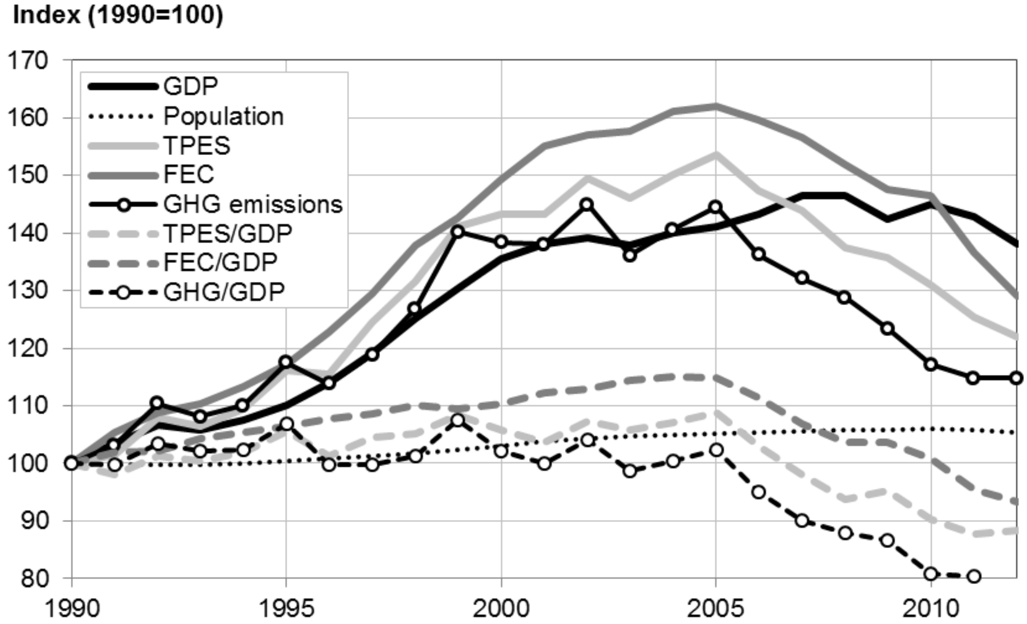

Figure 2. Evolution of main energy indicators for Portugal from 1990 until 2012. FEC stand for final energy consumption, TPES for total primary energy consumption, GHG for greenhouse gases emissions. Reference: own elaboration over data from (DGEG, 2013).

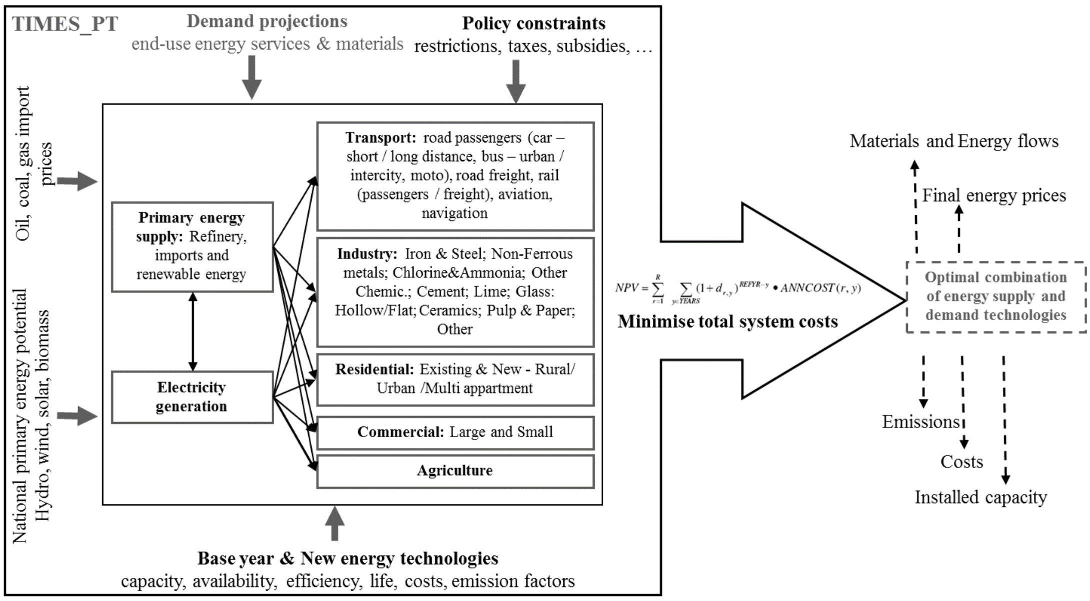

Figure 3. Overview of the TIMES_PT energy system model and its main inputs and outputs. Reference: (Simões, Cleto, Fortes, Seixas, & Huppes, 2008).

- Transport: passengers and freight transportation through road, railway, aviation and navigation expressed in pkm (passengers.kilometer) and tkm (ton.kilometer).

The demand projections are developed using a bottom-up approach for buildings and a top-down approach for the industry and transport sectors starting from macro-economic assumptions on GDP structure and evolution and on demographics. For the residential and commercial sectors, detailed assumptions are made on: stock of existing and new buildings; evolution of occupancy rate; average building area; evolution of heating and cooling comfort requirements per m^2; evolution of per capita water and cooking useful energy requirements, among others. The assumptions consider past statistics and forecasts on: population growth, private consumption and planned touristic developments as described in the socio-economic scenarios (Gouveia, Fortes, & Seixas, 2011). For the industry and transport sectors a relationship is assumed between the final demand for energy intensive materials (steel, paper, glass, cement, lime, ammonia and chlorine), transport and other energy services required for industry and evolution of sector gross added value (GAV). This relationship includes the effect of a price evolution factor, income and price elasticity of final demand to GAV (van Regemorter & Kanudia, 2006).

In this paper we take two socio-economic pathways for Portugal representing a 'best case' and 'worst case' scenario in terms of economic and population evolution. The High scenario assumes a higher recovery of the economy accompanied by its reindustrialization. Besides a GDP growth of 3.0 % pa over the period 2020–2050 this scenario has an increase of the weight of industry in the gross value added (GVA), from the current 19 % to 25 % in 2050. The high scenario is associated with the high estimates of population growth from the Portugal statistics institute (INE, 2014), which consider a decrease of population around 0.2 % pa from 2010 to 2050. The Base scenario keeps the development model followed in the last years leading to a GDP evolution of only 1.5 % pa for the period 2020–2050. Services are still 72 % of the GVA and industry 19 %. Base considers a decrease of population around 0.4 % pa between 2010 and 2050 (INE, 2014). Using the approach above described these two macro-economic scenarios were used to generate materials and energy services demand projections that were input into TIMES_PT. These were validated through an extensive stakeholder consultation process during 2013 and 2014 (Seixas et al., 2014).

Besides High and Base we have modelled four other scenarios that deviate from the more traditional economic optimism of High and Base. These are the Sufficiency and Revolution scenarios, respectively with a demand for energy services and materials evolution till 2050 constant from 2014 and a decrease by 7 % every 5 years. Additionally we model two variants of Base, Base_Transport and Base_Industry. For these two, only the demand for mobility (in Base_Transport) and for energy use for energy intensive industries (in Base_Industry) was reduced by 7 % every 5 years Therefore, we have considered the demand for energy services and materials as a proxy for economic "pessimism".

Results

In this section we present our results for the six different economic trajectories input into the TIMES_PT model: Base, High, Sufficiency, Revolution, Base_Transport and Base_Industry. We explore to what extent such differences in the considered energy services and material demand (and their underlying macroeconomic assumptions) affect the model outputs in terms of final energy consumption.

In Figure 4 we present the final energy consumption for the six modelled scenarios. As expected, the final energy consumption pattern follows closely each scenario's energy services demand assumptions, with the Revolution scenario being much lower than High and the other scenarios in-between. The interesting message to retain from this figure is the magnitude of the differences between scenarios; in 2020 we obtain a range of variation of more 2 % and less 13 % of final energy consumption than Base.

In 2030 these variations are of more 9 % to less 28 % than Base, and in 2050 of more 23 % to less 49 % than Base. Thus, only by comparing two "economically optimistic scenarios", High and Base, we derive variations in final energy consumption up to more 23 %. If we then take into account "non-optimistic" scenarios, as Sufficiency, the differences in the projections become much more relevant, up to less 17 % final energy consumption in 2050 than Base.

Taking 2010 as a reference year, with the traditional economic optimistic vision, the final end-use energy consumption in 2050 is 31 % less (Base) or 15 % less (High) than in 2010. In the Sufficiency and Revolution the final energy consumption in 2050 is 42–65 % less. In the variants Base_Industry and Base_transport the final energy consumption in 2050 is 35–44 % lower than in 2010. If an energy efficiency policy target is set based on a past consumption the different economic assumptions might lead to substantially different energy efficiency targets.

Another interesting finding is that when looking into degrowth only of transports (Base_transport) we see that the total final energy consumption is very close to the one of Sufficiency in 2050. Although the Base_transport scenario has a lower consumption of the transport sector of 56 % below Base, the total consumption of the energy system is identical to maintaining, for the whole country, energy demand values similar to the ones in 2014. This gives a very clear indication of the relevance of transports in the Portuguese energy system and on what could be a possible low-mobility future. The challenge is on how such a future could be achieved without a signifi-

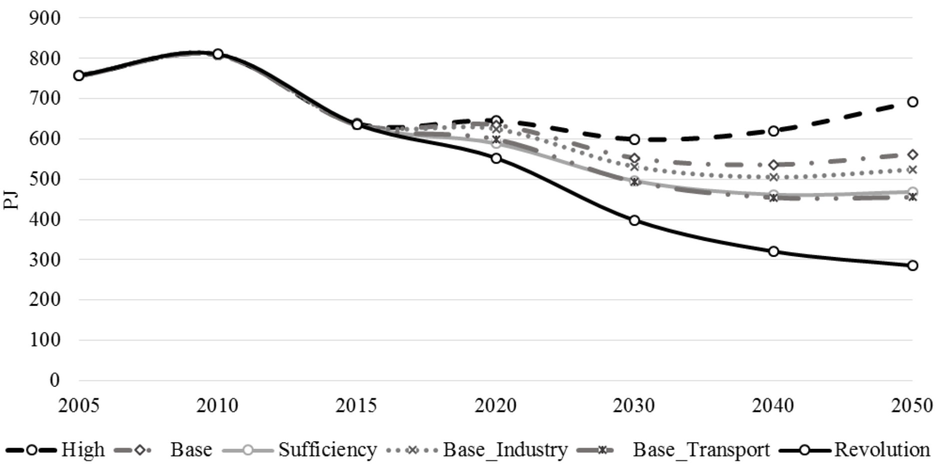

Figure 4. Final energy consumption for the six modelled scenarios.

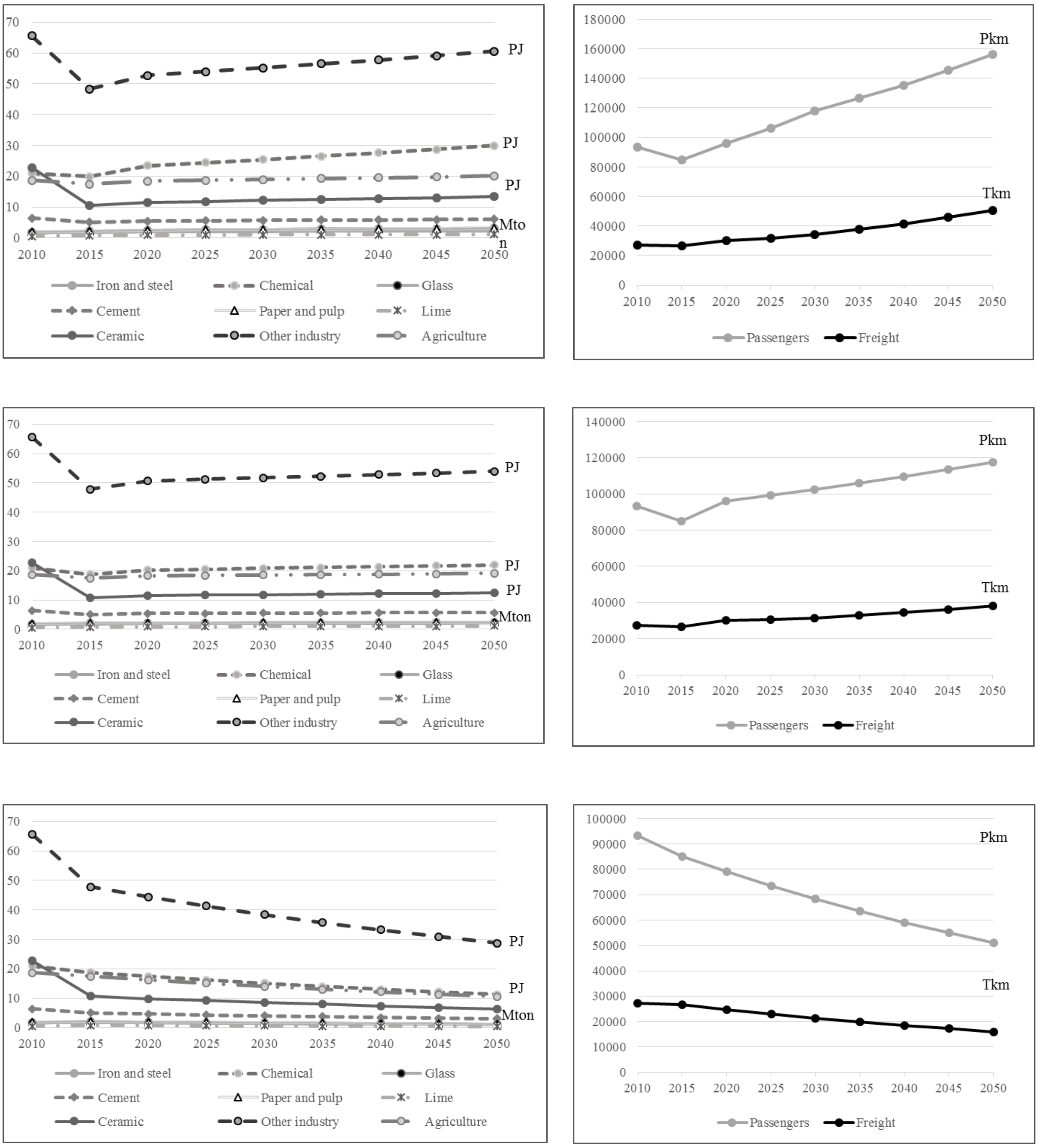

Figure 5. Energy services and materials demand input into TIMES_PT for High (top), Base (middle) and Revolution (low) scenarios.

cant loss of well-being. Could this be a world of teleworking? What would such lower passenger kilometres entail not in terms of technology but in terms of lifestyles? Note that in all our scenarios, cost-effective efficient car and trucks technologies replace the existing ones and it is possible to deliver the same passenger-kilometres with less energy consumption. But if we assume that the need for delivered passenger-kilometres is lower, then we also obtain less cars and less trucks, and not more trucks and cars, albeit more efficient.

In the Base_industry scenario, the national final energy consumption in 2050 is only less 7 % than in Base but this means that the industry sector's final energy consumption is less 21 % than in Base in 2050. This scenario would represent the disappearance of the energy intensive industry in Portugal (cement, ceramics, glass production and pulp and paper), but with relatively small differences in terms of consumed energy. This naturally does not represent an energy efficiency gain but it serves to illustrate the point that variations in macro-economic assumptions should be considered in designing long-term energy scenarios.

In terms of the different energy carriers it becomes visible that the different carriers do not vary substantially their relative share of in total final energy consumption depending on scenario. Table 2 shows the share of energy carriers in total Final Energy Consumption (FEC) in 2050 for the different modelled scenarios. The most evident change is in the relative share

Table 2. Share of energy carriers for 2050 for the different scenarios.

	Biomass	Biofuels	Coal	Electricity	Gas	Ambient Air	Oil	Solar
Base_industry	7 %	10 %	3 %	36 %	24 %	3 %	10 %	6 %
Base_transport	6 %	3 %	5 %	37 %	27 %	4 %	12 %	6 %
High	7 %	7 %	3 %	34 %	24 %	12 %	8 %	4 %
Revolution	7 %	5 %	3 %	36 %	24 %	4 %	11 %	10 %
Base	6 %	9 %	3 %	34 %	26 %	5 %	11 %	6 %
Sufficiency	6 %	7 %	4 %	36 %	27 %	2 %	12 %	7 %

of ambient air, here used as a proxy for assessing deployment of heat pumps in buildings for space heating and cooling. In High scenario, with a quite optimistic GDP growth assumption, deployment of heat pumps is cost-effective in buildings and ambient air represents 12 % of FEC. With such a scenario a policy maker could decide to give incentives to heat pumps as a means to ensure a cost-effective technology mix for heating and cooling. However, in scenarios with more moderate macro-economic assumptions (actually all other), the role of heat pumps is substantially lower.

Another interesting difference in terms of relative importance of energy carriers is the share of solar energy in total FEC, which is higher for the Revolution scenario (10 % of FEC) than for the other scenarios (varying from 4–7 % of FEC). This illustrates how different assumptions on macro-economic growth point to different ranking on the energy carriers. Likewise, in terms of primary energy consumption the results show the same trends as for final energy consumption. The lower demand for mobility results in 21 % less energy imports in 2050 than in Base.

Conclusions

Most long term energy scenarios are developed over macro-economic assumptions that consider long-term economic growth, which does not correspond to reality. In this paper we investigate to what extent such economic optimism affects the definition of long term energy efficiency goals set by energy system models. We modelled six different macro-economic trajectories in the linear optimization bottom-up TIMES_PT energy system model for Portugal. The Base has an underlying GDP growth of 1.5 % pa over the period 2020–2050, the High scenario a GDP growth of 3.0 % pa. The Sufficiency scenario considers an energy services and materials demand constant from 2014 values and the Revolution scenario a decrease in energy services demand of 7 % every 5 years. Additionally we modelled two variants of the Base, Base_Transport and Base_Industry. For these two, only the demand for mobility and for energy use by energy intensive industries is reduced by 7 % every 5 years, respectively for mobility and for products from energy-intensive industry.

With our analysis we find a substantial difference for energy efficiency target setting depending on the considered energy demand scenario. Energy system models inherently consider all possible energy efficiency improvement due to deployment of more efficient technologies. We argue that this is not enough when looking into long-term energy futures requiring an open mind frame and considering different economic structures and even lifestyles. This seems to be in line with what is stated by some ecological economists, that defend that to achieve sustainable development a combination of degrowth and energy (and materials) efficiency is necessary (Kallis et al., 2012). Note that in our analysis with the TIMES_PT model we combine the two effects as we have varied the exogenous demand for energy services and materials as a proxy for growth and the model inherently replaces energy supply and demand technologies with more efficient ones. One area for further research could be to separately study the effect of these two mechanisms, by varying only the demand for energy services.

It has to be stated that with this paper we do not defend that degrowth is a certain approach to ensure energy efficiency and achieve sustainability. There are multiple aspects that we do not consider in our simplified analysis – we represent only the energy part of the economy, and we assume perfect foresight and rationality of agents as in most bottom-up technology models. Our analysis is most limited in the sense that we cannot estimate what such a radical degrowth scenario such as Revolution would represent for the society. Most probably this could be an unviable country with such high unemployment levels that would lead to the economic and political collapse. Furthermore, most of the barriers to energy efficiency are not considered in the TIMES_PT model which thus underestimates the costs associated with meeting the national energy efficiency potential. Nonetheless, we believe that this type of exercises are necessary for, together with policy makers, explore futures where the demand for energy services is not necessarily growing. By doing so, the importance of policies focused on the drivers affecting energy services demand can be made more visible.

References

AYRES, R., TURTON, H., & CASTEN, T. (2007). Energy efficiency, sustainability and economic growth. *Energy*, *32*(5), 634–648. doi:10.1016/j.energy.2006.06.005

Bauhardt, C. (2014). Solutions to the crisis? The Green New Deal, Degrowth, and the Solidarity Economy: Alternatives to the capitalist growth economy from an ecofeminist economics perspective. *Ecological Economics*, *102*, 60–68. doi:10.1016/j.ecolecon.2014.03.015

Belke, A., Dobnika, F., & Dreger, C. (2011). Energy consumption and economic growth: new insights into cointegration relationship. *Energy Economics*, *33*(5), 782–789. doi:doi:10.1016/j.eneco.2011.02.005

Bibas, R., Méjean, A., & Hamdi-Cherif, M. (2015). Energy efficiency policies and the timing of action: An assessment of climate mitigation costs. *Technological Forecasting and Social Change*, *90*, 137–152. doi:10.1016/j.techfore.2014.05.003

Capros, P., Paroussos, L., Fragkos, P., Tsani, S., Boitier, B., Wagner, F., … Bollen, J. (2014). Description of models and scenarios used to assess European decarbonisation pathways. *Energy Strategy Reviews*, *2* (3–4), 220–230. doi:10.1016/j.esr.2013.12.008

Chen, P.-Y., Chen, S.-T., & Chen, C.-C. (2012). Energy consumption and economic growth – New evidence from meta analysis. *Energy Policy*, *44*, 245–255. doi:10.1016/j.enpol.2012.01.048

Chontanawat, J., Huntb, L. C., & Pierse, R. (2008). Does energy consumption cause economic growth?: Evidence from a systematic study of over 100 countries. *Journal of Policy Modelling*, *30* (2), 209–220. doi:10.1016/j.jpolmod.2006.10.003

DGEG. (2013). *Indicadores Energéticos - Principais Números [Energy Indicators – Main Numbers]*. Retrieved from http://www.dgeg.pt/.

European Commission. (2009). *The 2009 Ageing Report : Economic and budgetary projections for the EU-27 Member States (2008–2060)* (p. 444). Luxembourg. doi:10.2765/80301

European Commission. (2011). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A roadmap for moving to a competitive low carbon economy in 2050 (COM(2011) 112 final)*. European Commission. Retrieved from http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52011DC0112.

European Communities. (2011). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Energy Roadmap 2050* (p. /* COM/2011/0885 final */). Luxembourg: European Commission. Retrieved from http://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=pXNYJKSFbLwdq5JBWQ9CvYWyJxD9RF4mnS3ctywT2xXmFYhlnlW1!-868768807?uri=CELEX:52011DC0885.

European Communities. (2012). *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance* (pp. OJ L 315, 14.11.2012, p. 1–56). European Communities. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027.

Fortes, P., Alvarenga, A., Seixas, J., & Rodrigues, S. (2015). Long-term energy scenarios: Bridging the gap between socio-economic storylines and energy modelling. *Technological Forecasting and Social Change*, *91*, 161–178. doi:10.1016/j.techfore.2014.02.006

Fortes, P., Simões, S., Seixas, J., Regemorter, D. Van, & Ferreira, F. (2013). Top-down and bottom-up modelling to support low-carbon scenarios: climate policy implications. *Climate Policy*, *13* (3), 285–304.

Gambhir, A., Napp, T. A., Emmott, C. J. M., & Anandarajah, G. (2014). India's CO2 emissions pathways to 2050: Energy system, economic and fossil fuel impacts with and without carbon permit trading. *Energy*, *77*, 791–801. doi:10.1016/j.energy.2014.09.055

Gouveia, J. P., Fortes, P., & Seixas, J. (2011). Projections of energy services demand for residential buildings: Insights from a bottom-up methodology. *Energy*, *47* (1), 430–442. doi:10.1016/j.energy.2012.09.042

INE. (2014). *Resident population projections 2012-2060. Portuguese.* Lisbon. Retrieved from www.ine.pt.

Jackson, T. (2009). *Prosperity without Growth: Economics for a Finite Planet* (Routledge, p. 288). Routledge.

Kallis, G., Kerschner, C., & Martinez-Alier, J. (2012). The economics of degrowth. *Ecological Economics*, *84*, 172–180. doi:doi:10.1016/j.ecolecon.2012.08.017

Loulou, R., Remme, U., Kanudia, A., Lehtila, A., & Goldstein, G. (2005a). *Documentation for the TIMES model – PART I*. Retrieved from www.etsap.org/tools.htm.

Loulou, R., Remme, U., Kanudia, A., Lehtila, A., & Goldstein, G. (2005b). *Documentation for the TIMES model – PART II*.

Schulz, T. F., Kypreos, S., Barreto, L., & Wokaun, A. (2008). Intermediate steps towards the 2000W society in Switzerland: An energy–economic scenario analysis. *Energy Policy*, *36* (4), 1303–1317. doi:10.1016/j.enpol.2007.12.006

Seixas, J., Fortes, P., Dias, L., Barroso, J. E., Martinho, S., Gouveia, J. P., … Baptista, P. (2014). *GHG Emission scenarios and technological options for decarbonization in Portugal in 2020 and 2030 [Cenários de emissões de GEE e opções tecnológicas de descarbonização para Portugal em 2020 e 2030]. Study for the Portuguese Environmental Agency* (p. 53). Lisbon.

Seixas, J., Fortes, P., Dias, L., Gouveia, J. P., Alves, B., Dinis, R., & Simões, S. (2012). *Low Carbon RoadMap – Portugal 2050 – Energy and Waste Greenhouse emissions, [Roteiro Nacional de Baixo Carbono – Portugal 2050 – Modelação de gases com efeito estufa, Energia e Resíduos. Study for the Executive Committee of the Climate Change Commission*. Lisbon.

Seixas, J., Simões, S., Cleto, J., Fortes, P., Barroso, J. E., Alves, B., … Finote, S. (2008). *Relatório Final: Portugal Clima 2020 – Avaliação do Impacto da Proposta Energia-Clima da Comissão Europeia para Portugal [Final Report: Portugal Climate 2020 – Impact Evaluation of the EU Energy-Climate Policy Package for Portugal]. Study for the Executiv*. Lisbon.

Seixas, J., Simões, S., Fortes, P., Dias, L., Gouveia, J. P., Alves, B., & Maurício, B. (2010). *New Energy Technologies: RoadMap Portugal 2050 – Analysis of new national energy technologies & impact scenarios on the national energy system – D3: Competitiveness Assessment of New Energy Technologies, Portuguese Innovation Fund for Renewable Energy of* (p. 88). Lisbon.

Simões, S., Cleto, J., Fortes, P., Seixas, J., & Huppes, G. (2008). Cost of energy and environmental policy in Portuguese CO2 abatement-scenario analysis to 2020. *Energy Policy*, *36*(9), 3598–3611.

Simoes, S., Fortes, P., Seixas, J., & Huppes, G. (2014). Assessing effects of exogenous assumptions in GHG emissions forecasts – a 2020 scenario study for Portugal using the Times energy technology model. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2014.09.016

Van den Bergh, J. (2011). Environment versus growth – A criticism of "degrowth" and a plea for "a-growth." *Ecological Economics*, *70*, 881–890. doi:10.1016/j.ecolecon.2010.09.035

Van Regemorter, D., & Kanudia, A. (2006). *Projections of the demand of energy services for NEEDS*.

Victor, P. (2012). Growth, degrowth and climate change: A scenario analysis. *Ecological Economics*, *84*, 206–212. doi:10.1016/j.ecolecon.2011.04.013