The role of renewable energy in Portugal's decarbonisation strategy – application of the HyBGEM model

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Abstract

In the fight against climate change, the EU launched the Climate and Energy Package in 2009, with unilateral binding greenhouse gas emissions reduction and renewable energy promotion targets to be achieved by 2020. As Portugal is subject to the European regulations it is required to comply with country specific energy-climate targets. In this paper we evaluate the role of renewable energy sources in Portugal's decarbonisation strategy under the EU Climate and Energy Package commitments. The numerical simulations are performed with the HyBGEM model, a hybrid bottom-up general equilibrium E3 model specifically designed and calibrated for Portugal. The numerical analysis reveals that the technological options in electricity generation play a crucial role in the decarbonisation strategy of the Portuguese economy. The transition to a 'greener' economy through renewable energy promotion is central to the ongoing carbon reduction strategy.

JEL classification: C68; D58; Q48; Q54; Q58.

Keywords: renewable energy; carbon mitigation; energy-climate policy; impact assessment; hybrid CGE modelling; Portugal.

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1. Introduction

Energy is a critical factor in promoting economic growth, in achieving a less dependent and more competitive economy and in enabling the transition to a sustainable low carbon society. Economy-energy-environment (E3) interactions therefore play a crucial role in driving climate change mitigation and growth policies. Evidence of this can be seen in the recent adoption by the European Union (EU) of an integrated climate and energy policy that setts ambitious binding targets to be achieved by 2020: *i)* 20% reduction in EU greenhouse gas emissions compared to 1990 levels (or even 30% if an international agreement is reached that similarly commits other countries), *ii)* 20% of the EU's gross final energy consumption to come from renewable energy sources, and *iii)* 20% improvement in the EU's energy efficiency – known as the 20-20-20 targets of the EU Climate and Energy Package.

As one of the EU Member States, Portugal is required to comply with binding individual 2020 climate-energy targets: limit greenhouse gas emissions from activities outside the cap-and-trade system (the non-ETS sectors) to an increase of 1% compared to 2005 levels, and a 31% share of renewable energy sources use in gross final energy consumption by 2020.

In this paper we intend to assess the role of renewable energy sources in Portugal's decarbonisation strategy under the EU 2020 Climate and Energy Package commitments. A further aim of the empirical analysis is to gain insights into how national 2020 energy-climate targets interact with each other, what are their compliance costs, and what are the most cost-effective policy options. This question is of practical relevance for national decision–making on climate and energy policies. In our numerical simulations we make use of the Hybrid Bottom-up General Equilibrium Model (HyBGEM) for Portugal. HyBGEM is a single integrated, multi-sector, hybrid top-down/bottom-up general equilibrium E3 model formulated as a mixed complementarity problem.

The remainder of the paper is structured as follows. Section 2 provides an overview of the HyBGEM model with a description of its features, structure and computational implementation. The policy scenarios and simulation results are presented and discussed in Section 3. Section 4 concludes.

2. HyBGEM model

HyBGEM is a hybrid E3 general equilibrium model, establishing a top-down/bottom-up integration for a highly disaggregated sectoral structure. The model has been designed for applied energy and climate policy analysis in a small open economy like Portugal. In particular, HyBGEM combines a bottom-up activity analysis representation of the electricity sector with a top-down CGE model in a unified mathematical framework using the MCP format, where the production possibilities in the electricity sector are described by convex combinations of discrete technological options and the other production sectors are characterized by top-down aggregate functional forms, usually smooth (nested) CES production functions. This hybrid modelling approach strengthens the robustness of CGE analysis since key technological options for the impact assessment of energy and climate policy measures are explicitly represented based on an engineering foundation.

The HyBGEM model combines a consistent theoretical framework with an observed database covering all interactions between agents in the economy – firms, households, government, and the rest of the world. It is conceptually built within the Arrow-Debreu (1954) general equilibrium framework, where the competitive market equilibrium is determined by the optimization decisions of producers and consumers. The producers (a single representative firm per sector) maximize profits subject to technology constraints. A representative consumer agent maximizes welfare subject to a budget constraint. The government collects taxes, distributes transfers and provides a composite public good. Public expenditure is financed by tax revenues. The model imposes a revenue-neutral tax reform framework (equal-yield constraint), in the sense that the public good provision is kept constant at the benchmark level and any residual tax revenue is recycled as a lump-sum transfer to households. Bilateral trade between Portugal and the rest of the world is modelled based on the small open economy assumption and the Armington (1969) approach. A fixed trade balance is adopted as macroeconomic closure.

2.1 HyBGEM structure

Table 1 provides an overview of the current model’s dimensions for the Portuguese small open economy. Each of these dimensions will be discussed below.

Table 1 HyBGEM dimensions

Time Horizon			**2005 – 2020**				
Nr.	**Production Sectors/Commodities**		**Final Demand**	**Primary Factors**		**Regions**	
	Energy		Households	L	Labour	PRT	Portugal
1	COA	Coal	Government	K	Capital	ROW	Rest of the world
2	CRU	Crude oil	Investment	N	Natural resources		
3	OIL	Petroleum and coal products (refined)	Exports		FF Fossil-fuel resources		
4	GAS	Natural gas			Coal, Crude oil, Natural gas		
5	ELE	Electricity			R Renewable resources		
					Water, Wind, Sun, Trees		
	Non-Energy						
6	AFF	Agriculture, forestry, and fishery	**Representative Electricity Generation Technologies**				
7	CGI	Consumer goods industries	Conventional fossil-fuel technologies				
8	PPP	Pulp, paper, and print	Coal				
9	CRP	Chemical products	Gas				
10	NMM	Other non-metallic mineral products	Oil				
11	BAM	Basic metals	Renewable technologies				
12	MAE	Machinery and equipment	Hydro				
13	TEQ	Transport equipment	Wind				
14	CNS	Construction	Geothermal				
15	TRD	Trade, repair, and retail	Solar PV				
16	LWT	Land and water transport	Biomass				
17	ATP	Air transport					
18	TCI	Telecommunications, credit, and insurance					
19	OSR	Other services					

Factors market

Primary factors of production are labour, capital, and natural resources which aggregate fossil-fuel and renewable resources. Initial factors endowments are exogenous. HyBGEM assumes a perfectly competitive factors market where the prices of factors adjust so that supply equals demand, except in the labour market. Unemployment is introduced in the model by setting a wage curve which reflects empirical evidence on the inverse causality between the real wage rate and the unemployment rate in the economy (Blanchflower and Oswald, 1990). Labour and capital are assumed to be perfectly mobile across sectors, whereas natural resources are sector-specific. All factors are immobile between countries.

Carbon dioxide (CO_2) emissions accounting

Since CO_2 is the most abundant anthropogenic greenhouse gas in the atmosphere and, therefore, the largest contributor to global warming, HyBGEM only models these emissions. It should be noted that the EU energy and climate policy analysis has also focused predominantly on CO_2 emissions resulting from burning fossil-fuels.

Carbon emissions are largely caused by energy related activities, primarily by the combustion of fossil-fuels in production and consumption activities. Accordingly, CO_2 is introduced into the model as a fixed (Leontief) coefficient input into the production and consumption functions associated with fossil-fuels combustion. Carbon coefficients are therefore differentiated by the specific carbon content of fossil-fuels, such that for each unit of a fuel consumed a known quantity of carbon is emitted.

Production structure

The HyBGEM production structure comprises 19 sectors/commodities (5 energy sectors and 14 non-energy sectors), as depicted in Table 1. The model's sectoral structure has been defined according to the stated purpose of applied energy and climate policy analysis. For this energy-carbon intensive sectors are distinguished from the rest of the economy wherever the available data allows. Moreover, the structure is in line with the taxonomy commonly used in other E3 models (such as GTAP and GEM-E3[1]).

Producer behaviour is based on the profit maximization principle. A representative firm in each sector maximizes profits subject to constant returns to scale production technology.

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[1] GTAP, Global Trade Analysis Project model (http://www.gtap.agecon.purdue.edu/models/current.asp).
GEM-E3, General Equilibrium Model for Economy-Energy-Environment (http://ipts.jrc.ec.europa.eu/activities/energy-and-transport/gem-e3/model.cfm).

Production of goods other than primary fossil-fuels and technology-specific electricity for the domestic and the export markets is defined by an aggregate production function, which characterizes the technology through transformation possibilities on the output side and substitution possibilities on the input side (Figure 1 at Annex). On the output side, the production is split between goods produced for the domestic market and goods produced for the export market according to a constant elasticity of transformation (CET) function. On the input side, a three-level CES function captures the price-dependent use of inputs in production. At the top level, a CES material composite trades off with an aggregate of capital, labour, and energy. At the second level, the energy composite trades off with a value-added aggregate. Finally, at the third level, capital is combined with labour.

The sector-specific material composite for the production of good g is a single level CES function across all non-energy intermediate inputs (Figure 2 at Annex).

In the sector-specific energy composite production, energy inputs substitution possibilities are captured by a four-level function (Figure 3 at Annex). At the lower nest, fossil-fuel inputs are combined with CO_2 emissions in fixed proportions (Leontief production function). At the next level, liquid fuels (refined oil and natural gas) trade off with a constant elasticity of substitution. This aggregate is combined with coal through a CES function at the second level of the nest. Finally, at the top level, the fossil-fuel aggregate (primary energy inputs) and electricity are combined in a CES production function to form an energy composite good.

In the primary fossil-fuels production, a sector-specific fossil-fuel resource trades off with a Leontief composite of all other inputs (labour, capital, and intermediate inputs) at a constant elasticity of substitution (Figure 4 at Annex).

Bottom-up representation of the electricity sector

HyBGEM integrates bottom-up activity analysis into a top-down general equilibrium framework through the detailed technological representation of the electricity sector[2]. It should be noted that electric power generation is a major source of greenhouse gas emissions, primarily CO_2 from fossil-fuel combustion, and is therefore a critical sector in the context of climate change mitigation strategies[3].

Accordingly, the electricity sector is represented in the model by a set of discrete electric power generation technologies (t), providing a perfectly homogeneous electricity good, such

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[2] Our approach closely follows recent work by Böhringer and Rutherford (2008) and Böhringer et al. (2009).

[3] In Portugal, electricity and heat production is responsible for roughly 31% of total CO_2 emissions from fuel combustion (IEA, 2012).

that: $ELE = \sum_t ELE_t$. The technologies compete in the market based on the cost effectiveness principle. The market clearing price of electricity is then set by the supplier's marginal cost. The responsiveness of the different electricity generation technologies to changes in electricity prices is determined by technology-specific supply elasticities. Lower and upper bounds on production capacities will determine the expansion/contraction potential of the technologies.

HyBGEM differentiates eight representative electricity generation technologies – three conventional fossil-fuel technologies (coal, gas, and oil), and five renewable technologies (hydro, wind, geothermal, solar PV, and biomass), as described in Table 3.1[4]. Each generation technology is active or inactive in equilibrium depending on its profitability.

In the technology-specific electricity production, a technology-specific resource (capacity) is combined with a Leontief composite of all other inputs (labour, capital, and intermediate inputs) at a constant elasticity of substitution (Figure 5 at Annex).

Final consumption demand

Consumer behaviour is based on the welfare maximization principle. A representative consumer agent maximizes welfare subject to a budget constraint with an exogenously fixed level of public goods provision and investment.

Final consumption demand of the representative consumer agent is defined as a CES function which combines consumption of an energy composite and a non-energy composite good (Figure 6 at Annex) As already discussed, substitution patterns within the material composite are characterized by a single level CES function. The energy composite consists of several energy goods combined with a constant elasticity of substitution.

International trade

Bilateral trade between Portugal and the rest of the world is modelled assuming two common assumptions in the literature:

- The small open economy assumption, meaning that: *i)* Export and import prices in foreign currency are not affected by domestic market behaviour, i.e. Portugal is a price-taker in the world market and world import and export prices are therefore exogenous. Trade with ROW is then represented by perfectly elastic import-supply and export-demand functions. *ii)* The world market can satisfy all the importing and exporting needs of the Portuguese economy.

- The Armington (1969) assumption of international product differentiation for imports, in the sense that domestic and imported goods of the same type are imperfect substitutes; and,

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[4] The absence of nuclear power generation is due to the national political unacceptability of this option in the modelled time horizon.

symmetrically, the CET supply function for exports, meaning that domestic goods may be supplied both to the domestic market and the export market. The assumption of product heterogeneity implies that all goods used on the domestic market in intermediate and final demand correspond to a CES composite good which combines domestically produced and imported goods – the so-called Armington composite good (Figure 7 at Annex).

As macroeconomic closure, HyBGEM imposes a fixed trade balance with respect to the ROW. This model closure rule is introduced through a national balance of payments constraint according to which the value of Portugal’s exports to the ROW equals the value of its imports after accounting a constant benchmark trade surplus or deficit. The real exchange rate adjusts endogenously to bring about balance of payments equilibrium.

2.2 HyBGEM computational implementation

HyBGEM is implemented numerically as a system of simultaneous nonlinear inequalities using the Mathematical Programming System for General Equilibrium (MPSGE) analysis as a subsystem within the General Algebraic Modelling System (GAMS), and it is solved by means of the PATH solver.

GAMS is a high-level modelling system for mathematical programming and large scale optimization. It consists of a language compiler and a stable of integrated high performance solvers (Rosenthal, 2008). The GAMS modelling language was originally developed to assist economists at the World Bank with the quantitative analysis of economic policy questions. MPSGE is a modelling language developed by Rutherford (2005, 1999, and 1995) in the 1980s, specially designed to solve Arrow-Debreu economic equilibrium models, which uses GAMS as an interface[5]. The PATH solver is a Newton-based solver for MCP models (Ferris and Munson, 2010; Dirkse and Ferris, 1995).

2.3 HyBGEM calibration for Portugal

The calibration method is adopted in the parameter specification of our hybrid CGE model, as is usual in applied general equilibrium modelling. As pointed out by Wendner (1999), “calibration is basically the process of mathematical inference of the parameter values of an applied model,

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[5] For more details, see http://www.gams.com and http://www.mpsge.org.

such that the numerically specified model can replicate a base year's endogenous dataset (base case solution)"[6].

The HyBGEM model is calibrated to base year 2005 based on the Global Trade Analysis Project (GTAP) database, version 7 (released in May 2010)[7], supplemented and updated with more specific data from the national energy balances provided by the Portuguese Directorate-General for Energy and Geology (DGEG, 2012a, b) and data reported on Portugal's Low Carbon Roadmap 2050 (APA, 2012). Note that 2005 is the reference year for the EU ETS and effort sharing targets under the EU Climate and Energy Package by 2020.

The GTAP database builds upon input-output (I-O) tables which provide a detailed and consistent quantitative representation of the interrelations in an economy for a single year, summarizing the production structure and final use of all goods and services as well as a variety of initial taxes. In particular, the GTAP 7 database reconciles detailed national accounts of production, consumption, bilateral trade flows, energy, and carbon emissions data for 113 countries/regions, 57 sectors/commodities and 5 primary factors for the base year 2004 (Narayanan and Walmsley, 2008), which is taken in HyBGEM as a proxy of the year 2005. Given the HyBGEM dimensions (Table 1), the GTAP 7 database regions are aggregated into Portugal and a composite rest of the world (ROW) region. At a sectoral level, the 57 GTAP 7 sectors are aggregated into 19 sectors of two main types – 5 energy sectors and 14 non-energy sectors.

The reference values of HyBGEM elasticities are taken from a review of econometric literature, as is usual in the calibration of applied CGE models. In particular, substitution elasticities between production factors (capital, labour, energy, and material inputs) are based on empirical estimates reported by Okagawa and Ban (2008) and Beckman and Hertel (2010). The price elasticities of fossil-fuel supply are drawn from results reported by Graham et al. (1999) and Krichene (2002). Armington trade elasticities are taken from the GEM-E3 model (E3M Lab, 2010).

The HyBGEM calibration to future time periods requires a baseline or business-us-usual (BaU) scenario to be defined, reflecting the expected evolution of the Portuguese economy in the absence of exogenous energy-climate policy actions. This steady-state baseline growth path should not be viewed as a forecast (a CGE model is not a forecasting tool) but as a BaU

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[6] For discussion on the calibration approach, see e.g. Devarajan et al. (1994), and Mansur and Whalley (1984).

[7] GTAP is a global network of researchers and policy makers conducting quantitative analysis of international policy issues. The project, founded in 1993, is coordinated by the Center for Global Trade Analysis in Purdue University's Department of Agricultural Economics. Complete documentation about GTAP can be found at the webpage https://www.gtap.agecon.purdue.edu.

scenario built in line with the best current projections on the Portuguese economy's evolution, operating as a reference scenario in the counterfactual policy simulations.

Portugal's BaU scenario for horizon 2020 (the target year of the EU Climate and Energy Package) is built based on the following key drivers: gross domestic product (GDP), sectoral energy demand with associated carbon emissions, world market energy prices, and the electricity generation technology mix. We use projections of the Portuguese Department of Foresight and Planning and International Affairs (Alvarenga et al., 2011) and of the International Energy Outlook 2011 (EIA, 2011). In order to account for technological changes over time, HyBGEM also incorporates an implicit autonomous energy efficiency improvement (AEEI) index. The AEEI parameter reflects Portugal's long-run energy/carbon intensity changes that are not explained by price fluctuations. It is a heuristic measure of all non-price induced enhancements in energy use efficiency, including sector-specific technical progress and economic structural changes.

3. Policy scenarios and simulation results

3.1 Policy scenarios

Two policy scenarios, corresponding to stylised versions of Portugal's carbon emissions and renewable energy targets by 2020 under the EU Climate and Energy Package commitments, are modelled and simulated using the HyBGEM model to evaluate the role of renewable energy in Portugal's decarbonisation strategy. In addition, insights are gain into how these targets interact with each other, what are their compliance costs, and what are the most cost-effective policy options.

Low-Carbon Scenario (CO_2)

The EU is required to cut its overall greenhouse gas emissions to at least 20% below 1990 levels by 2020, pursuing the ambition to make Europe a low-carbon and energy-efficient economy over the current decade. Under the present EU emission market segmentation, this economy-wide reduction target is broken down into a 21% reduction in emissions from sectors covered by the EU Emissions Trading Scheme (the so-called ETS sectors), and a 10% reduction in emissions from sectors outside the carbon trading system (non-ETS sectors), taking 2005 as reference year. Portugal is required to limit the increase of emissions from the non-ETS sectors to 1% compared to 2005 levels by 2020. This country specific target must be reached through domestic policy measures. There is no national cap on emissions from the ETS sectors.

However, as stated above, a 21% reduction must be achieved jointly across the 27 EU Member States by 2020.

In this context, scenario CO_2 reflects a stylised version of Portugal's carbon emissions targets by 2020 under the EU emission market segmentation between ETS and non-ETS sectors as imposed by the current EU climate policy regime, as specified below:

- Portugal may increase carbon emissions from the non-ETS sectors by 1% compared to 2005 levels and should reduce carbon emissions from the ETS sectors to 21% below 2005 levels, assuming that the EU-wide ETS target applies to Portugal, since there in a lack of information about the specific objective which will be imposed on Portuguese installations.
- As policy instruments, there is an economy-wide cap-and-trade system for carbon emissions from energy-intensive sectors and the imposition of a domestic uniform carbon tax on emissions from sectors outside the carbon trading scheme.
- Tax revenues from carbon emissions regulation are recycled as lump-sum transfers to the representative household.

The emission market segmentation implies differential emissions pricing between ETS and non-ETS sectors, which means differentiated marginal abatement costs across sectors. The domestic CO_2 tax, meanwhile, ensures equal prices of emissions abatement across all non-ETS emission sources.

Renewables Scenario (RES-E)

In addition to a greenhouse gas emissions reduction target, the EU Climate and Energy Package sets binding country specific targets for renewable energy promotion. The purpose is to achieve an EU-wide renewable energy target of 20% by 2020. Portugal's target is set at 31% of energy from renewable sources in gross final energy consumption by 2020. The Portuguese NREAP (2010) splits this overall RES target into 55.3% RES-Electricity, 30.6% RES-Heating & Cooling, and 10.0% RES-Transport.

Since the HyBGEM model only differentiates between energy sources in the electricity generation sector we have focused on the analysis of the national 2020 RES-E target. Accordingly, scenario RES-E reflects a regulatory system where Portugal imposes a quantity constraint on the share of electricity produced from renewable energy sources at the level of the national RES-E target of 55.3% in 2020. The policy instrument used to achieve this objective is a feed-in tariffs (FITs) scheme, which has been the main support mechanism implemented by

Portugal for promoting renewable electricity generation[8]. Specifically, scenario RES-E corresponds to the implementation of a generation-based price-driven policy instrument, consisting of a fixed guaranteed tariff per unit of renewable electricity fed into the grid; the tariff is set statutorily by government above the market equilibrium price (in order to offset the cost disadvantage of RES-E technologies), differentiated by technology type (technology-specific tariff), and applied until the national 2020 RES-E target is achieved. Table 2 summarizes the average tariffs considered in the numerical simulations, which represent the FITs scheme currently in force in Portugal.

Table 2 Portugal's FITs for RES-E technologies

Technology	Indicative average tariff	Notes
	€/MWh	
Wind	74-75	Up to 33 GWh/MW or 15 years
Hydro (<10 MW)	91-95	Up to 25 years
Solar PV	257	Up to 34 GWh/MW or 20 years
Geothermal*	270	Up to 12 years
Biomass (forestry)	119	Up to 25 years

*High depth and high enthalpy, up to 3 MW per project and per entity, and up to a limit of 6 MW.
Source: DGEG (2012c)

The FITs are implemented in our modelling framework as an endogenous ad valorem output subsidy for RES-E generation, where the associated constraint ensures that the amount of the subsidy equals a given feed-in quantity based tariff, defined in real terms and differentiated by renewable technology type. The subsidy is paid by a lump-sum transfer from the representative household.

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[8] In a FITs scheme, a fixed amount of money (tariff) is guaranteed per unit of renewable electricity produced in order to compensate for the higher costs of RES-E technologies vis-à-vis conventional fossil-fuel alternatives. This fee is usually dependent on the stage of technology development and fixed for a long time (usually about 15–20 years) to create long term certainty for electricity producers. The national grid operator (Rede Eléctrica Nacional - REN) is legally obliged to enter into a contract on the purchase of renewable electricity fed into the grid at above market price set statutorily by government. The FITs system has been in place in Portugal since 1988 by means of Decree-Law No. 189/88, which set up the legal framework for the production of RES-E. Since then this regulatory framework has been amended a number of times. The main changes are related to adjustments in the formula used to determine the value of tariffs and in the guarantee period.

3.2 Simulation Results and Discussion

This section presents and discusses simulation results from the above policy scenarios. Impact assessment of policy-induced effects is made against the 2020 baseline projections for Portugal. Simulation results are thus reported as percentage changes from BaU values, except for the marginal abatement cost, quoted in US dollars per tonne of carbon dioxide (tCO_2), and the production structure of the electricity sector, given as a percentage of total electricity generation.

It is not feasible to measure the policy-induced effects exactly, as any model is only a crude approximation to the real-world. Instead, our foremost purpose is to identify the main trends followed by some relevant variables after the policy shock, together with the major mechanisms influencing them. Moreover, quantitative results are undoubtedly driven by the model structure and parameterization, along with the projected baseline growth path. Nevertheless, we consider that consistent and transparent numerical policy analysis based on empirical data can contribute towards better informed and more robust decision-making.

From the perspective of carbon emissions mitigation, the numerical analysis indicates that both imposition of CO_2 emissions constraints and subsidization of RES-E generation have a similar impact on economy-wide CO_2 emissions, as illustrated in Figure 1. Specifically, under scenario CO_2, overall emissions in 2020 are roughly 10.4% below baseline level, broken down into an 18.4% reduction in emissions from the ETS sectors (the effective cutback requirement for Portugal by 2020) and a 1.4% reduction in emissions from the non-ETS sectors. In scenario RES-E, meanwhile, the deployment of green electricity generation (with a share of 55.3 % in 2020 against 45.2% in BaU) leads to a 9.8% decrease of total emissions, with ETS emissions to decline by 18.6% (above the national target) and non-ETS emissions to rise about 0.1%. This is an interesting result since it indicates that the cut in CO_2 emissions resulting from achieving the national RES-E target by 2020 enables compliance with the national CO_2 emissions reduction commitment. We can therefore conclude that a major challenge for Portugal’s policy makers is to promote the effective decarbonisation of the electricity generation sector.

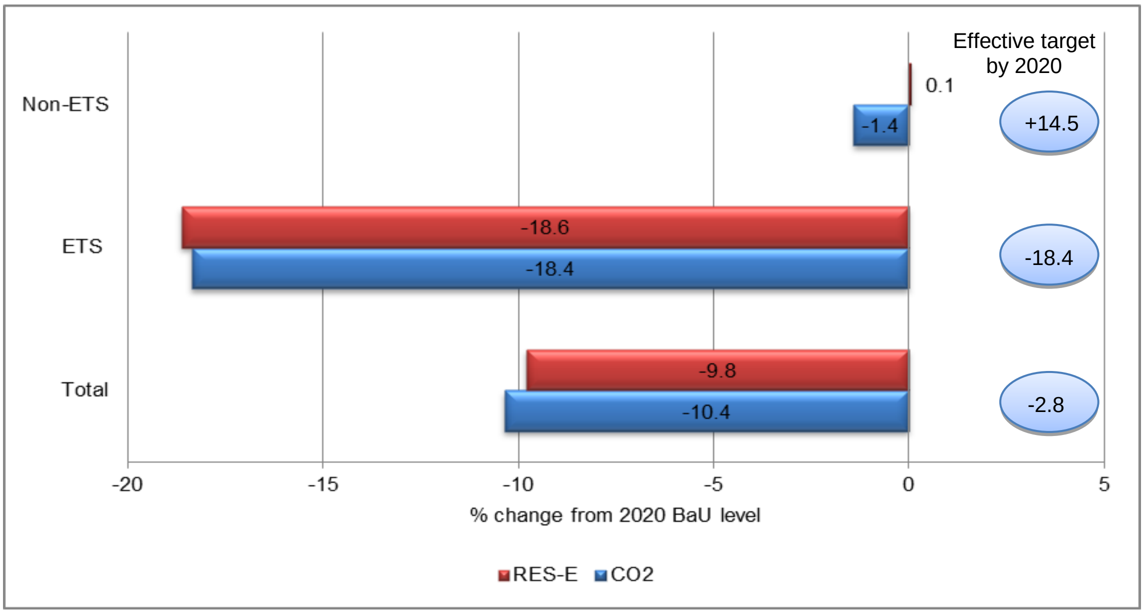

Figure 1 Effects on carbon emissions – scenario CO_2 versus RES-E

Figure 2 displays the simulated carbon emissions reduction effort by sector that is required to reach the 2020 target. Results support the conclusion that most domestic emissions abatement comes from the electricity sector, where CO_2 emissions fall 20.8% from BaU level under scenario CO_2 and 22.3% under scenario RES-E. Of the other major sources of carbon abatement, the standout one is the oil sector with emissions set to drop roughly 15.7% under scenario CO_2 and 13.9% under scenario RES-E. The observed reductions are mainly driven by changes in the production structure of the national electricity sector, along with lower levels of production, as discussed below.

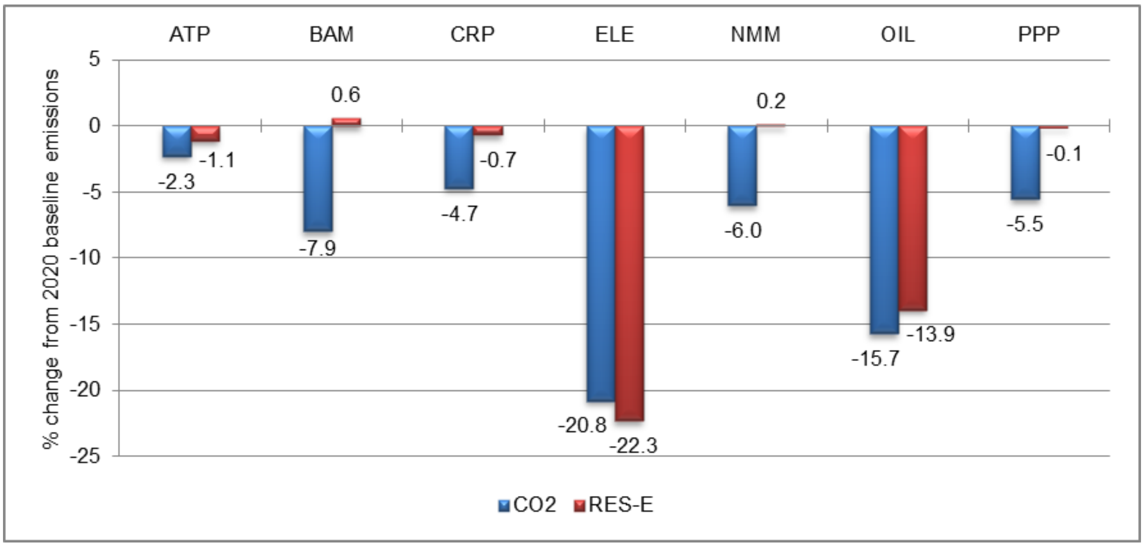

Figure 2 Carbon emissions reduction effort by sector – scenario CO_2 versus RES-E

The electricity sector, as already noted, plays a crucial role in the decarbonisation strategy of the Portuguese economy, both because it is the largest single emitter of domestic CO_2 emissions and has therefore a high reduction potential, and because it is subject to legally binding national targets for increasing the share of renewable energy sources in the electricity supply mix.

Figures 3 to 5 illustrate the policy impacts on Portugal's electricity generation technology mix under scenarios CO_2 and RES-E. Our results show a shift from high-carbon fossil-fuel power generation technologies, in particular oil, towards carbon-free renewable technologies such as hydro and wind, followed to a lesser extent by biomass. The share of geothermal and solar PV technologies remains practically negligible, given their huge cost disadvantage compared to other renewable options.

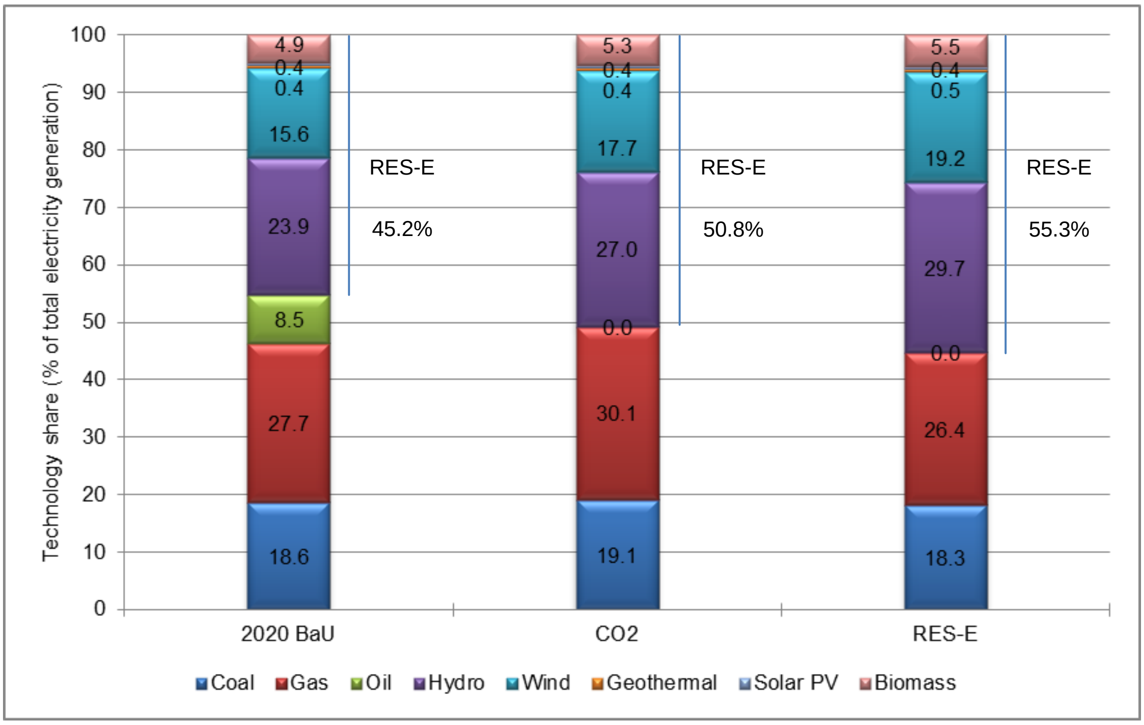

Figure 3 Electricity generation technology mix – scenario CO_2 versus RES-E

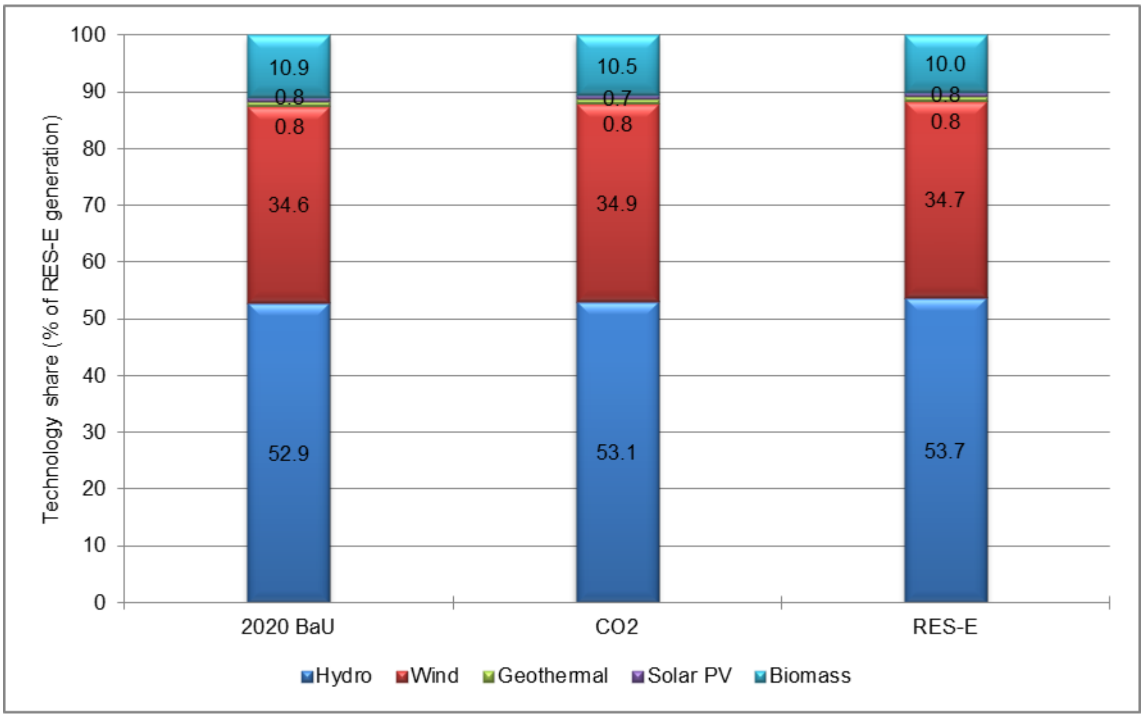

Figure 4 RES-E generation technology mix – scenario CO_2 versus RES-E

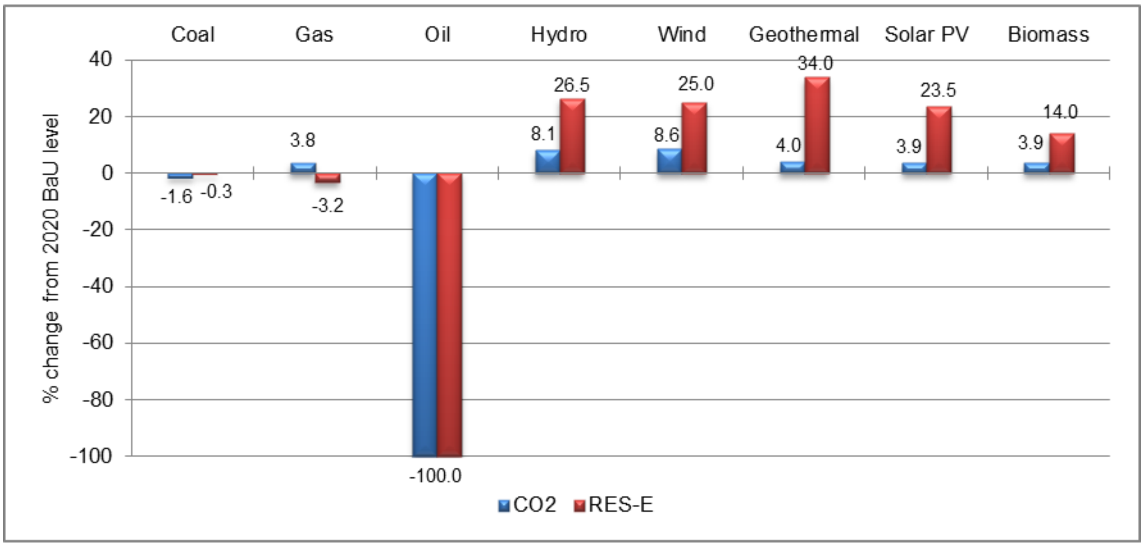

Figure 5 Electricity generation by technology – scenario CO_2 versus RES-E

Overall, the implemented policies lead to a change in the production structure of the national electricity sector with inter-technology and inter-fuel substitution, making it less carbon intensive and less dependent on energy imports but also more costly. Under scenario CO_2, carbon pricing makes conventional fossil-fuel generation technologies more expensive and therefore less competitive in relative terms. Under scenario RES-E, however, the competitiveness of renewable electricity compared to conventional generation is enhanced by the subsidization of electricity production from renewable energy sources. In both cases the result is to make green energy technologies cheaper and thus more profitable than less sustainable ones. Consequently, the share of renewable energy sources in electricity generation rises from 45.2% at baseline to 50.8% of Portugal's total electricity supply in 2020 in scenario CO_2, and to 55.3% in scenario RES-E (the national target by 2020). Notice that stand-alone carbon regulation leads to a significant increase in green power.

Moreover, the phase-out of oil power generation under both scenarios should be noted; it is mainly replaced by renewable energy sources and partly by gas (in scenario CO_2). Electricity production from coal sources also decreases in both scenarios, although its share increases slightly in scenario CO_2. When it comes to the RES-E technologies, hydropower is the most representative one, accounting for about 27.0% of total electricity generation and 53.1% of green electricity under scenario CO_2. In scenario RES-E, where deployment of renewable technologies is more pronounced, the hydropower shares are 29.7% and 53.7%, respectively. Wind power, meanwhile, amounts to 17.7% and 19.2% of total electricity generation, and 34.9% and 34.7% of green electricity, in scenarios CO_2 and RES-E, respectively. Power generation from biomass is about 5% of all and roughly 10% of green electricity in both scenarios.

Table 3 reports the policy-induced effects on significant macroeconomic variables, such as welfare – measured as Hicksian Equivalent Variation (HEV) in real income, gross domestic product, wage rate, capital rental rates, and unemployment. In addition, it considers the policies' impacts on carbon price.

Table 3 Simulation results: economic impacts

	Policy Scenarios	
	CO_2	RES-E
Macroeconomic variables (% change from 2020 BaU level)		
Welfare (HEV)	-0.22	-0.01
Real GDP	-0.18	0.06
Real wage rate	-0.14	0.33
Real capital rental rate	-1.01	-0.03
Unemployment rate	0.68	-1.63
CO_2 values (2004 $US per tCO_2)		
ETS	18.4	-
Non-ETS	-	-

The economic impact analysis of carbon mitigation policies in Portugal under scenario CO_2 reveals a decline of real GDP of 0.18% and a welfare loss of 0.22%, compared to baseline levels. Moreover, both the real wage rate and the real rental price of capital fall, by 0.14% and 1.01%, respectively. The effect on employment is also negative, with the unemployment rate set to increase by 0.68% from BaU level.

The carbon price in the sectors covered by the EU ETS is projected to amount to $US 18.40 per tCO_2 in 2020 (at 2004 prices). This value represents the marginal abatement cost of lowering CO_2 emissions, defined as the cost of removing the last tonne of CO_2 required to achieve the national emissions reduction target by 2020. As expected, the carbon price in the non-ETS sectors is zero, since such sectors are not subject to binding domestic emissions reduction targets. These results point up the huge differential between marginal abatement cost in ETS and non-ETS sectors induced by emission market segmentation, which suggests scope for cost savings if the EU ETS evolves to include more sectors.

Concerning compliance costs related to Portugal's RES-E target by 2020 (scenario RES-E), our simulation results indicate a slight welfare loss of 0.01% compared to baseline level, reflecting the decline in real household income induced by the subsidy payment for RES-E generation. In contrast, effects on real GDP and real wages are positive, with increases of 0.06% and 0.33%, respectively. The increase in wages leads, in turn, to positive employment effects translated into a 1.63% decline in the unemployment rate. The real capital rental rate shows a minor decrease of 0.03% from BaU. The induced variation in the price of factors labour and capital is mainly driven by the change in the economy's production structure.

Overall, when comparing results from scenarios CO_2 and RES-E, we conclude that the economic cost of compliance with Portugal's CO_2 reduction target in 2020 is significantly higher than the cost of achieving the national RES-E target of 55.3% in 2020, as illustrated in Figure 6.

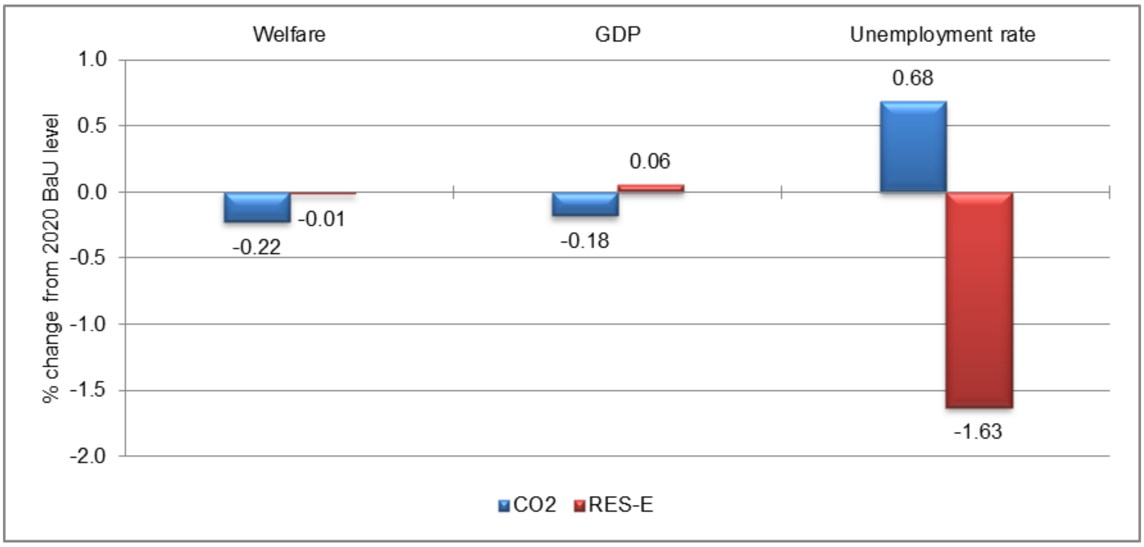

Figure 6 Macroeconomic effects – scenario CO_2 versus RES-E

4. Conclusions

In the fight against climate change, the EU launched the Climate and Energy Package in 2009, with unilateral binding greenhouse gas emissions reduction and renewable energy promotion targets to be achieved by 2020. As one of the EU Member States, Portugal is required to comply with binding individual targets: limit greenhouse gas emissions from activities outside the cap-and-trade system (the non-ETS sectors) to an increase of 1% compared to 2005 levels, and a 31% share of renewable energy sources use in gross final energy consumption by 2020.

In this paper we have provided an empirical impact assessment of Portugal's 2020 energy and climate policy targets to evaluate the role of renewable energy sources in the decarbonisation strategy of the Portuguese economy. The numerical simulations were performed with the HyBGEM model, a hybrid bottom-up general equilibrium E3 model specifically designed and calibrated for Portugal.

The numerical analysis indicates that the technological options in electricity generation play an important role in the decarbonisation strategy of the Portuguese economy. Simulation results indicate a switch from high-carbon fossil-fuel power generation technologies to carbon-free renewable technologies (particularly hydro and wind), making the electricity supply mix less carbon intensive and less dependent on energy imports but also more costly. A major challenge for policy makers is to promote an effective decarbonisation of the electricity generation sector through renewable-based technologies (particularly hydro and wind). It was found that the economic cost of compliance with Portugal's CO_2 reduction target in 2020 is significantly higher than the cost of achieving the national RES-E target, given that imposing CO_2 emissions constraints and subsidising RES-E generation via a FITs scheme both have a similar impact on economy-wide CO_2 emissions. This result suggests that the most cost-effective policy option to achieve the national 2020 energy-climate targets is to promote RES-E technologies, recommending that policy makers should proceed with support mechanisms to promote renewable power generation. The transition towards more green energy is thus central to tackling carbon mitigation.

Considering the large uncertainty surrounding baseline projections and their critical importance for the impact assessment of future policy constraints, further ongoing developments include a sensitivity analysis on alternative 2020 BaU scenarios for Portugal.

Acknowledgments

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Annex

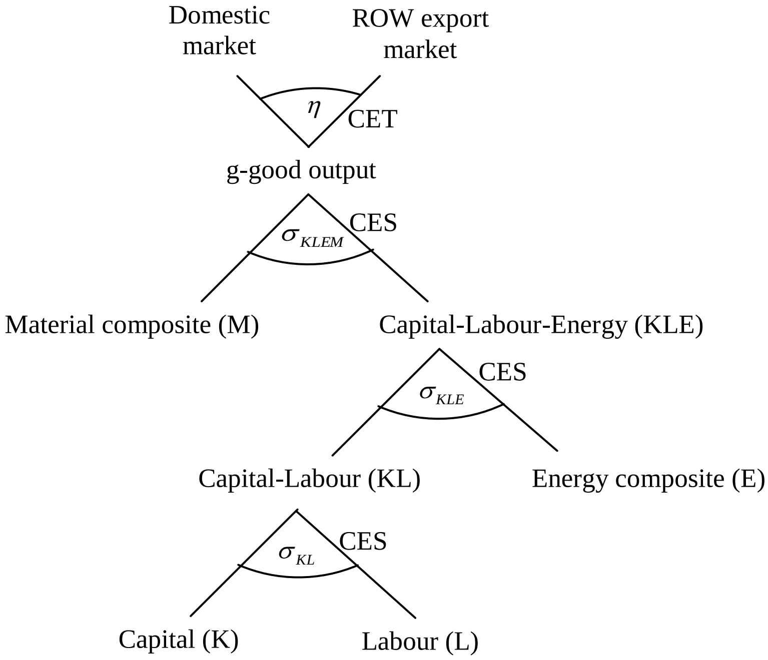

Figure 1 Nesting CES production structure of goods (other than primary fossil-fuels and technology-specific electricity)

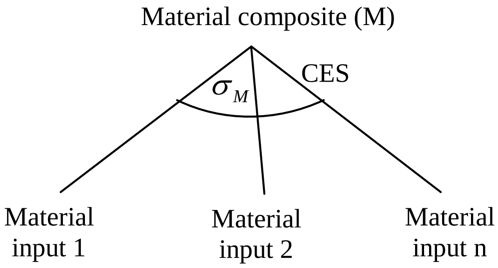

Figure 2 Nesting CES production structure of sector-specific material composite

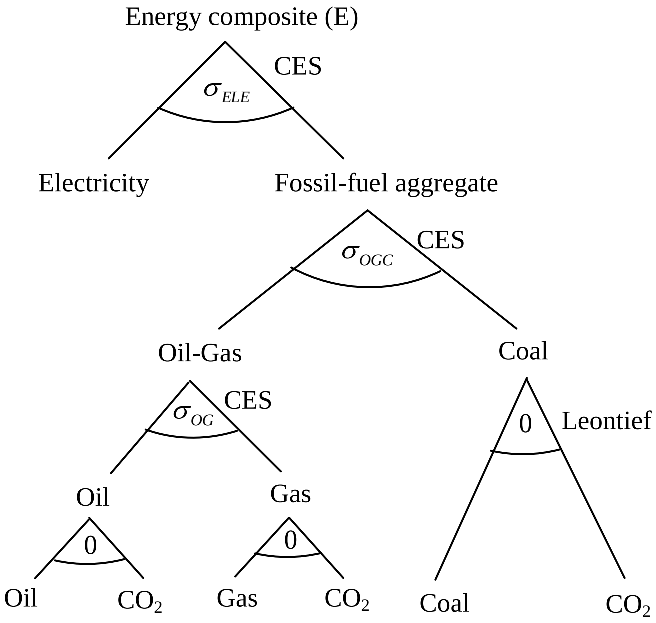

Figure 3 Nesting CES production structure of sector-specific energy composite

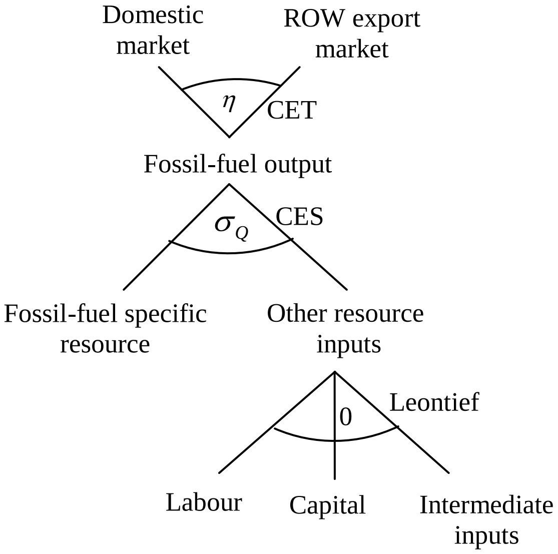

Figure 4 Nesting CES production structure of fossil-fuels

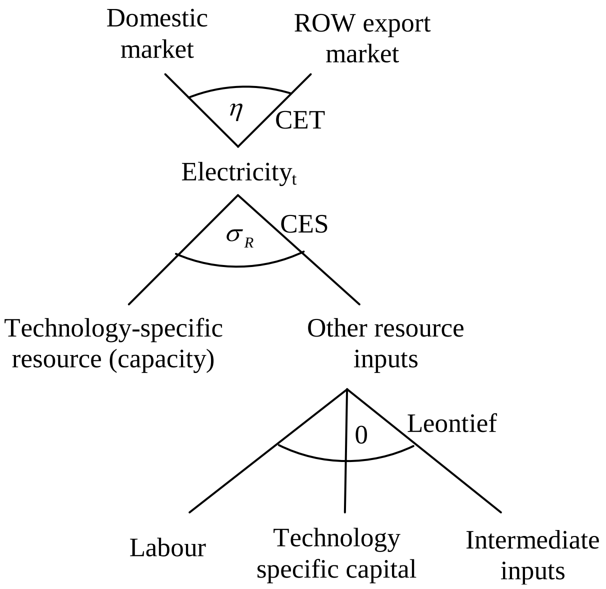

Figure 5 Nesting CES production structure of technology-specific electricity

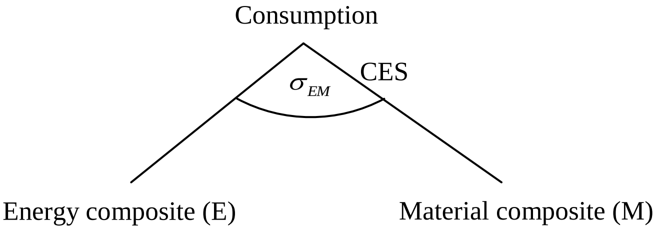

Figure 6 Nesting CES structure of final consumption demand

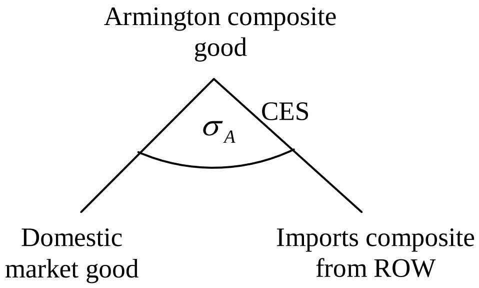

Figure 7 Nesting CES production structure of Armington composite good