The Role of Electricity for the Decarbonization of the Portuguese Economy - DGEP Technical Report

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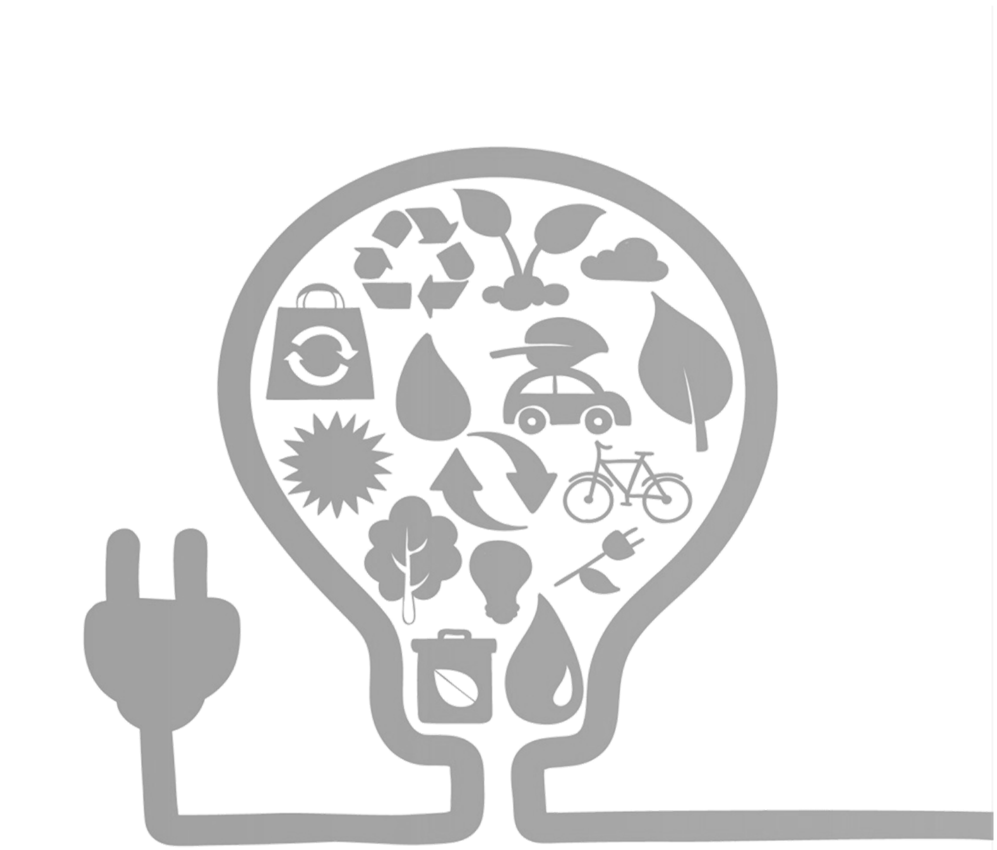
THE ROLE OF ELECTRICITY FOR THE DECARBONIZATION OF THE PORTUGUESE ECONOMY



TECHNICAL REPORT – ECONOMIC MODELLING

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ON THE IMPACT OF CARBON TAXATION AND ENVIRONMENTAL TAX REFORM IN PORTUGAL

FINAL REPORT

15.8.2017

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FACT SHEET

1. A more directed tax on the carbon content of fossil fuels will allow for a greater reduction in carbon dioxide emissions than would taxation of energy consumption or consumption of goods and services more broadly.

2. Overall, a tax on carbon tax alone can produce favorable budgetary outcomes but with serious and severe costs reflected in the adverse economic and distributional implications of the decarbonization policy.

3. Energy taxes and value added taxes have a smaller impact on macroeconomic performance than a tax on carbon dioxide emissions, the broader tax bases contribute towards smaller adverse macro-economic and distributional effects.

4. The economic mechanisms underlying decarbonization strategies imply a somewhat more conservative assessment of the environmental efficacy of decarbonization policies in reducing emissions. This stems from reliance on both reductions in output and consumption together with changes in the production process and household choices to reduce emissions.

5. The adverse macro-economic and distributional effects of the tax on CO_2 emissions motivate the need to consider a more comprehensive environmental tax reform that has the potential to reduce emissions, promote economic growth and job creation and address public sector budgetary concerns.

6. Environmental tax reform provides a politically and economically feasible mechanisms for realistically implementing the technologically feasible options identified with the TIMES CO_2-60% scenario. They lead to the desired environmental outcomes while at the same time encouraging positive and progressive economic outcomes, contributing towards public debt reduction and promoting the international competitiveness of the Portuguese economy.

7. We conclude that a balanced 50/50 mixed direct channel strategy of personal income tax and corporate income tax reductions, a balanced 50/50 mixed indirect channel of reductions to the value added tax and financing for investment tax credits and a balanced 50/50 mixed of reductions to the personal income tax and financing for investment tax credits can each yields all of the desirable policy outcomes: reductions in GHG emissions, positive macro-economic effects, progressive distributional effects, reductions to the public sector debt, and positive effects on international competitiveness.

Table of Contents

List of Tables

ON THE IMPACT OF CARBON TAXATION AND ENVIRONMENTAL TAX REFORM IN PORTUGAL

1 Introduction

1.1 Forward

The objective of the economic component of the project is to examine the environmental, economic, and distribution effects of carbon taxation and environmental tax reform policies in Portugal. Decarbonization of the Portuguese economy will necessarily be based on an increasing electrification of energy demand and the production of electricity from renewable energy resources. Carbon and energy pricing policies coupled with appropriate recycling of the carbon tax revenues can contribute towards the decarbonization of the Portuguese economy and an increase in the use of renewable energy resources in the production of electric power. In this report we provide full details as to the model, calibration, and simulation results with the economic framework of the DGEP model.

1.2 The Project

The latest official Portuguese report on greenhouse gas emissions (GHG) (APA, 2017) indicates that net emissions of greenhouse gases (i.e. including the contribution of land use, land-use change and forestry) in Portugal in 2015 are 1.58% lower than 1990 levels. Current GHG emissions amount to 5.8 tCO_2e per capita. GHG emissions from energy and industrial processes, however, have increased 18% and account for 80% of total emissions in Portugal.

The Paris climate agreement aims for carbon neutrality by the middle of the century. Given 2015 GHG sequestration levels from land use, land-use change and forestry activities, total GHG emissions in Portugal will need to be reduced from 68.7 $MtCO_2e$ in 2015 to 8.5 $MtCO_2e$ in 2050 (i.e. less than 1 tCO_2e per capita). To meet these goals, Portugal faces the challenge of reducing its GHG emissions by 87% in the next 35 years. The energy sector, and the power sector in particular, will play a major role in this path towards lower GHG emissions.

An integrated technological based modelling exercise up to 2050, supported by TIMES_PT model, was performed over the Portuguese energy system to assess the cost-effectiveness of GHG emissions reduction options, (i) with no reduction target imposed, and (ii) by imposing decarbonization targets of 50%, 60%, 75% and 85% in 2050, relative to GHG emissions level in 1990. Additionally, a set of electricity consumption targets (40%, 50%, and 70%) was imposed to assess the cost-effectiveness of energy technology options, both supply and demand, and how decarbonization would be induced. The energy technologies database supporting TIMES_PT modelling was fully updated (technical and economic parameters) to fully accommodate the current state-of-the-art information.

The macroeconomic, budgetary, distributional, and environmental impacts of energy and environmental policies are examined here using a dynamic, multi-sector, general equilibrium model of the Portuguese economy. We examine the effects of a carbon tax with the technical capacity to reduce emissions by 60% in 2050, relative to 1990 levels. We first consider the potential for the tax revenues generated by the tax on carbon to be directed towards debt consolidation efforts. We further consider alternative indirect tax instruments, including broader energy and consumption taxes, capable of generating the same level of revenue for the public sector. Finally, we consider various revenue recycling mechanisms, including reductions to the personal income tax, corporate income tax, value added tax and financing for investment tax credits together with mixed strategies along these different tax margins together with energy efficiency improvements. The DGEP model was greatly expanded to accommodate five income groups and thirteen production sectors as well as to incorporate up-to-date statistical information.

Besides the great effort put into the individual model developing by both the TIMES_PT and DGEP teams, the great value added of this research is that it brings together the two approaches – technological and economic – to address the issue of decarbonization from the two different angles. Only too often, the technological approach is oblivious to economic consideration as much as the economic approach is oblivious to technological considerations. Both models win by being brought together and thereby allowing the overall analysis to benefit from the strengths of both approaches. The optimism of a future opened to all technological possibilities unrestricted by economic and cost considerations of the TIMES_PT model is tempered with the pessimism of the economic approach of the DGEP model where inertial behavior is critical and future technological choices are limited.

1.3 The Economic Modelling Approach

The economic, budgetary, distributional, and environmental effects of decarbonization policies are further evaluated using a multi-sector, multi-household, dynamic general equilibrium model of the Portuguese economy. This new model builds upon the aggregate dynamic general equilibrium model of the Portuguese economy DGEP. Previous versions of this model are documented in Pereira and Pereira (2012) and have been used to evaluate the impact of tax policy [see Pereira and Rodrigues (2002, 2004)], of public pension reform [see Pereira and Rodrigues (2007)], and more recently of energy and climate policy issues [see Pereira and Pereira (2014a, 2014b, 2016a, 2016b)].

The dynamic multi-sector general equilibrium model of the Portuguese economy incorporates fully dynamic optimization behavior, detailed household accounts, detailed industry accounts, a comprehensive modelling of the public sector activities, and an elaborate description of the energy sectors. We consider a decentralized economy in a dynamic general equilibrium framework. There are four types of agents in the economy: households, firms, the public sector and a foreign sector. All agents and the economy in general face financial constraints that frame their economic choices. All agents are price takers and are assumed to have perfect foresight. With money absent, the model is framed in real terms.

Households and firms implement optimal choices, as appropriate, to maximize their objective functions. Households maximize their intertemporal utilities subject to an equation of motion for financial wealth, thereby generating optimal consumption, labor supply, and savings behaviors. We consider five household income groups defined by quintile of income. Preferences, income, wealth and taxes are household-specific, as are consumption demands, savings, and labor supply.

Firms maximize the net present value of their cash flow, subject to the equation of motion for their capital stock to yield optimal output, labor demand, and investment demand behaviors. We consider thirteen production sectors covering the whole spectrum of economic activity in the country. These include energy producing sectors, such as electricity and petroleum refining, other European Trading System [ETS hereafter] sectors, such as transportation, textiles, wood pulp and paper, chemicals and pharmaceuticals, rubber, plastic and ceramics, and primary metals, as well as non-ETS sectors such as agriculture, basic manufacturing and construction. Production technologies, capital endowments, and taxes are sector-specific, as are output supply, labor demand, energy demand, and investment demand.

The public sector and the foreign sector, in turn, evolve in a way that is determined by the economic conditions, and their respective financial constraints. All economic agents interact through demand and supply mechanisms in different markets: commodity markets, factor markets, and financial markets.

The general market equilibrium is defined by market clearing conditions in product markets, labor markets, financial markets, and the market for investment goods. The product market equilibrium reflects the national income accounting identity and the allocation of the output of each sector of economic activity to various types of expenditure. The total amount of a commodity supplied to the economy, be it produced domestically, or imported from abroad, must equal the total end-user demand for the product, including the use of these products as intermediate inputs in production, the demand for private consumption by households, by the public sector, and its use for private investment. The total labor supplied by the different households, adjusted by an unemployment rate that is assumed exogenous and constant, must equal total labor demanded by the different sectors of economic activity. There is only one equilibrium wage rate, although this translates into different household-specific effective wage rates, based on household-specific levels of human capital which differ by income level. Different firms buy shares of the same aggregate labor supply. Implicitly, this means that we do not consider differences in the composition of labor demand among the different sectors of economic activity, in terms of the incorporated human capital levels. Saving by households and the foreign sector must equal the value of domestic investment plus the budget deficit.

The evolution of the economy is described by the optimal and endogenous evolution of the stock variables – five household-specific financial wealth variables and thirteen sector-specific private capital stock variables including wind, solar and hydroelectric renewable energy sources, as well as their respective shadow prices/co-state variables. In addition, the evolution of the stocks of public debt and of the foreign debt act as resource constraints in the overall economy. The endogenous and optimal changes in these stock variables – investment, saving, the budget deficit, and current account deficit – provide the endogenous and optimal link between subsequent time periods. Accordingly, the model can be conceptualized as a large set of nonlinear difference equations, where critical flow variables are optimally determined through optimal control rules.

The intertemporal path for the economy is described by the behavioral equations, by the equations of motion of the stock and shadow price variables, and by the market equilibrium conditions. We define the steady-state growth path as an intertemporal equilibrium trajectory in which all the flow and stock variables grow at the same rate while market prices and shadow prices are constant.

The model is calibrated with data for the period 2005-2014 and stock values for 2015. The calibration of the model is ultimately designed to allow the model to replicate, as its most fundamental base case, a stylized steady state of the economy, as defined by the trends and information contained in the data set. Counterfactual simulations thus allow us to identify marginal effects of any policy or exogenous change, as deviations from the base case.

1.4 Integrated Modelling Economic and Energy Systems

The analysis of the role of the electricity in the decarbonization of the Portuguese economy is based on a soft-link between the energy technology systems model TIMES_PT and the dynamic multi-sector general equilibrium model of the Portuguese economy, DGEP. The two models bring together two complementary approaches to energy and climate policy analysis, an energy systems approach and an economic approach, providing a comprehensive view of the issues at stake.

The reference scenario was defined as a pathway for the energy sector and the economy that explicitly considers the energy and climate policy targets for 2020 and extended through 2050 with the objective of identifying the role of electricity in the energy system given the expected evolution of the costs and characteristics of the various energy technologies absent further policy objectives.

The energy system and economic models were integrated using a harmonization process designed to ensure that modeling approach provides a complementary and coherent analysis of the energy, environmental, macroeconomic, budgetary and distributional effects of electrification and decarbonization policies in Portugal. The soft-link between the energy technology systems model and the dynamic multi-sector general equilibrium model of the Portuguese economy process is depicted in Figure 2 and is based on key indicators for the energy system: carbon dioxide emissions, final demand for electricity, and share of renewables in the electricity production. The endogenously generated trajectories for these key energy system indicators in 2020, 2030, 2040 and 2050 iterated under the reference scenario until the difference in the model reference scenario converged to within 10% for each time period under consideration (Table 1). In addition, selected energy drivers generated by TIMES_PT model were adopted by the DGEP model (e.g. energy efficiency), while economic drivers generated by DGEP were used by the TIMES_PT model (e.g. household private consumption, GDP).

1.5 The Case for a Meaningful Carbon Tax

A general CO_2 tax is an effective measure in that it provides incentives to find the least-cost ways to reduce emissions among sectors (IEA, 2016). Portugal, under the principle of fiscal neutrality, has introduced a tax on carbon dioxide emissions, the net income of which is allocated to the reduction of personal income taxes with the goal of reconciling protection of the environment with economic growth. The carbon tax is indexed to the price of carbon permits in the EU-ETS (IEA, 2016).

A tax on carbon dioxide emissions is effective at reducing carbon dioxide emissions but comes at a cost in terms of macroeconomic performance (see Pereira and Pereira, 2014a, for example). In addition, carbon and energy pricing policies are regressive because of the larger relative share of energy demand in the budgets of low-income households; this pattern of demand and the regressivity of carbon and energy pricing policies is particularly pronounced for electricity demand (Parry, 2015). The regressivity of carbon pricing policies depends further on the sources of household income, with capital income potentially more affected by these policies and a more important source of income for higher income households (Fullerton and Heutel, 2010). Beck et al, (2015) and Dissou and Siddiqui (2014) show that the welfare effects of a carbon tax are determined primarily by the source of a households' income rather than by the disposition of its expenditures and that revenue recycling can produce a progressive policy. Indeed, Rausch et al. (2011) show that the impact of carbon pricing is determined by heterogeneity in household spending patterns across income groups as well as heterogeneity in factor income patterns across income groups and the precise formulation of the policy, that is, how the revenue from the carbon pricing policy are distributed.

Economists largely favor the incentives provided by carbon pricing policies to reduce emissions, encourage innovation and the development of new technologies and the deployment of cost-effective renewable energy sources. The relative cost-effectiveness of carbon pricing policies and clean energy standards, however, stems from differences in the policies' impact on electricity prices. For small levels of emissions reduction, a clean energy standard supported by a subsidy financed by a tax on non-qualifying electricity generated can implies a lower price for electricity than a cap-and-trade system that promotes the same emissions reduction. The lower prices generate smaller tax interaction effects and (depending on the extent of prior tax distortions) may allow for nearly as cost effective a reduction in emissions as a pricing policy (Goulder et al. 2014).

The negative macroeconomic and social justice effects of carbon taxation motivate the need to search for policies to mitigate such effects, including broader energy and value added taxes and revenue-neutral renewable energy support policies. The welfare effects of different climate policies depend on the fiscal options for allocating revenues generated by auctioned permits or carbon taxes, with a striking trade-off between cost-effectiveness and distributional considerations (Parry and Williams, 2010).

The regressive aspects of renewable energy promotion stems from higher electricity prices can be attenuated by alternative subsidy financing mechanisms which achieve the same level of electricity generation from renewable energy sources (Bohringer et al., 2016). Gonzalez (2012) finds that the distributional effects of a carbon tax depend on how the revenue is recycled, producing regressive effects when recycled as a manufacturing tax cut and progressive when distributed as a food subsidy. Kalkuhl et al. (2013) find that smart combinations of carbon prices and renewable energy subsidies can achieve ambitious carbon mitigation targets at moderate additional costs without leading to high energy price increases. Chiroleu-Assouline and Fodha (2014) show that whatever the degree of regressivity it is possible to design a recycling mechanism that renders the tax reform more Pareto efficient by simultaneously decreases the wage tax and increasing its progressivity.

Furthermore, public acceptance, and therefore the political feasibility, of a tax on carbon, depends in large part on how the revenue from the tax is used and how the tax is labeled and the information provided about it and its purpose. Given the diffuse nature of the benefits of a Pigouvian tax, recycling the revenues to purposes and goals important to more narrowly targeted groups, whether these are environmentally motivated or motivated by industry concerns, seems to increase support for taxation (Kallbekken, Kroll and Cherry, 2011). In fact, carbon taxation in Washington State because it was unpopular with social justice groups and divided environmental activists, many arguing it did not go far enough in promoting clean energy (https://insideclimatenews.org/news/09112016/washington-state-carbon-tax-i-732-ballot-measure).

1.6 Economic Scenarios

In this project, we examine the effects of a carbon tax with the technical capacity to reduce emissions by 60% in 2050, relative to 1990 levels. We first consider the potential for the tax revenues generated by the tax on carbon to be directed towards debt consolidation efforts. We further consider alternative indirect tax instruments, including broader energy and consumption taxes, capable of generating the same level of revenue for the public sector. Finally, we consider various revenue recycling mechanisms, including reductions to the personal income tax, corporate income tax, value added tax and financing for investment tax credits together with mixed strategies along these different tax margins together with energy efficiency improvements.

We examine the potential for mixed recycling strategies to achieve a triple dividend: an improvement in environmental quality, positive economic outcomes and a contribution towards budgetary consolidation. We first consider a direct tax channel, a combination of reductions in the PIT and the CIT; second, an indirect tax channel, a combination of reductions in the VAT and an increase in the ITC; and, third, a mixed channel in which we consider reductions in the PIT and an increase in the ITC. In all case, we conduct a grid search to identify the composition of the mixed recycling strategy capable of producing the most desirable outcome. In each case, part of the revenues raised by the tax on carbon are used to promote the adoption of energy efficiency technologies through selected VAT reductions and PIT credits for energy efficiency improvements for households and CIT financing and ITC credits for energy efficiency improvements for firms.

More specifically, two families of counterfactual economic scenarios were modeled by the DGEP general equilibrium model:

1. ***Decarbonization Scenarios***: Decarbonization strategies based on a carbon tax (1), an energy tax (2), and value added taxation (3). The tax levels are defined in a way that is consistent with the marginal costs of emissions reductions associated with the 60% reduction goal defined by the TIMES model. Each tax policy generates the same revenue for the public sector and the proceeds from these tax instruments are used to finance deficit reduction.
2. ***Decarbonization Scenarios with Environmental Tax Reform*****:** Reform to four tax margins are considered in conjunction with carbon taxation: the personal income tax, the corporate income tax, the value added tax, and financing for investment tax credits together with incentives for energy efficiency.

1.7 Summary of the Economic Effects

The TIMES_PT model results provide a wide variety of cost-effective strategies for achieving a 60% reduction in CO_2 emissions relative to 1990 levels by 2050. The corresponding shadow price of the emissions constraint reflect the marginal costs of CO_2 reductions and are modelled as a carbon tax in the DGEP model in order to identify the economic, budgetary and distributional effects of decarbonization policies for the Portuguese economy and to highlight the economic mechanisms underlying the transition to a low carbon economy. The carbon tax considered increases from its current level of 5 euros per ton of CO_2 to 183 euros per ton by 2050. The corresponding carbon tax revenues grows from 0.1% to 2.5% of the 2015 GDP.

The DGEP model results indicate that a carbon tax designed to meet the 60% reduction in emissions in 2050 with revenues reverting to the public budget would lead to adverse economic effects in terms of GDP, private consumption and investment and a deterioration of the trade balance. In addition, the labor market effects of this policy would be negative.

A tax on carbon dioxide emissions would be regressive and thereby produce undesirable distributional effects. The welfare effects of the tax on carbon are larger for lower income households than for higher income households which raises concerns about social justice emerging from these policies. These negative distributional effects are driven by labor supply responses, lower after-tax incomes and higher consumer prices.

The carbon tax would significantly improve the public budgetary situation. This is to be expected because the proceeds from the tax are directed towards the public account by design.

The tax is effective in reducing CO_2 emissions and allows for a substantial reduction in emissions. The underlying economic mechanisms, however, suggest a more conservative reduction in emissions than that implied by the TIMES_PT model. The more limited efficacy of the tax in the context of the economic system stems from a greater reliance on output reductions to reduce emissions relative to changes to process and activities given the substitution possibilities for carbon intensive goods and services for both households and firms and the electrification options that are technological feasible within the scope of the TIMES_PT model.

The carbon tax provides a direct incentive for reducing emissions that is superior to a more general tax on energy and on consumer goods as a strategy for reducing emissions. As two alternatives to a simple tax on carbon we consider an increase in the tax on energy products and the value added tax that generates the same level of revenue. The additional tax revenues is allocated to the general public sector account. In both alternative cases, the economic effects are substantially smaller although the smaller economic effects are just a reflection of a much less effective policy in reducing emissions. Clearly, a carbon tax, being a much more focused instrument, is much more effective in curtailing emissions.

The negative economic and distributional effects of the tax on carbon motivate the need to search for tax reforms that can address the adverse effects of the policy while reaching environmental objectives. The proceeds from the carbon tax open up the possibility of a more comprehensive tax reform in which the revenues generated can be carefully allocated to reducing distortions at the major tax margins of the Portuguese tax system, in isolation and together with energy efficiency objectives. Reductions to the personal income tax (PIT) can be designed to promote progressive policy outcomes. Reform to the value added tax (VAT) can also be used to address the adverse distributional effects of the carbon tax. Reductions to the corporate income tax (CIT) and financing for an investment tax credit (ITC) margins are particularly effective in reducing the adverse economic effects of the policy.

We examine the potential for mixed recycling strategies to achieve a triple dividend: an improvement in environmental quality, positive economic outcomes and a contribution towards social justice. We first consider a direct tax channel, a combination of reductions in the PIT and the CIT; second, an indirect tax channel, a combination of reductions in the VAT and an increase in the ITC; and, third, a mixed channel in which we consider reductions in the PIT and an increase in the ITC. In all case, we conduct a grid search to identify the composition of the mixed recycling strategy capable of producing the most desirable outcome. In each case, part of the revenues raised by the tax on carbon are used to promote the adoption of energy efficiency technologies through selected VAT reductions and PIT credits for energy efficiency improvements for households and CIT financing and ITC credits for energy efficiency improvements for firms.

Balanced 50/50 mixed revenue recycling policies yield all of the desirable results: economic growth and job creation, progressive distributional outcomes, and a reduction in CO_2 emissions. These mixed recycling strategies provide for a comprehensive package of policy instruments capable of addressing the environmental, social and economic dimensions of policy concerns facing the country and provide mechanisms for reducing CO_2 emissions by 60% relative to 1990 levels by 2050.

1.8 Organization of the Report

This report is organized as follows. Section 2 provides a description of the dynamic, multi-sector, general equilibrium model of the Portuguese economy. Section 3 describes the reference scenario and the design of the simulations in this study. Section 4 discusses the energy, economic and budgetary effects of reducing carbon dioxide emissions by 60% by 2050. Sector 5 examines alternative energy and consumption based taxation policies. Section 6 discusses environmental tax reform. Section 7 discusses carbon taxation with balanced recycling strategies and provisions for energy efficiency and section 8 concludes.

2 Model Description

2.1 Overview

We consider a decentralized economy in a dynamic general equilibrium framework. All agents are price-takers and have perfect foresight. With money absent, the model is framed in real terms. There are four types of agents in the economy: household sectors, production sectors, the public sector and a foreign sector. All agents and the economy in general face financial constraints that frame their economic choices. Households and firms implement optimal choices as appropriate to maximize their objectives. The public sector and the foreign sector, in turn, evolve in a way determined by the economic conditions and their respective financial constraints. The different agents interact through demand and supply mechanisms in different markets: commodity markets, factor markets, and financial markets. All markets are assumed to clear.

The evolution of the economy is described by the optimal and endogenous change in the stock variables –sector-specific private capital and renewable energy capital, including hydroelectric, wind and solar infrastructures – and their respective shadow prices/co-state variables. In addition, the evolution of the public debt and of the foreign debt act as resource constraints in the overall economy. The endogenous and optimal changes in these stock variables – investment, saving, public deficit, and current account deficit – provide the endogenous and optimal link between subsequent time periods. Accordingly, the model can be conceptualized as a large set of non-linear difference equations where critical flow variables are optimally determined through optimal control rules.

2.2 Household Behavior

We consider five household income groups per quintile. While the general structure of household behavior is the same for all household groups, preferences, income, wealth and taxes are household-specific as are consumption demands, savings, and labor supply.

Household h chooses consumption and leisure streams that maximize intertemporal utility subject to the consolidated budget constraint. The objective function is lifetime expected utility subjectively discounted at the rate of β. Preferences, are additively separable in consumption and leisure, and take on the CES form where σ is the constant elasticity of substitution.

C_h denotes the total consumption by household h, including both expenditure on goods and services. P_h is a household specific price index with reflects consumption levels of individual goods and services as well as their prices. The household specific price index reflects the individual basket of goods and services that each household selects. ℓ_h denotes the amount of time the household spends in leisure and recreational activities.

The budget constraint reflects the fact that consumption is subject to a value-added tax rate of $\tau_{VAT,C}$ and states that the households' expenditure stream discounted at the after-tax market real interest rate, $1 + (1 - \tau_r)r_{t+v}$, cannot exceed total wealth at t, $TW_{h,t}$. For the household h, total wealth, $TW_{h,t}$, is composed of human wealth, $HW_{h,t}$, and net financial wealth, $A_{h,t}$.

The household's wage income is determined by its endogenous decision of how much labor to supply, $LS_t = \bar{L} - \ell_t$, out of a total time endowment of $\bar{L}$, and by the stock of knowledge or human capital, HK_t. Labor earnings are discounted at a higher rate reflecting the probability of survival.

The effective wage rate, wHK_h, accomodates difference in income levels for the same number of work hours by accounting for differences in worker productivity reflected in differences in the level of human capital each household has accumulated. The level of human capital for each household reflects differences in education and experience among the various household groups. In this version of the model the household-specific HK is fixed or exogenously given.

A household's labor income is augmented by international transfers, R_t, and public transfers, TR_t as well as capital income - interest payments received on public debt, PD_t, net of payments made on foreign debt, and profits distributed by corporations, NCF_t, where s_{ht} is the share of household h of the aggregate market portfolio.

On the spending side, taxes are paid and consumption expenditures are made. Income net of spending adds to net financial wealth in the form of savings. To allocate aggregate consumption to specific commodities, goods and services, consumers maximize utility from consumption subject to their budget constraint:

$$\max_{\mathbf{QH_h}} \left[\; U^h(\mathbf{QH_h}) \;\mid\; PC_h QC_h \;\geq\; (\mathbf{1} + \boldsymbol{\tau}_{\mathbf{vat}})(\mathbf{PQ} + \boldsymbol{\tau}_{\mathbf{unit}}) \times \mathbf{QH_h} \right]$$

where $\boldsymbol{PQ}$ and $\boldsymbol{QH_h}$ denote a vector of price (\$/unit) and quantity (physical units) of a good consumed over the course of a year, respectively. $PC_{ht}QC_{ht}$ represents total expenditure on goods and services by the household h at time t. Expenditure on goods and services is subject to product and service specific value added tax rates, $\tau_{\mathrm{vat,c}}$, and other unit taxes, $\tau_{\mathrm{unit,c}}$, including the tax on petroleum and energy products (ISP). At optimality, the marginal rate of substitution is equal to the market opportunity cost. The exchange rate for the individual household required to maintain a given level of utility is exactly equal to the rate at which the household can exchange these goods in the marketplace.

This general framework is applied at two different levels. First, it is applied to determine the optimal allocation of total consumption spending among the three main category of goods: transportation services, residential energy, other goods and services. Second, it is applied to determine the optimal allocation within more specific categories within each one of these three main groups.

2.3 Producer Behavior

We consider thirteen production sectors. While the general structure of production behavior is the same for all sectors, technologies, capital endowments, and taxes are sector-specific as are output supply, labor demand, energy demand, and investment demand.

Firms maximize the present value of the firm which serves as a source of financial wealth for households. The firm maximizes the present value Hamiltonian which reflects the firms net cash flow and is subject to the equation of motion for private capital, and renewable energy capital, specified for hydroelectric, wind and solar power infrastructures.

The firms' net cash flow, NCF, represents the after-tax position when revenues from sales are netted of wage payments spending in energy and materials and investment spending. The after-tax net revenues reflect the presence of a private investment tax credit at an effective rate of τ_{ITC}, taxes on corporate profits at a rate of τ_{CIT}, and Social Security contributions paid by the firms on gross salaries, $w_t L_t^d$, at an effective rate of τ_{FSSC}.

The corporate income tax base is calculated as revenues net of total labor costs, $(1+\tau_{FSSC})w_t L_t^d$, as well as spending in energy and materials and is net of fiscal depreciation allowances over past and present capital investments, αI_t.

Output is produced using capital, labor, energy and material inputs. The production technology describes the level of output possible for the use of inputs to production employed by the firm. The production technology is assumed to be continuous and twice differentiable and thus, by the appropriate choices for the elasticity of substitution in production yields a smooth, continuous approximation to the discrete choice of processes, activities and equipment made at the plant level.

Capital, labor and energy inputs are separable into two broader categories, value added and energy inputs. Value added includes capital and labor inputs to production. A Constant Elasticity of Substitution technology is used to describe the level of value added produced from capital and labor inputs. Energy inputs consist of coal, natural gas, crude oil, refined oil products and electricity. These are aggregated according to a constant elasticity of substitution technology. The conditional demand for these inputs is defined from efforts by the firm to minimize the costs of producing the composite quantity required at the higher levels for the nested production structure.

Material inputs are goods and services produced by other industries needed in production. These material inputs are used in fixed proportions to the level of output. The firm cannot substitute among materials in production. The firm may, however, through its organization of assembly and manufacturing operations, substitute between material inputs and capital, labor and energy in production according to a constant elasticity of substitution production technology.

Private capital accumulation is characterized by the equation of motion for capital where physical capital depreciates at a rate δ_K. Gross investment, I_t, is dynamic in nature with its optimal trajectory induced by the presence of adjustment costs. These costs are modeled as internal to the firm - a loss in capital accumulation due to learning and installation costs - and are meant to reflect rigidities in the accumulation of capital towards its optimal level. Adjustment costs are assumed to be non-negative, monotonically increasing, and strictly convex. In particular, we assume adjustment costs to be quadratic in investment per unit of installed capital.

Optimal production behavior consists in choosing the levels of output supply, labor demand, aggregate energy demand, aggregate demand for intermediate materials, and demand for investment that maximize the present value of the firms' net cash flows, subject to the equation of motion for private capital accumulation.

Finally, with regard to the financial link of the firm with the rest of the economy, we assume that at the end of each operating period the net cash flow netted of investment spending is transferred to the consumers as return on their ownership of the firms.

2.4 Investment Supply and Demand

The output of various industries is used in the production of capital goods used by firms. Construction, equipment manufacturing, primary metals and other goods and services are used in the production of plant and equipment for firms. These industry determine the supply of investment goods. The supply of the investment good is a CES composite of the different types of investment goods available in the economy. Demand for individual component of the investment good is determined by the minimization of the cost of producing the desired amount of the investment good in the economy at time t. In turn, the demand for investment by firms is determined by the firms' maximization problem described above.

Financing for investment is available from savings by private households and foreign transfers reflected in the current accounts deficit and is affected by public deficits whereby reductions in tax revenues or unfinanced increases in expenditures increase the public deficit and crowd out private investment.

$$\sum_{c \epsilon C} PQ_{c,t} QINV_{c,t} = \sum_{h \in H} SAV_{h,t} + CAB_t + Public\ Deficit_t$$

2.5 The Foreign Sector

The current account deficit reflects the balance of payments with the foreign sector and incorporates both the trade balance and financial flows from abroad. The current accounts deficit is

$$CAD_t = \sum_{c \in MP} PM_{c,t} QM_{c,t} - \sum_{c \in EP} PE_{c,t} QE_{c,t} + ir_t FD_t - \sum_{i \in I} TR_{i,ROW}$$

and accumulates in foreign debt.

Because of the nature of the currency markets where the economy finds itself, we assume that the foreign exchange rate is exogenous and fixed. This means that in the absence of import and export duties, the import and export prices for the same commodity would be the same.

Net imports are financed through foreign transfers and foreign borrowing. Foreign transfers grow at an exogenous rate. The domestic economy is assumed to be a small, open economy. This means that it can obtain the desired level of foreign financing at a rate which is determined in the international financial markets. This is the prevailing rate for all domestic agents.

Domestic production and imports are absorbed by domestic expenditure and exports. Domestic demand is satisfied by domestic production and imports from abroad following an Armington specification. Goods produced domestically are supplied to both the national (domestic) market and exported internationally and follow a Constant Elasticity of Transformation (CET) specification

2.6 The Public Sector

The equation of motion for public debt reflects the fact that the excess of government expenditures over tax revenues, i.e., the public deficit, has to be financed by increases in public debt. Given the nature of our approach, the evolution of public debt is determined by the endogenous evolution of the tax revenues or more specifically by the endogenous evolution of the different tax bases. Specifically, no behavioral changes on the expenditure side are considered.

Tax revenues include personal income taxes, corporate income taxes, value added taxes as well as other product-specific taxes, social security taxes levied on firms and workers, as well as duties levied on imports and/or exports. All of these taxes are levied on endogenously defined tax bases. Residual taxes are modeled as lump sum, obtained by calibration and are assumed to grow at an exogenous rate.

On the expenditure side, the public sector engages in public consumption and public investment activities. In addition, the public sector transfers funds to households - in the form of pensions, unemployment subsidies, and social transfers also at an exogenous growth rate. Because these expenditures consistent primarily of expenditures on compensation of public sector employees and on social transfers, these expenditures are assumed to grow at an exogenous rate g. Finally, the public sector pays interest on outstanding debt

The allocation of public consumption spending among the different goods and services in the economy is responsive to relative prices and is obtained through the solution to the public sector's cost minimization problem of achieving the desired aggregate consumption level. While aggregate consumption in volume is determined exogenously, public consumption expenditure is affected by endogenous changes in prices determined by the model supply and demand considerations.

2.7 General Market Equilibrium

The general market equilibrium is defined by the national income accounting identity and equilibrium in product markets, labor markets, the market for the investment goods (savings = investment), and financial markets.

The product market equilibrium reflects the national income accounting identify and the expenditure components of commodity output by sector of economic activity. The total amount of a commodity supplied to the economy, both through domestic production and imported from abroad, must equal the total end-user demand for the product, including demand by households, the public sector, use as an intermediate demand and as an investment good.

The total labor supplied by the different households, adjusted by the unemployment rate, ur, must equal total labor demanded by the different sectors of economic activity. In the current version of the model the unemployment rate is exogenous and constant. The unemployment rate is to be interpreted as the long-term rate of natural unemployment. There is only one equilibrium wage rate although this translates into different household-specific effective wage rates based on the household-specific levels of human capital. Different firms buy shares of the same aggregate labor supply. This implicitly means that we do not consider differences in the composition of labor demand among the different sectors of the economic activity in terms of the incorporated human capital levels.

Saving by households and the foreign sector, i.e., the current account deficit must equal the value of domestic investment plus the public deficit.

2.8 Model Calibration and Solution

The calibration of the model is ultimately designed to allow the model to replicate as its most fundamental base case, a stylized steady state of the economy as defined by the trends and information contained in the data set. In the absence of any policy changes or any other exogenous changes the model implementation will just replicate forward such stylized economic trends. Counterfactual simulations allow for identifying the marginal effects of any policy or exogenous change as deviations from the base case.

We define the steady-state growth path as an intertemporal equilibrium trajectory in which all the flow and stock variables grow at the same rate g, while market prices and shadow prices are constant. There are three types of calibration restrictions imposed by the existence of a steady-state. First, it determines the value of critical production parameters, like adjustment costs and depreciation rates given the initial capital stocks. These stocks, in turn, are determined by assuming that the observed levels of investment of the respective type are such that the ratios of capital to GDP do not change in the steady state. Second, the need for constant public debt and foreign debt to GDP ratios implies that the steady-state public account deficit and the current account deficit are a fraction g of the respective stocks of debt. Finally, the exogenous variables, such as public transfers or international transfers, have to grow at the steady-state growth rate, g.

2.9 Computational Implementation

The dynamic general equilibrium model is fully described by the behavioral equations and accounting definitions and thus constitutes a system of nonlinear equations and nonlinear first order difference equations. No objective function is explicitly specified due to the fact that each of the individual problems (the household, firm and public sector) are set as first order and Hamiltonian conditions. These are implemented and solved using the GAMS (General Algebraic Modeling System) software and the MINOS nonlinear programming solver.

MINOS uses a reduced gradient algorithm generalized by means of a projected Lagrangian approach to solve mathematical programs with nonlinear constraints. The projected Lagrangian approach employs linear approximations for the nonlinear constraints and adds a Lagrangian and penalty term to the objective to compensate for approximation error. This series of sub-problems are then solved using a quasi-Newton algorithm to select a search direction and step length.

2.10 Data Description and Sources

Data are from the Instituto Nacional de Estatistica (www.ine.pt). The data are based on the Portuguese National Accounts (ESA 2010, base 2011). These data include A – main aggregates for the Portuguese economy, including 1) Gross Domestic Product and its components, 2) Income, Saving and Net Lending/ Borrowing, 3) External Balances, 4) Employment and 5) Goods and Services account. These further include B – Institutional Sectors including, the Government, Households and the Rest of the World (the Foreign Sector). We further consider specific tables by industries including Gross Value Added – Compensation of Employees, Gross Operating Surplus and Taxes/Subsidies on Production, as well as Production and Intermediate Consumption by the A38 classification of economic activity described below. We further use detailed supply and use tables to construct the social accounting matrix for Portugal.

Data for household expenditure are taken from two surveys. The first is the Inquérito ao Consumo de Energia no Sector Doméstico, a one-time survey conducted in 2010. The second is the Inquérito as Despesas das Famílias a survey conducted every five years. The model largely employs data from the 2010/2011 survey in allocating income to household by income group and describing the expenditure patterns for each household type.

The Energy Sector in Portugal

Portugal imports fossil fuels and has a large potential for renewable energy resources, namely wind, solar and hydropower. Renewable energy resources accounted for 25.9% of domestic primary energy consumption in Portugal in 2014, primarily used in the production of electricity. Petroleum and petroleum products accounted for 43.4% of primary energy consumption in Portugal in 2014. Natural gas (16.7% and coal (12.8%) are important sources of energy as well.

Transportation demand for energy amounted to 36.3% of the total final demand for energy in 2014, followed closely by industry (31.2%). Diesel is the dominant fuel in transportation in Portugal (4.072 Mtep in 2014), followed by gasoline (1.136). Residential demand for energy amounted to 16.8% of the total and demand in services accounted for 12.8%. The remaining 2.8% constitutes final energy demand in agriculture. With respect to electricity, services (36.7%) and industry (34.5%) are much more important as is residential demand for electricity (26.4% of the total). Agriculture (1.8%) and transportation (0.7%) do not use electricity extensively.

Electricity

Renewable energies have made substantial advances in Portugal since 2005. In 2005, thermal electricity general amounted to 85% of the total and renewable energies, including hydroelectric, wind, geothermal and solar power, amounted to 15% of electricity generation. By 2014, electricity generation grew to account for 56.4% of electricity generated in continental Portugal lead by a substantial increase in wind energy generation which accounted for 23.4% of electricity production in 2014, a year with very favorable hydrological conditions which allowed for electricity from hydroelectric facilities to account for 31.9% of total electricity produced. The increased reliance on domestic, renewable energy sources has contributed towards a reduction in emissions factor for the electric power industry from 462 tCO_2 per Gwh in 2005 to 217 tCO_2 per Gwh in 2014.

Table 2.1 Energy Prices and Taxes

	Unit	PST	IVA	ISP	Carbon Tax	Other	PVP
Coal	Eur/ton	50.60[1]			15.11		65.71
Natural Gas	Eur/GJ	25.41	6.00	0.30000	0.38000		32.09
Butane and Propane	Eur/kg	1.29	0.30	0.00799	0.01477		1.62
Gasóleo	Eur/l	0.58	0.23	0.27841	0.01260	0.11	1.21
Gasolina 95	Eur/l	0.55	0.27	0.51895	0.01156	0.09	1.43

1: The price per ton of coal was found from the Factura Energetica, 2015 based on import costs and quantities
Source: DGEG

In 2008 and 2009 the final demand for electricity in Portugal fell 1.2% and 0.9%, respectively. During the crisis that followed, electricity demand fell 8.8%, from 48.9 Twh in 2010 to 44.6 Twh in 2014, falling 3.0% in 2011 and 4.1% in 2012, respectively. This reduction in emissions is likely attributable to low levels of economic output and consumer confidence during the crisis (Eurostat, 2017)

Energy Prices and Taxes

Energy products in Portugal are subject to value added taxation and product specific taxes. Since January 1, 2011 the value added tax (IVA) rate on energy products is 23% (Lei nº51-A/2011, September 30), up from 19% in 2005. Energy products are subject to a specific tax on petroleum products (ISP) and to carbon taxation. Industrial use of natural gas is exempt from carbon taxation. The carbon tax rate for 2017 is based on an average price in the EU-ETS of 6.85 Euro/tCO_2 (Portaria nº 10/2017, August 1).

The Portuguese Economy

The Portuguese economy was dramatically affected by the sovereign debt crisis experienced in many parts of Europe since 2011. The late 1990s was a period of substantial growth in Portugal during which time the Portuguese economy grew at an average annual rate of 4.2%. During the early 2000s, the Portuguese economy began to stagnate and grew at an average annual rate of 1.5% between 2000 and 2004. Since 2005, growth in Portugal has been very weak. The real annual rate of growth of economic activity between 2005 and 2014 was -0.2%. In fact, since the financial crisis Portugal lost 6.8% of its national income between 2010 and 2013. Growth has picked up over that the last few years with the real growth rate of estimated for 2015 at 1.6%.

Gross domestic product consists of private consumption (66.44%), public consumption (19.94%), investment (19.66%) and net exports (-8.21), the difference between exports (28.75%) and imports (36.96%). From the income side, employment made up 46.23% of GDP between 2005 and 2014 while gross operating surplus for firms amounted to 41.44% of GDP. These figures imply that labor income made up 52.73% of income and capital income accounted for 47.27% of income.

The largest sectors of economic activity, in terms of employment levels between 2005 and 2014, were Wholesale and retail trade (15.6%), construction (9.3%), agriculture (7.5%), the public sector, accommodation and food services (5.8%) , and manufacturing of textiles, wearing apparel and leather products (4.9%).The principal exports in Portugal are automobiles and transportation equipment with exports from the manufacturing of transport equipment accounting for 3.2% of GDP followed by the manufacturing of textiles, wearing apparel and leather products which exported products valued at 3.1% of GDP between 2005 and 2014. Other energy intensive manufacturing industries, including basic metals and fabricated metal products (2.3%), non-metallic mineral products (2.0%) and wood and paper products (1.8%), have also been very important tradable sectors in the Portuguese economy. (Instituto Nacional de Estatistica)

The Public Sector in Portugal

Since 2005, public debt has exploded from 67.4% of GDP to 130.6% of GDP in 2014. Public deficits in Portugal reached 6.8% of GDP in 2009 and 8.2% of GDP in 2010.

The tax burden in Portugal amounted to 34.5% of GDP in 2015. In recent years, the increase in taxation in the context of austerity measures to address high levels of public indebtedness have focused on increases in the corporate income tax, the value added tax and social security contributions. The tax burden in Portugal was below the EU28 average of 39.0% in 2015. Taxes on income, including personal income taxes (9.27%) and social security contributions (7.98% of GDP from employers and 3.74% from workers) are the largest source of revenue for the Portuguese government. Value added and excise taxes are the second largest source of income for the Portuguese government. Revenues from the value added tax amounted to 8.0% of GDP between 2005 and 2014 and product specific excise taxes, including taxes on energy products amounted to 4.37% of GDP.

Household Income and Expenditure

Households consume energy to satisfy demand for transportation services and for residential use. Residential energy consumption accounted for 3.91% of household expenditure while energy demand for personal transportation accounted for 4.55% of household expenditure. Diesel fuel is the dominant source of fuel for automobile transportation in Portugal, accounting for 56.9% of energy consumption in transportation. Residential energy demand includes the use of electricity for heating (11.1% of expenditure) and cooling (0.7%) the residence, heating water (27.4%), energy consumption in the kitchen (39.7%), associated with electrical appliances (15.0%) and lighting (6.1%). Residential demand for energy is dominated by electricity consumption which accounts for 42.5% of consumption and 62.5% of expenditure on energy across households. Butane, propane and liquefied petroleum gases (LPG) are also an important source of energy in residences accounting for 18.0% of consumption and 24.3% of expenditure. These are particularly important sources of energy for hot water furnaces and for use in cooking in the kitchen. Natural gas use in residences has increased in recent years but remains relatively modest accounting for 9.3% of consumption and 6.1% of expenditures. Coal is used in small amounts in households and almost exclusively for cooking.

Patterns of energy consumption across household groups at different income levels tend to suggest that energy services are normal goods, whose consumption increases with income, and that these are necessary goods, that they tend, generally to make up a larger share of a household's budget at lower levels of income than at higher levels of income. This pattern of consumption is particularly apparent for electricity demand. Expenditure on electricity amounted to 4.04% (3.91%) of expenditure for households in the lowest income quintile in 2010, 3.49% (3.11%) for those in the second quintile, 3.07% (2.69%) for those in the third quintile, 2.63% (2.26%) for those in the fourth quintile and 2.25% (1.70%) for those in the highest income quintile. Natural gas consumption tends to follow a similar pattern of expenditures, though expenditures in the lowest income quintile are slightly lower (0.42% of income) than those in the second (0.56%) and third (0.45%) of income. Expenditure on natural gas for households in the highest two income quintile is somewhat lower, at 0.29% and 0.10% of income, respectively.

Much of Portugal, and the larger cities of Lisbon and Porto, in particular, is equipped with a well-developed public transportation system which includes buses, trains, boats and light rail networks. The availability of this public transportation network coupled with high gasoline and diesel prices, lower salaries, and the relatively compact city structures have contributed towards making cars something of a luxury, though expenditure shares vary little across income groups. Diesel and gasoline consumption together account for 4.32% of expenditure among low income households, 4.49% among households in the second income quintile, 4.55% among those in the third income quintile, 4.63% among those in the fourth income quintile and 4.57% among those in the highest income quintile.

3 The Reference Scenario and Simulation Design

3.1 The Reference Scenario

The reference scenario provides a trajectory for the economy through 2050. This scenario serves as a reference for evaluating the impact of policies that follows. The reference scenario embodies several assumptions regarding climate policy and technological progress. The principal climate policy considerations present in our reference scenario are first, that the tax of 5 Euro/tCO_2 persists at this level through 2050 and second that the major coal fired power plants in Portugal cease operations at the end of their useful life and no additional coal capacity is installed. Power has two major coal fired power plants, one in Sines and one in Pego which together accounted for 22% of greenhouse gas emissions in Portugal in 2012. The plant in Sines is scheduled to close in 2035 and the plant in Pego in 2040. Fuel prices follow forecasts given by the International Energy Agency (2016). Finally, we assume an increase in energy efficiency in transportation and in electricity usage of 35% by 2030 with moderate to no improvement thereafter.

These assumptions imply a reference scenario in which greenhouse gas emissions fall 36.8% from 2015 levels, from 64.6 Mt CO_2e in 2015 to 44.3 Mt CO_2e in 2050. This reduction is largely the result of closing the Sines and Pego power plants but is also driven by increasing oil and natural gas prices. The closing of Sines and Pego is also associated with a substantial increase on domestic reliance on renewable energy resources. Renewable energy resources increase from 52.6% of electricity production in 2015 to 86.5% in 2050, a 64.4% increase over 2015 levels. The greatest increase in the importance of renewable energy in electricity production occurs between 2030 and 2040 with the closure of the coal fired power plants in Portugal. Electricity demand is projected to increase in Portugal by 23.9% in 2050 over 2015 levels, from 46.9 Twh 2015 to 58.1 Twh in 2050. This is in large part driven by technological progress in the electric power industry.

Table 3.1 Fossil Fuel Price Scenario

		2015	2020	2025	2030	2035	2040	2045	2050
Oil	$/bbl	51.0	79.0	95.5	111.0	118.0	124.0	128.8	132.7
Natural Gas	$/Mbtu	7.0	7.1	8.7	10.3	10.9	11.5	12.0	12.3
Coal	$/t	57.0	63.0	68.5	74.0	75.5	77.0	79.1	81.3

Source: International Energy Agency

3.2 The Harmonization of the Reference Scenario in the TIMES_PT and DGEP Models

The analysis of decarbonization and electrification of the Portuguese economy is based on a soft-link between the energy systems model TIMES and the dynamic multi-sector general equilibrium model of the Portuguese economy, DGEP. The joint analysis of policies to promote decarbonization and electrification of the Portuguese economy rests on a consistent harmonization of the reference scenarios employed by the model projecting the energy and economic systems between 2020 and 2050. The reference scenario describes the trajectory for carbon dioxide emissions, the demand for electricity and the use of renewable energy in the production of electricity, among many other characteristics of the energy system and the economy.

The harmonization process has the objective of bringing into alignment certain key indicators in the reference scenarios of the TIMES and DGEP models, thereby allowing for a analysis in which the effects of decarbonization and electrification policies on the energy system and the economy are comparable and consistent and allow for an analysis of the effects of these policies. This procedure allows the detail and focus of each model to provide a complementary and coherent analysis of the policies in question and provide a complete picture of the energy, environmental and macroeconomic effects of decarbonization of electrification of the Portuguese economy.

The key indicators considered for the harmonization process are carbon dioxide emissions, the final demand for electricity, and the share of renewables in the electricity production. To assess the degree of coherence between the models, we examined the endogenously generated trajectories for these key indicators in 2020, 2030, 2040 and 2050 for the two modelling platforms. Convergence among the reference, business-as-usual trajectories generated endogenously is achieved with the key model indicators identified for each year with 10% of each other.

The reference scenario for the energy sector was constructed, as discussed above, through consultation with EDP, and in consultation with stakeholders in energy and manufacturing industries. The reference scenario were amended and approved by EDP, together with the key harmonization values for the energy sector. The macroeconomic demand drivers for the TIMES energy system model, namely the long-run trajectory for GDP, private consumption and output by sector of economic activity were specified by the DGEP.

In turn, the DGEP model assumptions were adjusted to generate the desired harmonization for the key indicators identified above. Energy intensity and the exogenous energy efficiency improvements in the dynamic general equilibrium model of the Portuguese economy are specified based on the energy system characteristics endogenously defined by the TIMES model. In addition, the trajectory for carbon dioxide emissions, final demand for electricity and the use of renewable energy in the production of

Table 3.2 Harmonization of Reference Scenarios of TIMES_PT and DGEP Models

TIMES | REFERÊNCIA — Harmonização dos modelos — REFERÊNCIA | DGEP

2015=100	2020	2030	2040	2050
		CO_2 Emissions		
TIMES	95.7	84.7	64.0	57.6
DGEP	95.0	89.1	64.5	63.2
Diff (%)	0.8	-4.9	-0.8	-8.9
		Final Demand for Electricity		
TIMES	101.4	109.4	119.0	122.9
DGEP	106.3	121.3	119.2	123.9
Diff (%)	-4.7	-9.8	-0.2	-0.8
		Electricity Production from Renewable Sources (%)		
TIMES	113.2	126.4	160.4	171.7
DGEP	105.0	114.1	158.5	164.4
Diff (%)	7.8	10.8	1.2	4.4

electricity are defined within the framework of the TIMES model and matched endogenously in the DGEP model.

With minimal harmonization efforts, the results from the two models tended to be relatively close for 2020 and 2030. For 2040 and 2050, however, very large discrepancies existed. These discrepancies were traced to two central assumptions of the TIMES model that were not naturally present in the DGEP model. On one hand, the issue of the closure of the Sines and Pego power plants projected in the TIMES for 2035 and on the other hand the accelerated level of electrification of energy demand for transportation in the last two decades. The DGEP harmonization efforts in the second stage, therefore, were centered first on closing the option of electricity generation through coal power plants, something that necessitated a fair amount of changes in the model coding as well as increasing the penetration of electricity in the transportation sector, something achieved mostly through changes in parameterization.

Table 3.2 presents the key endogenous harmonization indicators for the two modelling platforms. Convergence among the two models and the desired harmonization has been achieved as targeted for all indicators and for all years. In each cases, we considered deviations in the model results for 2020, 2030, 2040, and 2050, relative to the model-generated 2015 figures. In the case of the DGEP model, and by construction, the 2015 model-generated figures coincide with the historical figures. The levels for harmonization achieved for CO_2 emissions, the level of final electricity demand and for the percentage of electricity production from renewables are very high. In all cases within or close to a 10% variation band, well within the 20% objective defining convergence among the two models with respect to the reference scenario.

3.3 Simulation Design

The reference scenario adopted by the TIMES_PT and the DGEP models — the starting point for the analysis of the macroeconomic effects of decarbonization policies — incorporates sizable reduction in CO_2 emissions and advances in electrification and the use of renewable energy sources relative to a business as usual scenario. The central policy objective we consider is a 60% reduction in carbon dioxide emissions, relative to 1990 levels, in 2050, which we will refer to as the 60/50 scenario. The TIMES_PT model results provide a wide variety of cost-effective strategies for achieving a 60% reduction in CO_2 emissions relative to 1990 levels by 2050. The shadow price of the emissions constraint measures the marginal cost of carbon dioxide emissions reductions associated with the emissions constraint. This shadow price is used as the level of the tax required to meet the emissions reductions goal.

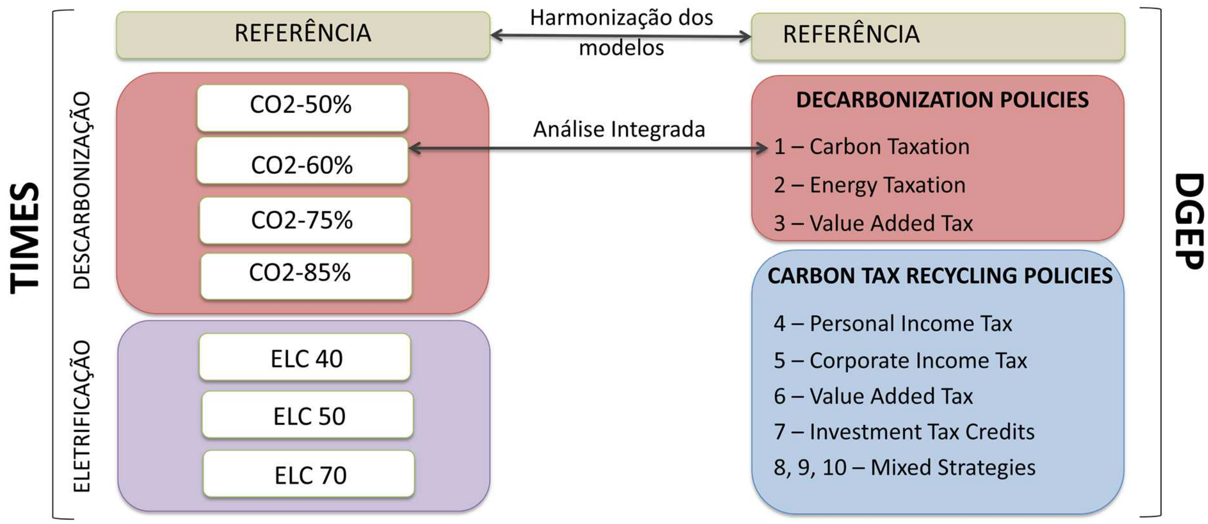
We start from this reference scenario to define a whole array of counterfactual scenarios divided in two groups. First, we consider decarbonization policies based on a tax on carbon, a broader-based energy tax and an increase in the value added tax on private consumption. Second, we consider carbon taxation in the context of a broader environmental tax reform with revenues from the tax on carbon recycled by a reduction in distortionary tax margins and together with credits and incentives for energy efficiency improvements. All counterfactual results are presented as percentage deviations from the reference scenario. All results reported here refer to long-term effects in 2050.

In our first simulation scenario, the marginal costs from the TIMES model are implemented as a carbon tax, that is, carbon pricing in its most basic and direct form. This policy also reflects the current state of carbon pricing in Portugal in which the carbon tax levied on households and firms not participating the European Union Emissions Trading System (EU-ETS) are indexed to prices in the EU-ETS, thereby generating a single, economy-wide price for carbon dioxide emissions.

More specifically, two families of counterfactual economic scenarios were modeled by the DGEP general equilibrium model:

1. ***Decarbonization scenarios***: Decarbonization strategies based on a carbon tax (1), an energy tax (2), and value added taxation (3). The tax levels are defined in a way that is consistent with the marginal costs of emissions reductions associated with the 60% reduction goal defined by the TIMES model. Each tax policy generates the same revenue for the public sector and the proceeds from these tax instruments are used to finance deficit reduction.
2. ***Decarbonization scenarios with Environmental Tax Reform*:** Reform to four tax margins are considered in conjunction with carbon taxation: the personal income tax, the corporate income tax, the value added tax, and financing for investment tax credits together with incentives for energy efficiency.

Table 3.3 Counterfactual Simulations for TIMES_PT and DGEP Models



3.4 The Anchoring of the DGEP Simulations Scenarios

The TIMES_PT model results provide a wide variety of cost-effective strategies for achieving a 60% reduction in CO_2 emissions relative to 1990 levels by 2050. The corresponding shadow price of the emissions constraint reflect the marginal costs of CO_2 reductions and are modelled as a carbon tax in order to identify the economic, budgetary and distributional effects of decarbonization policies for the Portuguese economy and to highlight the economic mechanisms underlying the transition to a low carbon economy. The emissions constraint suggests that the tax on CO_2 emissions will need to increase from its current level of 5€/tCO_2 to 33€/tCO_2 in 2030, 49€/tCO_2 in 2040 and 183 €/tCO_2 in 2050.

Comparisons among the different decarbonization policies based on carbon taxes, energy taxes and consumption taxes are possible and are based on the design of these policy instruments to raise the same level of revenue for the public sector and the use of these revenues to reduce the public deficit. To have a sense of the magnitude of these policies, given the marginal cost implied by the TIMES_PT model, these pricing policies would generate revenues for the public sector equal to approximately 0.1% of 2015 GDP in 2020; 1% in 2030, 1.1% in 2040 and 2.5% in 2050. As a reference, currently the personal income tax revenues represent about 10% of the GDP, while the corporate income tax represents 2.5% and the value added tax about 8%. Considering 2015 GDP values the carbon tax revenues would amount to 175 million euros in 2020 and would steadily increase to 4.400 million by 2050.

4 Implementing 60 / 50 Climate Policy Objectives with Carbon Taxation

4.1 Introduction

To benchmark our results, we now focus on the most direct economic counterpart to the TIMES_PT decarbonization policies in defining the marginal costs of emissions reductions as a tax on CO_2 emissions. The discussion in this chapter is based on the results reported in Tables 4.1 to 5.12 and in more detail in Appendix 1.

4.2 Energy and Environmental Effects

Carbon taxes and auctioned permits increase the price of fossil fuels in direct relation to the carbon content of the fuel and thereby increase the market opportunity cost of fuels with a greater carbon content. The tax on carbon dioxide emissions introduced to meet the 60/50 climate policy objectives increases the composite price of final energy demand by 57.5% over the long run.

The changes in the individual energy prices naturally reflect their carbon content with coal showing by far the largest increase of 379.0%, followed by natural gas and diesel, with 43.1% and 44.5%, respectively. The increase in electricity price is more moderate 9.2% due to the presence of renewables while the effects on the price of biomass is marginal.

As a result of the overall increase in the price of final energy demand, we observe a 14.4% overall decline in final energy consumption. Besides final demand for coal with a sharp decline of 67.8%, final demand for natural gas and diesel are particularly affected with reductions of 27.4% and 24.5%, respectively. Final demand for electricity falls just by 5.7%.

Firms and business sharply reduce their energy consumption in response to the tax on carbon dioxide emissions. This reduction in final energy demand is driven by changes in production levels and the demand for the firms output as well as changes in the input structure away from carbon intensive sources of energy. The sectors that show the largest reductions are refining [a1], construction [a6], transportation [a7], and rubber [a11] followed closely by agriculture [a4] and equipment [a5]. These sectors are highly energy intensive with few substitution possibilities for energy demand.

In turn, household demand for energy falls by 8.5%. Households in all income brackets reduce their final demand for energy. The largest reductions, with respect to final demand for each household, are realized by households at the lowest income levels, in the two lowest income quintiles, and those in the highest income quintile. These reductions are due to the greater importance of energy consumption in the budget of low-income households and the larger effect of carbon taxation on capital income which is a relatively more important source of income for higher-income households.

Table 4.1 Carbon Tax: Effect on Final Energy Prices

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Composite Energy Price	2.666	12.745	19.868	57.523
Coal	19.774	86.345	135.623	392.032
Natural Gas	2.326	9.949	15.240	43.061
Butane, Propane and LPG	0.632	5.952	9.722	27.607
Fuel Oil	2.252	5.450	7.763	18.747
Gasoline	1.306	6.545	10.281	29.066
Diesel	2.313	9.885	15.434	44.510
Electricity	-0.011	1.690	2.770	9.192
Biomass	-0.336	-0.042	-0.378	1.969

In the electricity market we see a reduction in electricity production of 4.8%, due to a 21.0% decline in the production form non-renewables sources and despite the increase in production from renewable sources. Indeed, **the share of renewables in total electricity production increases by 9.1%.**

Overall, the demand for electricity declines by 5.7%. The larger reduction in demand suggests an increase in net imports of electricity of 9.4%, due simultaneously to a decrease in exports and increase in imports. The reduction in electricity demand stems largely from a reduction in demand for electricity in production activities of 5.9%. The sectors that are the most affected are refining [a1], equipment [a5], wood [a9], rubber [a11], and metals [a12]. In all industries we observe an increase in the share of electricity in final demand. The decline in electricity demand comes mostly from industries, with a decline of 6.4%. Household demand for electricity decreases by 1.6% relative to reference levels with a

Table 4.2 Carbon Tax: Effect on Final Energy Demand

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.230	-3.550	-5.698	-14.351
Coal	-3.046	-31.844	-43.232	-67.820
Natural Gas	-0.549	-7.345	-11.371	-27.373
Butane, Propane and LPG	-0.351	-4.528	-7.214	-17.946
Gasoline	-0.267	-3.527	-5.658	-14.511
Diesel	-0.452	-6.187	-9.868	-24.520
Electricity	0.012	-1.146	-1.795	-5.717
Biomass	0.320	1.207	2.153	3.472

more pronounced reduction in demand among low-income households. **Despite this overall reduction in electricity demand due to the increase in electricity prices induced by the tax on carbon dioxide emissions, the share of electricity in final energy demand increases by 10.8% reflecting an overall improvement in the market opportunity cost of electricity relative to natural gas, coal and other residential sources of energy.**

The tax on carbon dioxide emissions is effective in reducing carbon dioxide emissions. The tax on carbon dioxide emissions reduces emissions by 24.3% in 2050, sufficient to meet climate policy objectives. Both households and firms reduce carbon dioxide emissions in response to the pricing mechanism.

Firms reduce their carbon dioxide emissions by 26.0% in the long run. These emissions reductions are led by reductions in emissions in agriculture [a4], equipment [a5], construction [a6], rubber [a11], and metals [a12], closely followed by refining [a1], textiles [a8] and other [a13].

Households reduce their carbon dioxide emissions by 21.1%. This reduction in emissions is primarily due to reductions in residential energy demand and the associated emissions from coal, natural gas and liquefied petroleum gases, which are more readily substitutable for electricity. Carbon dioxide emissions associated with residential energy demand fall by 37.5%. Household Carbon dioxide emissions associated with transportation decreases by 15.8% this is largely due to the more limited substitution possibilities available which primarily include public transportation and transportation services.

Households at the lowest income levels contribute a relatively larger amount to emissions reductions efforts. Households in the lowest income group, the first income quintile reduce emissions by 24.1% which those households in the highest income group reduce emissions by 17.6%. This pattern of behavior is consistent for both residential and transportation uses of energy.

Table 4.3 Carbon Tax: Effect on the Electric Power Industry

(Percent change relative to the reference scenario)

	2020	**2030**	**2040**	**2050**
Carbon tax				
Electricity Production	0.007	-0.991	-1.535	-4.840
Renewable Energy Share	0.333	2.290	4.213	9.095
Final Demand for Electricity	0.012	-1.146	-1.795	-5.717
Electricity Demand by Households	0.055	-0.080	-0.230	-1.637
Electricity Demand by Firms	-0.007	-1.264	-1.944	-5.865
Electricity Share in Final Demand	0.254	2.742	4.437	10.785

Table 4.4 Carbon Tax: Effect on Carbon Dioxide Emissions

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Carbon Dioxide Emissions	-0.394	-5.036	-10.355	-24.322
Households	-0.534	-6.298	-9.682	-21.083
Residential	-1.373	-14.885	-21.108	-37.549
Transportation	-0.281	-3.708	-6.070	-15.841
Firms	-0.348	-4.613	-10.694	-25.987

Both the energy systems model, TIMES_PT and the DGEP dynamic general equilibrium model provide information about the environmental effectiveness of the policies under consideration. We can therefore provide some comparison of the effects of these climate policies in both models. Although energy and environmental indicators are used in the harmonization process, the two evaluation approaches yield results consistent with their own optimization framework in the counterfactual simulations. Accordingly, the comparison here are meaningful as the two sets of results and conclusions are not hardwired. To facilitate comparisons, we consider changes vis-à-vis the observed 2015 levels of the different variables.

We start by noting that final energy demand is reduced in the DGEP model by 9.7% compared to a mere reduction of 3.4% in the TIMES_PT model. This is a central results as it points to the fact that a lot of the changes in the energy sector are in the DGEP model of a scale effect, meaning the contraction of energy demand, while in the TIMES_PT model they are a results of the substitution effect, switching energy sources. This is seem clearly in the case of electricity demand, which increases by 19.6% in the DGEP model and by 34.7% in the TIMES_PT. Not surprisingly other indicators are more aligned. The share of electricity in final demand increases by 35.5% in the DGEP model and by 36.0% in the TIMES_PT model while share of renewables in electricity production increases to 87.5% in the DGEP model and to 92% in the TIMES_PT.

Finally, in terms of emissions reductions, we observe that it is not just the mechanisms that are different – reduction of economic activity in the DGEP model and substitution in the TIMES_PT model, but the final magnitudes are different. The same carbon tax leads to a 53.2% reduction in CO_2 emissions vis-à-vis 2015 in the DGEP model and 64.2% in the TIMES_PT. This means that the economic mechanisms and inertia which are absent in the TIMES_PT model lead to an erosion of the environmental gains estimated for any given marginal abatement cost.

4.3 Macroeconomic Effects

The increase in energy prices associated with the tax on carbon dioxide emissions increases input prices and provides the firm with the incentive to alter its input structure to accommodate the changes in the market opportunity cost which will affect the firms production levels in a fashion consistent with the technical rate of substitution embodied by the firms production technology and the marginal product of each of the firms inputs.

The net effect of both these substitution and scale effects in production is to reduce the firms' net cash flow and increase output prices. The higher prices The structure of the economy changes in a manner consistent with the marginal rate of transformation as the marginal cost of production increases for firms, increasing by more for firms with low substitution possibilities and greater energy intensities. These effects, coupled with demand reduction associated with the greater prices for energy and goods and services produced in energy-intensive industries, contribute towards a negative effect of carbon taxation on macroeconomic performance.

The increase in energy system costs due to the introduction of the tax on carbon dioxide emissions causes firms to substitute among energy inputs and, more importantly, reduce energy consumption. Firms substitute capital and especially labor inputs for energy inputs in response to the greater cost of energy in production. Overall, investment by firms decreases by 2.9% and employment falls by only 2.1%, substantially less than the reduction in final energy demand by firms noted above.

Table 4.5 Carbon Tax: Effect on Macroeconomic Performance

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
GDP	-0.055	-0.976	-1.621	-4.284
Consumption	-0.032	-0.412	-0.774	-2.370
Gross Fixed Capital Formation	0.155	-0.434	-0.691	-2.890
Exports	-0.212	-2.220	-3.759	-9.180
Imports	-0.070	-0.979	-1.475	-3.459
Foreign Debt	0.042	0.792	2.501	5.324
Trade Deficit	0.488	3.607	5.785	13.151
Public Debt	-0.011	-1.441	-4.784	-12.578

The reduction in investment is particularly strong in refining [a1] and equipment [a5], followed by wood [a9], rubber [a11] and metals [a12]. Investment increases in electricity [a2], biomass [a3], and transportation [a7]. Similarly, the most pronounced reductions in employment are in refining [a1], followed by equipment [a5], transportation [a7], chemicals [a10], rubber [a11], and metals [a12]. This reflects not only substitution possibilities within these industries but also the feedback effects associated with higher prices for output on the demand for goods and services produced in these industries by households and other firms. This is certainly apparent for petroleum refining which responds substantially to the lower demand levels associated with increases in the prices for refined petroleum products both for industrial uses and in transportation services. The reduction in equipment manufacturing is directly driven by the lower levels of investment activity carried out by firms in response to the increase in energy system costs as well as the savings behavior by households and the effects of the tax on the public sector account to be discussed below.

The reduction in input demand and use by firms naturally indicates that output levels are lower as a result of the tax on carbon dioxide emissions. **The introduction of carbon pricing comes at a cost of a 4.3% reduction in GDP**. The sectors most negatively affected are refining [a1], equipment [a5], transportation [a7], and rubber [a11] with reductions of 18.7%, 11.1%, and 11.1% respectively. They are closely followed by chemicals [a10] and metals [a12]. Only biomass is affected in a positive although small manner.

Table 4.6 Carbon Tax: Industry Effects – Output

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.055	-0.976	-1.621	-4.284
A1. Petroleum Refining	-0.351	-4.528	-7.214	-17.946
A2. Electricity Production	0.007	-0.991	-1.535	-4.840
A3. Biomass	0.320	1.207	2.153	3.472
A4. Agriculture	-0.059	-0.854	-1.501	-4.039
A5. Equipment Manufacturing	-0.501	-2.776	-5.051	-10.177
A6. Construction	0.122	-0.465	-0.747	-2.848
A7. Transportation	-0.115	-2.567	-4.027	-10.914
A8. Textiles	-0.091	-1.106	-1.949	-5.078
A9. Wood, pulp and paper	-0.225	-1.771	-3.103	-7.148
A10. Chemicals and pharmaceuticals	-0.155	-2.081	-3.409	-8.684
A11. Rubber, plastic and ceramics	-0.289	-3.055	-5.011	-12.035
A12. Primary metals	-0.319	-2.184	-3.872	-8.466
A13. Other	-0.012	-0.477	-0.848	-2.461

Table 4.7 Carbon Tax: Industry Effects – Investment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	0.155	-0.434	-0.691	-2.890
A1. Petroleum Refining	-5.723	-8.875	-12.759	-16.136
A2. Electricity Production	3.011	3.941	5.853	4.565
A3. Biomass	4.163	5.341	7.830	6.238
A4. Agriculture	-0.472	-1.576	-2.609	-5.617
A5. Equipment Manufacturing	-7.692	-12.823	-18.459	-23.090
A6. Construction	0.539	-0.127	-0.565	-2.310
A7. Transportation	2.371	2.993	4.578	2.562
A8. Textiles	-0.915	-2.279	-3.736	-7.072
A9. Wood, pulp and paper	-3.233	-5.759	-8.507	-12.187
A10. Chemicals and pharmaceuticals	-0.856	-2.029	-3.052	-6.181
A11. Rubber, plastic and ceramics	-3.634	-6.216	-8.926	-12.173
A12. Primary metals	-4.474	-7.656	-11.173	-14.875
A13. Other	0.209	-0.355	-0.593	-2.715

Table 4.8 Carbon Tax: Industry Effects – Employment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.015	-0.458	-0.755	-2.065
A1. Petroleum Refining	-0.325	-4.223	-6.704	-16.724
A2. Electricity Production	0.014	-0.087	-0.038	-0.231
A3. Biomass	0.185	1.190	1.999	4.282
A4. Agriculture	-0.028	-0.423	-0.731	-1.981
A5. Equipment Manufacturing	-0.460	-2.510	-4.561	-9.101
A6. Construction	0.172	-0.118	-0.115	-1.301
A7. Transportation	-0.080	-1.785	-2.731	-7.254
A8. Textiles	-0.071	-0.790	-1.390	-3.600
A9. Wood, pulp and paper	-0.171	-1.337	-2.319	-5.297
A10. Chemicals and pharmaceuticals	-0.133	-1.673	-2.703	-6.780
A11. Rubber, plastic and ceramics	-0.236	-2.483	-4.031	-9.607
A12. Primary metals	-0.284	-1.897	-3.359	-7.246
A13. Other	-0.003	-0.251	-0.436	-1.295

From a national accounting perspective, this reduction in GDP of 4.3% comes from a 2.4% reduction in private consumption and a 2.9% decrease in investment. Exports are particularly affected, declining by 9.2%.

The tax on carbon contributes to an increase in foreign debt in 5.3% due to a deterioration of the trade deficit of 13.2% led by a sharp decline in exports. Total exports decline by 9.2%. The exports of refined energy products [a1], and electricity [a2] are very significantly affected as are exports of equipment [a5], transportation [a7], chemicals [a10], and rubber [a11]. There is a decrease in imports of 3.5%. In terms of the imports, naturally, we see a sharp decline in imports of fossil fuels – crude, coal, natural gas, and diesel – but an important increase in the imports of electricity [a2] of 6.1% and of transportation services [a7] with 3.2%.

In terms of the public account, the increase in tax revenues due to carbon pricing there is an overall increase in revenues of 4.2%. This despite the fact that due to a decline in the tax bases, personal income tax, social security contributions and corporate income tax revenues decline. The value added tax revenues increase as well despite the reduction in demand and due to an increase in consumer prices. **Overall, public debt is 12.6% lower than in the reference scenario as a result of the tax on carbon.**

4.4 Household Effects

The tax on carbon dioxide emissions affects household income and, by affecting relative prices for goods and services, distort the consumer's choice set. Households alter their consumption patterns in a manner consistent with their marginal rate of substitution while firms alter their input structure in a manner consistent with their marginal rate of technical substitution. In addition, the factor incidence of the tax on carbon will affect household income in manner consistent with its composition. In addition, endogenous labor supply decisions will be influence by the reduction in real wages stemming from higher prices for goods and services due to the tax on carbon.

Total labor supply declines by 2.1% as a result of the carbon pricing, which represents an overall loss of about 95,000 permanent jobs. We observe that the percentage change in employment increases with income. For the lowest income group labor supply declines by 1.0% while for the two highest income group it declines by 2.1% and 2.3%. In light of the reduction in employment and in the absence of any changes in public transfers, income declines across all income groups. For the two lower income groups, however, it declines by less than the reduction in employment. Finally, all income groups experience an increase in consumer prices. The changes for the lowest three income groups are similar and are around 4%. For the two highest income groups the increase in CPI is milder due to the lesser relative reliance on energy products.

Overall consumption declines for all consumptions types and for all income groups. Aggregate consumption declines 3.4% for the lowest income group and 1.8% for the highest income group showing therefore a sharp regressive pattern. This goes with the highest income groups experiencing a lower reduction in after-tax income and being exposed to a lower increase in the CPI.

Table 4.9 Carbon Tax: Distributional Effects on Households – Employment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.009	-0.219	-0.365	-1.005
Second Quintile	-0.013	-0.354	-0.593	-1.645
Third Quintile	-0.016	-0.467	-0.776	-2.130
Fourth Quintile	-0.015	-0.471	-0.778	-2.129
Fifth Quintile (Highest Income)	-0.016	-0.515	-0.846	-2.302

Table 4.10 Carbon Tax: Distributional Effects on Households – After-Tax Income

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.004	-0.134	-0.200	-0.539
Second Quintile	-0.013	-0.385	-0.590	-1.583
Third Quintile	-0.019	-0.550	-0.846	-2.261
Fourth Quintile	-0.023	-0.625	-0.966	-2.573
Fifth Quintile (Highest Income)	-0.024	-0.660	-1.019	-2.706

Table 4.11 Carbon Tax: Distributional Effects on Households – Consumer Prices

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	0.044	0.837	1.459	4.290
Second Quintile	0.046	0.858	1.498	4.393
Third Quintile	0.045	0.820	1.434	4.207
Fourth Quintile	0.042	0.766	1.343	3.945
Fifth Quintile (Highest Income)	0.039	0.709	1.246	3.658

Table 4.12 Carbon Tax: Distributional Effects on Households – Equivalent Variation

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.039	-0.682	-1.187	-3.427
Second Quintile	-0.038	-0.582	-1.037	-3.046
Third Quintile	-0.033	-0.440	-0.822	-2.511
Fourth Quintile	-0.031	-0.381	-0.732	-2.275
Fifth Quintile (Highest Income)	-0.027	-0.278	-0.567	-1.836

The consumption category most affected for all consumers is transportation services. For these the lowest income group sees a decline of 9.9% while the highest income group experiences a decline of 9.6%. The reduction in residential consumption is also greatly affected but to a lesser degree and in a more regressive manner: the lowest income group declines by 7.5% and the highest by 5.8%. The consumption of other goods and services shows a much lower reduction with a much more regressive nature.

The welfare effects of a tax on carbon, measured by the consumption-based equivalent variation in income, are regressive with negative welfare effects for all income groups. The welfare loss is 3.4% for the lowest income group and 1.8% for the highest, with a factor of regressivity of 1.9. This pattern is to be expected due to the fact spending on energy is a much larger fraction of lower incomes.

4.5 Carbon Taxation: Concluding Remarks

The introduction of a carbon tax leads to significant reductions in CO_2 emissions, although by less than suggested by the TIMES_PT model. These reductions, however, come at steep economic and distributional costs. These costs cast doubts on the political feasibility of implementing a carbon tax as defined with its revenues reverting to the general public budget. One could think about the DGEP scenario we have been considering, as an implementation of the TIMES_PT scenario of reduction of CO_2 emission by 2050 of 60% of 1990 levels, that is totally focused on the environmental effects and toally oblivious to the macroeconomic or distributional effects.

This is the starting point for the rest of our analysis. We start by considering in section 5 other tax strategies that may be less punishing for the economy and social justice. Then, we continue in sections 6 and 7 by considering a whole variety of strategies for recycling the carbon tax revenues. In all cases we are searching for alternatives that are equally effective environmentally as the carbon tax we consider in this section while at the same time mitigating or even reversing the economic and social justice costs.

5 Carbon and Energy Pricing Policies

5.1 Introduction

The carbon pricing policy considered above implies a corresponding stream of revenues for the public sector. The next set of simulations considers the same stream of revenues but focuses on different ways of collecting these revenues. Accordingly, the impact of each of the three policies on the tax burden in the country is, by design, the same, and thereby makes the three cases strictly comparable.

All of the tax mechanisms we consider penalize CO_2 emissions. The principal difference among these prices mechanisms is in how focused the instruments are on reducing emissions and is reflected in the tax base upon which these taxes are levied. The economy-wide carbon pricing is the most focused. Scenario 2 consider an ad valorum tax on energy products. While the tax on final energy demand increases the price of energy products, it does not do so in function of their carbon content and therefore is a more diffuse instrument. Finally, Scenario 3 considers a general increase in the valued added tax (VAT). Again this policy affects the price of energy goods but in an even more diffuse manner, affecting also the price of other goods and services directly.

The discussion in this chapter is based on the results reported in Tables 5.1 to 5.12 and in more detail in Appendices 1, 2, and 3.

5.2 Energy and Environmental Effects

Carbon taxes and auctioned permits increase the price of fossil fuels in direct relation to the carbon content of the fuel and thereby increase the market opportunity cost of fuels with a greater carbon content. **A more directed tax on the carbon content of fossil fuels will allow for a greater reduction in carbon dioxide emissions than would taxation of energy consumption or consumption of goods and services more broadly.** The tax on final energy demand leads to a reduction in emissions of 9.4% and the increase in the VAT leads to reductions in 4.4% reduction in emissions. The greater reduction in emissions associated with the tax on final energy demand stems from the incentive provided for households to consume less energy and for firms to alter their production processes to employ relatively more workers and equipment instead of energy inputs. The reductions in emissions associated with the tax on final energy demand and the increase in the VAT are substantially lower than the 24.3% reduction in CO_2 emissions achieved through a carbon tax.

The reduction in CO_2 emissions due to taxes on final energy demand and due to general increases in value added tax levels are substantially lower than the ones achieved through a carbon tax. The reduction in emissions for the tax on final energy demand is driven by an increase in the price level for energy goods which stimulates a change in behavior that moves both consumers and producers away from

Table 5.1 Decarbonization Policies: Effect on Final Energy Prices

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Composite Energy Price	2.666	12.745	19.868	57.523
Coal	19.774	86.345	135.623	392.032
Natural Gas	2.326	9.949	15.240	43.061
Butane, Propane and LPG	0.632	5.952	9.722	27.607
Fuel Oil	2.252	5.450	7.763	18.747
Gasoline	1.306	6.545	10.281	29.066
Diesel	2.313	9.885	15.434	44.510
Electricity	-0.011	1.690	2.770	9.192
Biomass	-0.336	-0.042	-0.378	1.969
Energy tax				
Composite Energy Price	0.787	4.308	4.993	13.139
Coal	0.429	1.860	2.098	5.424
Natural Gas	0.429	1.860	2.098	5.424
Butane, Propane and LPG	0.372	4.790	5.709	15.495
Fuel Oil	1.964	4.196	4.659	9.594
Gasoline	1.284	6.414	7.345	19.361
Diesel	1.567	6.493	7.379	19.036
Electricity	-0.055	1.375	1.826	5.132
Biomass	-0.251	0.079	-0.191	0.822
Value added tax				
Composite Energy Price	0.203	1.750	2.124	5.528
Coal	0.186	0.792	0.901	2.243
Natural Gas	0.186	0.792	0.901	2.243
Butane, Propane and LPG	-0.349	1.694	2.270	6.519
Fuel Oil	1.481	2.335	2.501	4.464
Gasoline	0.456	2.735	3.214	8.233
Diesel	0.739	2.879	3.305	8.115
Electricity	-0.300	0.337	0.656	2.031
Biomass	-0.233	-0.079	-0.093	0.379

energy products more generally and goods and services produced in energy-intensive industries. In addition, the overall increase in prices for both the tax on final energy demand and the increase in the VAT reduces the purchasing power of households' income and, through second order income effects, reduces income levels as well. The substitution effect is much more blunt here for both the tax on final energy demand and value added taxation than for a tax on carbon dioxide emissions. These policies provide a weaker incentive for households and firms to use electricity over carbon-intensive fossil fuels and the pattern of emissions reductions reflects these changes in the incentive environment. As a result, household demand for energy associated with the demand for transportation services falls by more than residential energy demand where liquefied petroleum gases and natural gas provide alternative means for households to satisfy residential demand for heating and cooling, hot water heating and cooking. In

Table 5.2 Decarbonization Policies: Effect on Final Energy Demand

(Percent change relative to the reference scenario)

		2020	2030	2040	2050
Carbon tax					
Total		-0.230	-3.550	-5.698	-14.351
	Coal	-3.046	-31.844	-43.232	-67.820
	Natural Gas	-0.549	-7.345	-11.371	-27.373
	Butane, Propane and LPG	-0.351	-4.528	-7.214	-17.946
	Gasoline	-0.267	-3.527	-5.658	-14.511
	Diesel	-0.452	-6.187	-9.868	-24.520
	Electricity	0.012	-1.146	-1.795	-5.717
	Biomass	0.320	1.207	2.153	3.472
Energy tax					
Total		0.080	-2.346	-2.877	-7.583
	Coal	11.270	9.715	8.713	6.759
	Natural Gas	1.213	-0.470	-0.849	-3.982
	Butane, Propane and LPG	-0.169	-3.781	-4.459	-11.323
	Gasoline	-0.313	-3.742	-4.354	-11.074
	Diesel	0.168	-3.665	-4.389	-11.816
	Electricity	0.013	-1.046	-1.354	-3.605
	Biomass	0.133	0.559	0.941	1.513
Value added tax					
Total		0.431	-0.938	-1.307	-3.922
	Coal	11.427	10.158	9.241	7.943
	Natural Gas	1.251	-0.153	-0.586	-2.955
	Butane, Propane and LPG	0.399	-1.497	-1.944	-5.593
	Gasoline	0.270	-1.428	-1.786	-5.171
	Diesel	0.760	-1.213	-1.685	-5.522
	Electricity	0.121	-0.624	-0.891	-2.358
	Biomass	0.058	0.252	0.405	0.551

contrast, the carbon tax penalizes these energy sources and substantially alters relative prices to encourage firms to reduce emission associated with final energy demand from residential uses.

As with the tax on carbon dioxide emissions, firms reduce carbon dioxide emissions by a greater amount, relative to their consumption levels in the reference scenario, than do households, though firms play a larger relative role in emissions reductions efforts under these alternative financing mechanisms.

Firms reduce their emissions by 11.2% in response to the tax on final energy demand and by 5.7% in response to an increase in the VAT, compared to 26.0% in response to the tax on carbon. The sectors of economic activity with the largest reductions in CO_2 emissions are petroleum refining [a1], agriculture [a4], equipment [a5], construction [a6], transportation [a7], metals [a12], and other goods and services [a13] for both the tax on final energy demand and the increase in the VAT. To be noted, the dispersion in emissions reductions is much smaller in the case of the VAT than the other two cases.

Table 5.3 Decarbonization Policies: Effect on the Electric Power Industry

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Electricity Production	0.007	-0.991	-1.535	-4.840
Renewable Energy Share	0.333	2.290	4.213	9.095
Final Demand for Electricity	0.012	-1.146	-1.795	-5.717
Electricity Demand by Households	0.055	-0.080	-0.230	-1.637
Electricity Demand by Firms	-0.007	-1.264	-1.944	-5.865
Electricity Share in Final Demand	0.254	2.742	4.437	10.785
Energy tax				
Electricity Production	-0.111	-1.417	-1.732	-4.505
Renewable Energy Share	-0.271	0.242	0.458	1.789
Final Demand for Electricity	0.013	-1.046	-1354	-3.605
Electricity Demand by Households	-0.029	-0.396	-0.579	-1.599
Electricity Demand by Firms	-0.187	-1.945	-2.357	-6.089
Electricity Share in Final Demand	-0.171	1.113	1.260	3.638
Value added tax				
Electricity Production	0.057	-0.728	-0.961	-2.513
Renewable Energy Share	-0.351	-0.092	-0.038	0.606
Final Demand for Electricity	0.121	-0.624	-0.891	-2.358
Electricity Demand by Households	0.118	-0.004	-0.103	-0.547
Electricity Demand by Firms	0.005	-1.097	-1.414	-3.578
Electricity Share in Final Demand	-0.386	0.197	0.265	1.319

Carbon dioxide emissions from households decline by 5.9% in response to the tax on final energy demand and 1.8% in response the increase in the VAT. These reductions are, in both cases, primarily from reductions in emissions associated with transportation energy demand. Emissions associated with transportation demand by households decline by 8.1% for the tax on final energy demand and 3.2% for the increase in the VAT. In contrast, the tax on carbon dioxide emissions provides a stronger incentive to increase the use of electricity by households and, as a result, a larger component of the reduction in emissions stems from substitution among energy sources for residential uses. The larger reduction in emissions associated with the tax on final energy demand relative to the increase in the VAT and the greater relative reduction in emissions associated with transportation stems from the greater increase in relative prices for gasoline and diesel fuel associated with these tax policies.

Table 5.4 Decarbonization Policies: Effect on Carbon Dioxide Emissions

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Carbon Dioxide Emissions	-0.394	-5.036	-10.355	-24.322
Households	-0.534	-6.298	-9.682	-21.083
Residential	-1.373	-14.885	-21.108	-37.549
Transportation	-0.281	-3.708	-6.070	-15.841
Firms	-0.348	-4.613	-10.694	-25.987
Energy tax				
Carbon Dioxide Emissions	0.462	-1.998	-3.216	-9.419
Households	1.120	-1.056	-1.509	-5.883
Residential	4.669	3.479	3.000	0.966
Transportation	0.044	-2.424	-2.934	-8.063
Firms	0.245	-2.314	-4.075	-11.235
Value added tax				
Carbon Dioxide Emissions	0.823	-0.511	-1.073	-4.374
Households	1.559	0.544	0.299	-1.754
Residential	4.872	4.125	3.749	2.657
Transportation	0.554	-0.537	-0.792	-3.158
Firms	0.580	-0.865	-1.764	-5.720

In addition, and consistent with the prevalence of personal vehicles in households of different income levels and the resulting pattern of expenditure on fuel in transportation across income groups, reductions in total emissions by households follows an U-shape with the minimum in the middle income groups (second or third quintile. In both the cases of the energy tax and the VAT, this pattern is the result of an inverted U-shaped reduction in emissions from residential consumption and a clear regressive change in emissions from transportation consumption.

The reduction in emissions follows closely changes in both the level of final energy demand and the types of energy sources in the composition of energy demand among firms and households. Given the smaller reduction in emissions, it is no surprise that the effects of an increase in taxes on final energy demand and an increase in the VAT on the composite energy price index are much more subdued. The price of final energy demand increases by 13.1% in response to the tax on final energy demand and 5.5% in response to the increase in the VAT compared to a 57.5% increase for the tax on carbon. The changes come mostly from changes in the price of refined oil products – butane and others, gasoline and diesel. The increase in electricity prices is very modest: 5.1% for the tax on final energy demand and 2.0% for the increase in the VAT, compared to 9.2% for the tax on carbon.

As a result, we observe a more subdued decline in final energy consumption in response to both the tax on final energy demand and the increase in the VAT. Final energy demand declines by 7.6% in response to the tax on final energy demand and 3.9% in response to the increase in the VAT in contrast to the decline of 13.9% in response to the tax on carbon. The reductions are due primarily to reductions in final demand for refined oil products but also from reductions in final demand for natural gas. Final demand for electricity declines by just 3.6% in response to the tax on energy products and by 2.4%, in response to the increase in the VAT, compared to 5.7% in response to the tax on carbon. As a result of the relative reductions in final energy demand and the changing composition of energy sources used in final energy demand among households and firms, these tax mechanisms provide a weaker incentive for electrification of the Portuguese economy. The increase in the tax on energy products increases the share of electricity in final energy demand by 3.6% while the increase in the VAT increases the share of electricity in final energy demand by 1,.3, clearly smaller than the 10.8% increase in the share of electricity in final energy demand observed in response to the tax on carbon.

Demand for energy among firms, declines by 8.3% in response to the tax on final energy demand and 4.5% in response to the increase in the VAT, compared to a 13.2% reduction in response to the tax on carbon. For both the tax on final energy demand and the increase in the VAT, as with the tax on carbon, we observe that the sectors of economic activity with the largest reduction in demand, owing to both reduction in consumer demand, demand from other firms for their products as intermediate inputs and changes to the firms input structure, naturally mirrors the changes in emissions presented above.

In turn, final energy demand by households declines by 4.6% for the tax on energy products and 1.8% for the increase in the VAT, compared to 8.5% for the tax on carbon. Given the patterns of expenditures and source of income across households, the tax on energy products and the VAT produce inverted U-shaped reductions in final energy demand among household income groups.

Domestic electricity production declines by 4.5% in response to the tax on final energy demand and 2.5% for the increase in the VAT, compared to 4.8% in response to the tax on carbon. These reductions in domestic production are due primarily to lower levels of thermal electricity generation. Production of electricity from fossil fuels declines 5.8% in response to the tax on final energy demand and 2.6% for the increase in the VAT, compared to 21.0% for the tax on carbon. The share of renewables in electricity production increases by just 1.8% for the tax on final energy demand and 0.6% for the increase in the VAT as opposed to 9.1% for the tax on carbon. Net imports of electricity increase by 0.3% for the tax on energy products and decrease by 0.6% for the increase in the VAT, compared to 9.4% increase in the tax on carbon. In both cases the changes in net imports are led by reductions in electricity exports as domestic prices increase.

Table 5.5 Long Run [2050] Environmental Effects

(Percent change relative to the reference scenario)

	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
Carbon Tax	-14.36	-5.72	10.79	9.10	-24.32
Energy Tax	-7.58	-4.51	3.64	1.79	-9.42
Value Added Tax	-3.92	-2.51	1.32	0.61	-4.37

Electricity demand declines by 4.5% for the tax on energy products and 2.5% for the increase in the VAT, compared to 5.7% in the carbon tax case. The decline in electricity demand is driven by reductions in demand by firms. The demand for electricity among firms declines by 6.1% for the tax on energy products and 3.6% for the increase in the VAT, reflective of the greater increase in the price of electricity associated with the tax on energy products than for the increase in the VAT. In this context it is also important to highlight that the use of fuels in the production of electricity is not subject to an increased level of taxation in the case of a tax on final energy demand and the increase in price is due to the change in the tax on final demand and competitive price pressures, where relevant. The sectors that are the most affected by the tax on final energy demand and the VAT tax are petroleum refining [a1], equipment manufacturing [a5], wood and paper products [a9], rubber, ceramics and non-metallic minerals [a11], and primary metals [a12].

In turn, household demand decreases by 1.6% for the tax on energy products and less than 0.6% for the increase in the VAT, compared to a 1.7% reduction for the tax on carbon. As with the tax on carbon, the reductions in electricity demand are observed primarily the lowest income group.

5.3 Macroeconomic Effects

Energy taxes and value added taxes have a smaller impact on macroeconomic performance than a tax on carbon dioxide emissions. The increase in the tax on energy products and the increase in the VAT lead to substantially lower reductions in GDP than the carbon tax. The reduction in GDP is driven by reductions across all components of domestic demand, with reductions observed in private consumption, investment and exports. The tax on energy products and the increase in the VAT, however, produce smaller reductions in consumption and exports which contributes to smaller reductions in GDP.

Both the tax on energy products and the increase in the VAT have a negative effect on macroeconomic performance. We observe a 2.3% reduction in GDP for the tax on final energy demand and a 2.4% reduction in GDP for the increase in the VAT. These macroeconomic effects are substantially smaller than the 4.3% decline resulting from the tax on carbon. From a national accounting perspective, the decline in GDP associated with the tax on energy products is due in equal parts to reductions in consumption, investment, and imports and a particularly pronounced 4.6% decline in exports. Reductions in GDP stemming from the increase in the VAT, however, come largely from a 3.2% reduction in investment and a 4.6% reduction in exports. The effects of the tax on the competitive position of the Portuguese economy are important in determining the effects of the tax policies on output. For both the increase in the tax on energy products and the increase in the VAT, smaller reductions in exports compared to the 9.2% in the carbon tax case, contribute to smaller GDP losses from these policies.

Table 5.6 Decarbonization Policies: Effect on Macroeconomic Performance

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
GDP	-0.055	-0.976	-1.621	-4.284
Consumption	-0.032	-0.412	-0.774	-2.370
Gross Fixed Capital Formation	0.155	-0.434	-0.691	-2.890
Exports	-0.212	-2.220	-3.759	-9.180
Imports	-0.070	-0.979	-1.475	-3.459
Foreign Debt	0.042	0.792	2.501	5.324
Trade Deficit	0.488	3.607	5.785	13.151
Public Debt	-0.011	-1.441	-4.784	-12.578
Energy tax				
GDP	0.001	-0.691	-0.875	-2.277
Consumption	0.022	-0.250	-0.348	-1.110
Gross Fixed Capital Formation	-0.025	-0.526	-0.583	-1.640
Exports	-0.005	-1.383	-1.868	-4.620
Imports	0.012	-0.610	-0.707	-1.729
Foreign Debt	-0.024	0.400	1.409	2.956
Trade Deficit	0.076	2.245	2.984	6.662
Public Debt	0.154	-0.124	-1.306	-4.846
Value Added Tax				
GDP	-0.049	-0.733	-1.080	-2.363
Consumption	0.128	-0.046	-0.118	-0.673
Gross Fixed Capital Formation	-0.705	-1.495	-1.980	-3.166
Exports	-0.006	-1.330	-2.125	-4.559
Imports	-0.053	-0.646	-0.838	-1.818
Foreign Debt	-0.112	0.186	1.272	2.982
Trade Deficit	-0.243	1.877	3.254	6.139
Public Debt	0.092	-0.631	-2.668	-8.334

The tax on energy products increases energy costs for firms and simultaneously reduces the firms' net cash flow and alters the relative price of inputs which drives changes in the firms input structure in a manner that is consistent with the marginal product and technical rate of substitution among inputs in production. These mechanisms lead to a reduction in energy demand coupled with a shift in the firms input structure that favors labor inputs and capital inputs. The overall reduction in the firms' net cash flow and output levels, however, implies a reduction in all inputs across the board. The increase in the VAT, in contrast, affects intermediate demands, certainly, but will also have a more pronounced effect of the demand for the firms' products by raising the price of domestically produced goods.

As a result, we observe a reduction in private investment by firms in response to both a tax on energy products and an increase in the VAT. The reduction in investment, however, is greater for the increase in the VAT than for the tax on energy products. Private investment declines by 1.7% in response to the tax on energy products. This reduction in private investment is particularly pronounced for petroleum refining [a1] and equipment manufacturing [a5], followed by wood, pulp and paper [a9], rubber, ceramics, glass and non-metallic mineral products [a11] and primary metals [a12]. In contrast, private investment declines by 3.3% in response to the increase in the VAT and follows a similar pattern across industries with the bulk of the reduction in private investment coming from petroleum refining [a1] and equipment manufacturing [a5]. The increase in the VAT, however, produces large declines in private investment in textiles [a10], rubber [a11] and primary metals [a12], as well. The distributional effects across sectors of economic activity are, essentially, the same as those for the tax on carbon.

Energy taxes and value added taxes have a smaller impact on employment than a tax on carbon dioxide emissions. The labor market effects of these alternative tax policies are more moderate than the tax on carbon. The sector that is the most affected in both cases is refining [a1] with important reductions in equipment [a5] and rubber [a11]. The energy tax – as in the carbon tax case - also adversely affects transportation [a7] and chemicals [a10], while the VAT increase adversely affects construction [a6] and metals [a12]. Overall, employment declines by slightly less than 1.0% in response to the tax on energy products and just over 1.0% for the increase in the VAT. These effects are somewhat smaller than the 1.8% reduction in employment observed for the tax on carbon. Petroleum refining [a1] continues to be the sector that is most greatly affected, particularly due to energy taxes, with a decrease in employment of 13.2% and a 5.6% reduction in employment associated with the increase in the VAT. Important reductions in employment are also observed for equipment manufacturing [a5] and rubber, ceramics, glass and non-metallic mineral products [a11]. Taxation of energy products, as with the carbon tax, also adversely affects transportation [a7] and chemicals [a10]. The increase in the VAT also adversely affects construction [a6] and metals [a12]. The effects on construction and equipment manufacturing reflect, in part, the lower levels of private investment that result from the higher prices for energy products.

Table 5.7 Decarbonization Policies: Industry Effects – Output

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.055	-0.976	-1.621	-4.284
A1. Petroleum Refining	-0.351	-4.528	-7.214	-17.946
A2. Electricity Production	0.007	-0.991	-1.535	-4.840
A3. Biomass	0.320	1.207	2.153	3.472
A4. Agriculture	-0.059	-0.854	-1.501	-4.039
A5. Equipment Manufacturing	-0.501	-2.776	-5.051	-10.177
A6. Construction	0.122	-0.465	-0.747	-2.848
A7. Transportation	-0.115	-2.567	-4.027	-10.914
A8. Textiles	-0.091	-1.106	-1.949	-5.078
A9. Wood, pulp and paper	-0.225	-1.771	-3.103	-7.148
A10. Chemicals and pharmaceuticals	-0.155	-2.081	-3.409	-8.684
A11. Rubber, plastic and ceramics	-0.289	-3.055	-5.011	-12.035
A12. Primary metals	-0.319	-2.184	-3.872	-8.466
A13. Other	-0.012	-0.477	-0.848	-2.461
Energy tax				
Total	0.001	-0.691	-0.875	-2.277
A1. Petroleum Refining	-0.169	-3.781	-4.459	-11.323
A2. Electricity Production	-0.111	-1.417	-1.732	-4.505
A3. Biomass	0.133	0.559	0.941	1.513
A4. Agriculture	0.019	-0.515	-0.708	-1.917
A5. Equipment Manufacturing	-0.207	-1.630	-2.621	-5.232
A6. Construction	-0.018	-0.503	-0.569	-1.579
A7. Transportation	0.074	-1.763	-2.010	-5.661
A8. Textiles	0.046	-0.572	-0.846	-2.238
A9. Wood, pulp and paper	-0.009	-0.907	-1.392	-3.190
A10. Chemicals and pharmaceuticals	0.047	-1.274	-1.633	-4.280
A11. Rubber, plastic and ceramics	0.154	-1.243	-1.766	-4.460
A12. Primary metals	-0.095	-1.275	-1.953	-4.204
A13. Other	0.013	-0.341	-0.448	-1.275
Value added tax				
Total	-0.049	-0.733	-1.080	-2.363
A1. Petroleum Refining	0.399	-1.497	-1.944	-5.593
A2. Electricity Production	0.057	-0.728	-0.961	-2.513
A3. Biomass	0.058	0.252	0.405	0.551
A4. Agriculture	0.042	-0.421	-0.682	-1.698
A5. Equipment Manufacturing	-0.536	-2.658	-4.380	-7.824
A6. Construction	-0.627	-1.504	-1.964	-3.366
A7. Transportation	0.292	-0.841	-1.190	-3.365
A8. Textiles	-0.079	-1.147	-1.778	-3.874
A9. Wood, pulp and paper	-0.069	-1.083	-1.796	-3.697
A10. Chemicals and pharmaceuticals	0.052	-1.265	-1.825	-4.301
A11. Rubber, plastic and ceramics	0.041	-1.398	-2.218	-4.723
A12. Primary metals	-0.233	-1.604	-2.702	-4.976
A13. Other	-0.021	-0.421	-0.642	-1.491

Table 5.8 Decarbonization Policies: Industry Effects – Investment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	0.155	-0.434	-0.691	-2.890
A1. Petroleum Refining	-5.723	-8.875	-12.759	-16.136
A2. Electricity Production	3.011	3.941	5.853	4.565
A3. Biomass	4.163	5.341	7.830	6.238
A4. Agriculture	-0.472	-1.576	-2.609	-5.617
A5. Equipment Manufacturing	-7.692	-12.823	-18.459	-23.090
A6. Construction	0.539	-0.127	-0.565	-2.310
A7. Transportation	2.371	2.993	4.578	2.562
A8. Textiles	-0.915	-2.279	-3.736	-7.072
A9. Wood, pulp and paper	-3.233	-5.759	-8.507	-12.187
A10. Chemicals and pharmaceuticals	-0.856	-2.029	-3.052	-6.181
A11. Rubber, plastic and ceramics	-3.634	-6.216	-8.926	-12.173
A12. Primary metals	-4.474	-7.656	-11.173	-14.875
A13. Other	0.209	-0.355	-0.593	-2.715
Energy tax				
Total	-0.025	-0.526	-0.583	-1.640
A1. Petroleum Refining	-5.160	-7.297	-9.988	-11.963
A2. Electricity Production	-0.926	-1.401	-1.774	-2.978
A3. Biomass	1.934	2.246	3.413	2.725
A4. Agriculture	-0.177	-0.898	-1.241	-2.670
A5. Equipment Manufacturing	-4.073	-6.844	-9.402	-11.774
A6. Construction	-0.154	-0.624	-0.643	-1.336
A7. Transportation	1.260	1.301	2.108	1.126
A8. Textiles	-0.471	-1.355	-1.972	-3.602
A9. Wood, pulp and paper	-1.513	-2.919	-4.043	-5.859
A10. Chemicals and pharmaceuticals	-0.357	-1.135	-1.514	-3.029
A11. Rubber, plastic and ceramics	-1.761	-3.226	-4.386	-6.030
A12. Primary metals	-2.357	-4.105	-5.618	-7.453
A13. Other	0.163	-0.270	-0.237	-1.229
Value added tax				
Total	-0.705	-1.495	-1.980	-3.166
A1. Petroleum Refining	-2.211	-3.865	-5.547	-7.303
A2. Electricity Production	-0.818	-1.389	-1.853	-3.157
A3. Biomass	1.008	0.887	1.281	0.171
A4. Agriculture	-0.231	-1.157	-1.707	-3.298
A5. Equipment Manufacturing	-7.817	-12.002	-15.948	-18.442
A6. Construction	-2.420	-3.056	-3.198	-3.381
A7. Transportation	-0.180	-0.845	-1.041	-2.487
A8. Textiles	-2.763	-4.536	-6.510	-8.616
A9. Wood, pulp and paper	-2.549	-4.494	-6.225	-8.281
A10. Chemicals and pharmaceuticals	-2.359	-3.907	-5.356	-7.296
A11. Rubber, plastic and ceramics	-3.412	-5.489	-7.301	-9.060
A12. Primary metals	-4.567	-7.118	-9.459	-11.419
A13. Other	-0.355	-1.046	-1.426	-2.555

Table 5.9 Decarbonization Policies: Industry Effects – Employment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.015	-0.458	-0.755	-2.065
A1. Petroleum Refining	-0.325	-4.223	-6.704	-16.724
A2. Electricity Production	0.014	-0.087	-0.038	-0.231
A3. Biomass	0.185	1.190	1.999	4.282
A4. Agriculture	-0.028	-0.423	-0.731	-1.981
A5. Equipment Manufacturing	-0.460	-2.510	-4.561	-9.101
A6. Construction	0.172	-0.118	-0.115	-1.301
A7. Transportation	-0.080	-1.785	-2.731	-7.254
A8. Textiles	-0.071	-0.790	-1.390	-3.600
A9. Wood, pulp and paper	-0.171	-1.337	-2.319	-5.297
A10. Chemicals and pharmaceuticals	-0.133	-1.673	-2.703	-6.780
A11. Rubber, plastic and ceramics	-0.236	-2.483	-4.031	-9.607
A12. Primary metals	-0.284	-1.897	-3.359	-7.246
A13. Other	-0.003	-0.251	-0.436	-1.295
Energy tax				
Total	-0.001	-0.327	-0.410	-1.079
A1. Petroleum Refining	-0.172	-3.594	-4.206	-10.715
A2. Electricity Production	-0.204	-0.990	-1.118	-2.759
A3. Biomass	0.032	0.591	0.864	1.846
A4. Agriculture	0.008	-0.257	-0.348	-0.939
A5. Equipment Manufacturing	-0.201	-1.482	-2.386	-4.699
A6. Construction	-0.036	-0.338	-0.312	-0.913
A7. Transportation	0.051	-1.225	-1.363	-3.769
A8. Textiles	0.035	-0.389	-0.586	-1.542
A9. Wood, pulp and paper	-0.011	-0.683	-1.043	-2.355
A10. Chemicals and pharmaceuticals	0.033	-1.011	-1.286	-3.317
A11. Rubber, plastic and ceramics	0.124	-0.989	-1.402	-3.486
A12. Primary metals	-0.095	-1.111	-1.710	-3.609
A13. Other	0.003	-0.191	-0.243	-0.688
Value added tax				
Total	-0.083	-0.450	-0.633	-1.299
A1. Petroleum Refining	0.372	-1.382	-1.764	-5.130
A2. Electricity Production	-0.097	-0.514	-0.551	-1.327
A3. Biomass	-0.035	0.221	0.367	0.704
A4. Agriculture	0.002	-0.239	-0.369	-0.869
A5. Equipment Manufacturing	-0.516	-2.399	-3.976	-6.950
A6. Construction	-0.699	-1.261	-1.578	-2.344
A7. Transportation	0.208	-0.538	-0.747	-2.085
A8. Textiles	-0.031	-0.725	-1.161	-2.498
A9. Wood, pulp and paper	-0.080	-0.855	-1.399	-2.806
A10. Chemicals and pharmaceuticals	0.050	-0.919	-1.323	-3.069
A11. Rubber, plastic and ceramics	0.002	-1.132	-1.797	-3.686
A12. Primary metals	-0.236	-1.402	-2.377	-4.238
A13. Other	-0.041	-0.280	-0.390	-0.878

The pattern of changes in input demand reflects an overall reduction in output levels and a change in the input structure of firms that favors employment and private investment over energy inputs. As such, the sectoral distribution of the effects of the energy tax reflects the energy intensity of each sector of economic activity as well as demand by those products by households and other firms. The 2.0% in output associated with the tax on energy products is driven primarily by reductions in petroleum refining [a1] and transportation [a7], both sectors that rely heavily on the demand for diesel and gasoline and other refined petroleum products for their revenues (in petroleum refining) and operations (transportation services). Output in the petroleum refining sector [a1] falls by 13.7% in response to the tax on energy products and demand for transportation services [a7] falls by 7.0%. Other energy intensive industries, including electricity production [a7], chemicals [a10] and rubber, ceramics, glass and non-metallic minerals [all] are also affected by the tax on energy products. The increase in the VAT produces a smaller reduction in output of the petroleum refining industry (6.0%) [a1], but also reduces output in equipment manufacturing [a5] of 6.0%. Chemicals, [a10], rubber, ceramics, glass and non-metallic minerals [a11] and the manufacture of primary metals [a12] are also adversely affected by the increase in the VAT.

The effects of energy taxation and value added taxation on the foreign account differ and reflect the effects that these two policies have on domestic demand and production costs. The tax on energy products raises the price of domestically produced goods and contributes towards a small, 0.2%, increase in foreign debt due to a deterioration of the trade deficit of 2.9%. The increase in the VAT, however, in a manner consistent of a domestic fiscal depreciation (absent direct changes in unit labor costs), encourages production for foreign markets and yields an 1.4% reduction in foreign debt due to a much smaller increase in the trade deficit of 1.6%. As a point of reference, the tax on carbon produced a small, 0.6%, increase in foreign debt driven by a deterioration of the trade balance amounting to a 5.8% reduction in net exports.

The tax on energy products reduces exports by 4.7%. These reductions in exports are due to reductions in the export of refined petroleum products, electricity and transportation services, sectors that have a minor contribution to exports in Portugal but are very much affected by the tax on energy products. The output effects on petroleum refining are driven, in part, by the particularly pronounced reduction in exports of refined petroleum products. Exports of products of other energy intensive industries, including chemicals and rubber, ceramics, glass and non-metallic mineral products are also affected, by both the increase in the tax on energy products and the VAT. The 3.8% reduction in exports is smaller for the increase in the VAT than for the tax on energy products and the industry composition of the effects is similar to the tax on energy products and that for the tax on carbon. Imports fall 1.7%, less than the reduction observed for exports. This reduction in imports is driven by reductions in the demand for fossil fuels and compensated somewhat by outsourcing of transportation services.

Table 5.10 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

	GDP	Consumption	Investment	Employment	Public debt	Foreign debt
Carbon tax	-4.28	-2.37	-2.89	-2.07	-12.58	5.32
Energy tax	-2.28	-1.11	-1.64	-1.08	-4.85	2.96
Value Added Tax	-2.36	-0.67	-3.17	-1.30	-8.33	2.98

Both the tax on energy products and an increase in the VAT produce an **improvement in the public sector account** though this is less pronounced than the improvement observed for the carbon tax. These differences are due to expenditure affects associated with the implicit price of public expenditures and second-order tax revenue effects. Public debt declines by 11.7% with the tax on energy products and 16.1% due to the increase in the VAT. In contrast, public debt declines by 20.1% as a result of the tax on carbon. As with the tax on carbon, the reduction in public debt is induced mostly by an overall increase in tax revenues, despite the reductions in personal income, social security, and corporate income tax revenues stemming from the demand responses to higher prices and the resulting contraction in the tax bases.

5.4 Household Effects

Taxes on final energy demand and general value added taxes are regressive in nature. The equivalent variations in income is negative for all income groups albeit much lower than in the carbon case. The welfare loss is still regressive, with approximately the same regressivity factor for the energy tax, 1.9, but much more regressive with the VAT (2.6).

The welfare effects of the policies stem from reductions in real incomes as well as changes in expenditure patterns stemming from the change in relative prices induced by the respective policies, both directly and indirectly through their impact on product market equilibrium prices. Despite changes in their expenditure patterns, consumer prices increase across all quintiles of income. The increase in consumer price indices for households associated with the tax on energy products is largest (2.3%) for households in the lowest quintile of income and smallest (2.0%) for households in the highest income quintile. The increase in the VAT produces the same percentage increase in prices across all commodities, which once filtered through the product market equilibrium and changes in consumer expenditure patterns, yields approximately the same (1.4%) increase in the consumer price index across all household groups. In each of these two tax policies, the changes in consumer prices are more moderate than the tax on carbon. Qualitatively, the energy tax and the carbon tax produce similar patterns of change in consumer prices.

The increase in prices reduce real incomes and, coupled with reductions in input demand by firms, contributes towards a reduction in labor supply by 1.0% for the tax on energy products and the increase in the VAT. These employment effects are smaller than the 1.8% reduction in employment observed for the tax on carbon. Labor supply among lower income groups is less responsive than those in higher income quintile. As a result, labor supply among households in the lowest income quintile is essentially unaffected which we observe a reduction in labor supply among households in the highest income quintiles.

In addition to the reductions in real wages stemming from higher prices, the reduction in labor supply, together with losses in capital income due to lower levels of investment, leads to a reduction in income across all quintiles of income. This is particularly important for the increase in the VAT which had larger effects in financial markets and produces reductions in income that are greater than the reduction in employment across income quintiles.

Table 5.9 Decarbonization Policies: Distributional Effects on Households – Employment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.009	-0.219	-0.365	-1.005
Second Quintile	-0.013	-0.354	-0.593	-1.645
Third Quintile	-0.016	-0.467	-0.776	-2.130
Fourth Quintile	-0.015	-0.471	-0.778	-2.129
Fifth Quintile (Highest Income)	-0.016	-0.515	-0.846	-2.302
Energy tax				
First Quintile (Lowest Income)	0.000	-0.162	-0.194	-0.515
Second Quintile	-0.001	-0.258	-0.319	-0.849
Third Quintile	-0.001	-0.334	-0.420	-1.110
Fourth Quintile	-0.001	-0.335	-0.423	-1.114
Fifth Quintile (Highest Income)	-0.001	-0.365	-0.461	-1.208
Value Added Tax				
First Quintile (Lowest Income)	-0.023	-0.185	-0.255	-0.545
Second Quintile	-0.054	-0.328	-0.462	-0.968
Third Quintile	-0.079	-0.448	-0.634	-1.311
Fourth Quintile	-0.088	-0.467	-0.660	-1.355
Fifth Quintile (Highest Income)	-0.101	-0.521	-0.733	-1.491

Table 5.11 Decarbonization Policies: Distributional Effects on Households – After-Tax Income

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.004	-0.134	-0.200	-0.539
Second Quintile	-0.013	-0.385	-0.590	-1.583
Third Quintile	-0.019	-0.550	-0.846	-2.261
Fourth Quintile	-0.023	-0.625	-0.966	-2.573
Fifth Quintile (Highest Income)	-0.024	-0.660	-1.019	-2.706
Energy tax				
First Quintile (Lowest Income)	0.009	-0.040	-0.102	-0.285
Second Quintile	0.019	-0.161	-0.308	-0.839
Third Quintile	0.025	-0.242	-0.445	-1.203
Fourth Quintile	0.026	-0.287	-0.510	-1.373
Fifth Quintile (Highest Income)	0.028	-0.302	-0.539	-1.447
Value Added Tax				
First Quintile (Lowest Income)	-0.019	-0.115	-0.207	-0.508
Second Quintile	-0.054	-0.334	-0.564	-1.332
Third Quintile	-0.078	-0.481	-0.802	-1.873
Fourth Quintile	-0.085	-0.543	-0.898	-2.087
Fifth Quintile (Highest Income)	-0.089	-0.571	-0.947	-2.205

Table 5.12 Decarbonization Policies: Distributional Effects on Households – Consumer Prices

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	0.044	0.837	1.459	4.290
Second Quintile	0.046	0.858	1.498	4.393
Third Quintile	0.045	0.820	1.434	4.207
Fourth Quintile	0.042	0.766	1.343	3.945
Fifth Quintile (Highest Income)	0.039	0.709	1.246	3.658
Energy tax				
First Quintile (Lowest Income)	-0.023	0.547	0.712	2.070
Second Quintile	-0.026	0.548	0.714	2.083
Third Quintile	-0.023	0.531	0.692	2.015
Fourth Quintile	-0.018	0.508	0.662	1.923
Fifth Quintile (Highest Income)	-0.014	0.483	0.629	1.818
Value Added Tax				
First Quintile (Lowest Income)	-0.057	0.429	0.642	1.727
Second Quintile	-0.061	0.425	0.640	1.728
Third Quintile	-0.054	0.427	0.640	1.716
Fourth Quintile	-0.043	0.430	0.642	1.702
Fifth Quintile (Highest Income)	-0.030	0.440	0.652	1.704

The higher prices coupled with lower incomes lead to a reduction in consumption. The tax on energy products reduces consumption by 2.5% for households in the lowest income quintile and by 1.1% for households in the highest income quintile. The increase in the VAT shows a more sharply regressive pattern of changes in consumption with a 1.6% reduction in consumption among households in the lowest income quintile and 0.3% for households in the highest income quintile. Overall, however, these reductions in consumption levels are substantially smaller than the reductions in consumption observed in response to the tax on carbon in which consumption fell by 4.4% among households in the lowest income quintile and 1.6% among households in the highest income quintile.

As with the tax on carbon, the largest reduction in household demand is for transportation services, followed by residential energy demand and then other goods and services. The size of the reduction in consumption, however, are uniformly smaller for the tax on energy products and the increase in the VAT.

Table 5.13 Decarbonization Policies: Distributional Effects on Households – Equivalent Variation

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.039	-0.682	-1.187	-3.427
Second Quintile	-0.038	-0.582	-1.037	-3.046
Third Quintile	-0.033	-0.440	-0.822	-2.511
Fourth Quintile	-0.031	-0.381	-0.732	-2.275
Fifth Quintile (Highest Income)	-0.027	-0.278	-0.567	-1.836
Energy tax				
First Quintile (Lowest Income)	0.026	-0.427	-0.566	-1.658
Second Quintile	0.030	-0.341	-0.463	-1.411
Third Quintile	0.026	-0.255	-0.357	-1.147
Fourth Quintile	0.021	-0.232	-0.327	-1.063
Fifth Quintile (Highest Income)	0.016	-0.176	-0.256	-0.871
Value Added Tax				
First Quintile (Lowest Income)	0.087	-0.274	-0.424	-1.259
Second Quintile	0.121	-0.137	-0.240	-0.915
Third Quintile	0.138	-0.030	-0.096	-0.640
Fourth Quintile	0.135	-0.018	-0.081	-0.607
Fifth Quintile (Highest Income)	0.133	0.022	-0.026	-0.493

Table 5.14 Long Run [2050] Distributional Effects: Equivalent Variation in Income

(Percent change relative to the reference scenario)

	Carbon Tax	Energy Tax	Value Added Tax
First quintile (lowest income)	-3.34	-1.66	-1.26
Second quintile	-3.05	-1.41	-0.92
Third quintile	-2.51	-1.15	-0.64
Fourth quintile	-2.28	-1.06	-0.61
Fifth quintile (highest income)	-1.84	-0.87	-0.49

The tax on energy product and the increase in the VAT produce negative effects on household welfare. Although these policies have a negative effect on households, the effects of these policies is much smaller than the tax on carbon. In addition, these taxes tend to be, on their own, more regressive than the tax on carbon dioxide emissions. The welfare effects for households in the lowest income quintile is 2.8 times greater than the effect on households in the highest income level for the tax on carbon. In contrast, the tax on energy products produces welfare effects for low income households that are 2.4 times that of higher income households and the increase in the VAT produces welfare effects for low income households that are 4.6 times the effect on higher income households.

5.5 Energy and Value Added Taxes: Concluding Remarks

These two alternatives to the carbon tax, the energy tax and the VAT increase, are successful in reducing the economic and welfare costs. However, not only they do not eliminate the economic losses as well as the welfare losses and their regressive patterns but fail in generating meaningful environmental effects. These two alternatives, therefore, greatly dampen all of the effects of the carbon tax, the positive and the less so. We can conceptualize these two alternatives as timid approaches to the environmental concerns, which turns out to be ineffective in both eliminating the economic and welfare effects or in generating the appropriate environmental results. Accordingly, these are not viable alternatives to the straight out carbon tax.

This leads us to return to the carbon tax scenario while at the same time concentrating on alternative recycling strategies in which the carbon tax revenues are used to reduce revenues at other tax margins.

6 Environmental Tax Reform: Carbon Taxation with Revenue Recycling

The negative economic and distributional effects of the tax on carbon motivate the need to search for tax reforms that can address the adverse effects of the policy while reaching environmental objectives. The proceeds from the carbon tax open up the possibility of a more comprehensive tax reform in which the revenues generated can be carefully allocated to reducing distortions at the major tax margins of the Portuguese tax system, in isolation and together with energy efficiency objectives. Reductions to the personal income tax (PIT) can be designed to promote progressive policy outcomes. Reform to the value added tax (VAT) can also be used to address the adverse distributional effects of the carbon tax. Reductions to the corporate income tax (CIT) and financing for an investment tax credit (ITC) margins are particularly effective in reducing the adverse economic effects of the policy.

In this section we examine the impact of using revenue from the tax on carbon to finance reductions in distortionary tax margins in the Portuguese economy. Detailed results are presented in Tables 6.1 to 6.15.

6.1 Introduction

The adverse macro-economic and distributional effects of the tax on CO_2 emissions motivate the need to consider a more comprehensive environmental tax reform that has the potential to reduce emissions, promote economic growth and job creation and address distributional concerns. Such comprehensive environmental tax reform potentially provides for a politically feasible mechanism to address environmental, economic and industry and social concerns associated with decarbonization policies and promote positive and progressive economic outcomes.

Environmental tax reform is made possible through the proceeds generated by the tax on CO_2 emissions. These revenues can be used to finance reductions in the personal income tax (PIT), corporate income taxes (CIT), value-added taxes (VAT) and to finance investment tax credits (ITC) for private capital. Because of their specific nature we do not consider changes in the social security contributions, the only important tax margin in the Portuguese tax system we omit. As the carbon tax revenues are judiciously allocated to reducing distortions at the other major tax margins of the Portuguese tax system, thereby allowing for the possibility of simultaneous reductions in emissions and positive economic and distributional effects. This is because the revenues from the carbon tax allowing for a reduction in the other tax margins also allow for the reduction of the corresponding distortions or losses in efficiency.

The reductions in the different tax margins are considered in isolation and together with incentives for the purchase of energy efficient equipment and technologies. They include selected reduction in the VAT and personal income tax credits for energy efficiency appliances as well as corporate income tax deductions and investment tax credits for the purchase of energy efficiency equipment and technologies.

The motivation for considering these energy efficiency cases comes, in general, from acknowledging the central role of energy efficiency in this discussion. Indeed, comparisons with other mechanisms for reducing emissions highlights the virtuosity of energy efficiency. If one were to consider strict increases in the prices of fossil fuels in the international markets one would clearly expect a reduction in emissions. This reduction, however, would come from a reduction in economic activity following a loss of resources of the energy-importing economy that goes with higher fossil fuel prices. If we were to consider a carbon tax, we have also reductions in emissions induced in good part by reduction in economic activity as the firms are directly penalized through higher energy prices. At the same time, the loss for the firms is a gain for the public sector. With energy efficiency we are in the best of all worlds as the same output is being generated with lesser energy-intensive technologies and therefore there is no leakage in the economy, nobody is worse off.

From a practical perspective, the results from the TIMES_PT model, make it very clear that there are plenty of cost-effective energy efficiency opportunities in the Portuguese economy. Indeed, the energy efficiency opportunities are reckoned by the TIMES_PT model to be the first and the most cost-effective frontier in the path to decarbonization. This said, energy efficiency is notoriously hard to implement even when we consider cost effective opportunities. Part of the problem is the natural inertia in adoption of new technologies, which is this case is compounded by information gaps. More importantly, the existence of cost-effective energy efficiency alternatives, does not imply a decision to adopt as this requires a more comprehensive consideration of general opportunity costs of financing. This means that the fact that an energy efficiency is cost effective does not mean it is the best allocation of financial funds. As a corollary, the need of financial incentives or subsidies play a leading role in the adoption of even cost-effective energy efficiency alternatives.

The potential costs of energy efficiency improvements crowding out other productive private investments does suggest the need for additional incentives and explains/justifies the cost per unit of increased energy efficiency financed by the tax on carbon. The tax reform can be designed to provide incentives for energy efficiency and the adoption of energy efficiency equipment. This is done by incorporating specific provisions for the purchase of energy efficiency appliances and technologies in the reforms themselves. This includes personal income tax credits for the purchase of energy efficient household appliances, including hot water heaters, furnaces, refrigerators, washer/dryer, stoves, and electronics and for fuel efficiency personal vehicles.

In terms of energy efficiency for producers, we consider an across the board increase in the productivity of energy resources in production of 7.5% for each sector of economic activity. The incentives for these investments assume the form of corporate income tax credits for private investment and reductions in the effective corporate income tax rate faced by firms who invest in energy efficient technologies.

Energy saving technological progress in firms, produces a substantial contribution to economic growth. Indeed technological change is a principal driver of long-run economic growth. As such, it is no surprise that an increase in the efficiency with which firms employ energy inputs has a strong positive effect on GDP and on employment.

As to energy efficiency for households, the increase in energy efficiency in household appliances affects household welfare by increasing the amount of disposable income available to spend on other goods and services while still allowing the household to maintain a given level of energy service demand. This increase in efficiency in residential and transportation energy demand are positive for households but provide only a very minor stimulus to aggregate demand and therefore have little to no effect on GDP and on employment.

As a practical consideration, the increase in energy efficiency for households produces a small rebound in energy consumption consistent with the lower unit cost of operating a motor vehicles and associated with household electricity and energy use, which may be reflected, for example, in marginally greater thermostat setting during winter months and greater use of cooling fans and similar equipment in the summer months relative to strict technological considerations of the potential for efficiency improvements to reduce energy demand.

A key issue when considering the targeting activities that promote energy efficiency is determining the levels of investment necessary to induce specific energy-efficiency gains. As a reference point, we use the value of 400 million euros in investment as the amount necessary to generate a 1,000 Ktoe of energy efficiency savings. This value is based on the average cost of avoided energy consumption at the industrial price in the US of $13.8 per MMBTU, presented in the abatement cost structure in Granade et al. (2009). When applied to the Portuguese case, this unit value implies that a persistent annual increase in energy efficiency of about 1% of the total primary energy consumption would require a yearly investment of 85-100 million Euros. In our case, this would implies a subsidy level of approximately 17% of the carbon tax revenues over the period in analysis. This means that the resources required for these levels of investment necessary to induce the annual gains in energy efficiency we are considering are readily available.

6.2 Environmental Tax Reform: Revenue Recycling to Individual Tax Margins

In the simulations that follow we consider the application of carbon tax revenue to reducing the effective tax rates on direct and indirect taxes. The revenues generated from carbon taxation are used to finance a reduction in the personal income tax rate, the corporate income tax rate, the value added tax rate and to provide corporate income tax credits for private investment. The tax rate on carbon dioxide emissions is that required to reduce carbon dioxide emissions by 60% in 2050 defined as the shadow price of the emissions constraint by the TIMES_PT model.

We start by considering policy options in which the revenues from the tax are used to reduce individual tax margins with and without incentives for energy efficiency improvements.

We consider first the case of **recycling the carbon tax revenues through reduction in the personal income tax**. The magnitude of the reductions in the personal income tax made possible by the recycling can be detailed as follows. PIT revenues are now 10.1% of GDP. With recycling they would be 10% by 2020 and 7.5% by 2050, a reduction equivalent to 75% of the current values.

Progressive changes to the personal income tax can always be modelled to produce progressive distributional effects for the decarbonization policies. There is naturally a great degree of subjectivity in how regressive the changes in the personal income tax should be. For the sake of illustration we consider a case in which by 2020 the reductions for the different income groups would be: 15%, 5%, 2.5%, 1.5% and 1.0%, and they increase maintaining the same proportionality after that year. Of course in all cases the total change for all income groups together strictly matches the carbon tax revenues under consideration.

Overall, recycling the carbon tax revenues through reductions in the PIT, leads to slightly less favorable energy demand and CO_2 emissions outcome. It also leads to less adverse economic effects mainly led by much smaller reductions in personal consumption. The most important change in in the distributional from where we observe much more favorable welfare effects. There are welfare gains for the two lowest income groups and we observe a clear pattern of progressivity of the welfare effects.

Second, we consider the case of **recycling of the carbon tax revenues through reductions in the corporate income tax**. The CIT revenues are currently 2.6% of GDP. With recycling they would be 2.5% by 2020 and would virtually be totally replaced by 2050.

Under the recycling of the carbon tax revenues through reductions in the CIT, the effects in the energy markets and CO_2 emissions are close to the simple carbon tax case. The economic effects, however, are substantially less adverse, mainly acting through the private investment channel. Finally, it flattens the distributional welfare effects, which nevertheless remain negative and still show some regressivity.

We consider third, the case of **recycling of the carbon tax revenues through reductions in the value added tax**. The magnitude of the reductions in the VAT can be illustrated as follows. VAT revenues are currently 8.0% of GDP. With recycling they would be 7.9% by 2020 and 5.5% by 2050, a reduction equivalent to 69% of the current values.

With the recycling of the carbon tax revenues through reductions in the VAT, we see less of a reduction in energy demand and less of a reduction in emissions due to a rebound in private consumption. The economic losses are somewhat mitigated as are the negative welfare effects. The regressive pattern of the welfare losses, however, remains.

Fourth, and finally, we consider the **recycling of the carbon tax revenues through additional investment tax credits**. Investment tax credits are currently not significant in the Portuguese tax system. Under this strategy they would reach 2.5% of GDP by 2050.

Under the recycling of the carbon tax revenues through increases in the ITC, the effects in the energy markets and CO_2 emissions remain close to simple carbon tax case. The economic effects, however, are substantially less adverse, mainly through a substantial rebound in private investment. It is interesting to note as well that the economic effects are more favorable under the investment tax credit than the corporate income tax recycling. This is because the ITC effectively subsidizes new capital investments as opposed to the CIT which subsidizes all capital, new and already installed. Finally, under this recycling strategy, the distributional effects are overall more negative than the simple carbon tax case due to the sharper reduction in private consumption. They are, however, essentially flat across the different income groups.

Let’s consider now the effects of adding energy efficiency objectives, household energy efficiency subsidies in the context of the PIT and VAT recycling and production energy efficiency subsidies in the cases of CIT and ITC.

The consideration of energy efficiency subsidies for households makes little difference in terms of the economic effects. Its effects translate mostly into better energy markets and emissions outcomes. Indeed, for households, energy demand decreases while emissions are further reduced compared to the cases in which energy efficiency subsidies are absent. Economic effects are marginal improvements compared to such cases, except for consumption where we see a clear rebound. Accordingly, overall it increases substantially the desirable welfare effects, for PIT positive and progressive effects, for VAT positive but regressive.

In turn, energy efficiency subsidies for firms, reduces energy costs in production and increases energy demand relative to the cases in which energy efficiency subsidies are absent. By reducing production costs it helps improve economic performance and employment. It therefore leads to a rebound effect. This rebound effect translates into substantial gains in terms of the public and foreign debt to GDP ratios. On the other hand, while reductions in CO_2 emissions are more pronounced than without energy efficiency subsidies and with the carbon tax alone, the rebound effect prevents the difference from being significant. Finally, energy efficiency subsidies to firms, reduces welfare losses and induces more progressivity.

To be noted, the fact that energy efficiency to producers is more effective in generating positive economic outcomes that energy efficiency subsidies for households, is consistent with the conceptual predominance of supply side effects [firms] over demand side effects [households] when it comes to long term economic performance.

As a final conclusion, generally, the use of carbon tax revenues to reduce the personal income tax rate and VAT rates are particularly effective in reducing the magnitude of the adverse distributional effects of the carbon tax and in the PIT case in reversing the regressive patterns. In turn, reductions to the corporate income tax and even more so financing for private investment tax credits are particularly effective in reducing the adverse economic effects and can, in some instances, encourage economic growth and job creation. Attaching to the CIT and ITC energy efficiency subsidies for firms is very important in achieving favorable economic outcomes.

Table 6.1 Long Run [2050] Environmental and Energy Effects

(Percent change relative to the reference scenario)

	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
PIT	-12.80	-3.72	10.67	8.89	-22.94
PIT – Efficiency	-15.74	-5.67	11.57	9.08	-25.77
CIT	-13.66	-3.84	11.44	10.07	-24.24
CIT – Efficiency	-9.77	3.00	16.98	10.24	-24.40
Carbon Tax	-14.36	-5.72	10.79	9.10	-24.32

Table 6.2 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

	GDP	Consumption	Investment	Employment	Public Debt	Foreign Debt
PIT	-3.02	-0.35	-0.88	-0.55	3.87	7.72
PIT – Efficiency	-3.00	0.80	-0.80	-0.37	4.61	7.09
CIT	-1.70	-2.41	4.76	-0.50	0.09	0.66
CIT – Efficiency	3.46	-0.91	7.07	1.66	-21.80	-25.32
Carbon Tax	-4.28	-2.37	-2.89	-2.07	-12.58	5.32

Table 6.3 Long Run [2050] Distributional Effects – Equivalent Variations

(Percent change relative to the reference scenario)

	PIT	PIT - Efficiency	CIT	CIT - Efficiency	Carbon Tax
First Quintile (Lowest Income)	0.39	1.69	-2.69	-0.16	-3.34
Second Quintile	0.15	1.44	-2.75	-0.83	-3.05
Third Quintile	-0.14	1.09	-2.58	-1.15	-2.51
Fourth Quintile	-0.55	0.61	-2.41	-0.99	-2.28
Fifth Quintile (Highest Income)	-0.71	0.32	-2.12	-0.95	-1.84

Table 6.4 Long Run [2050] Energy and Environmental Effects

(Percent change relative to the reference scenario)

	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
VAT	-12.05	-4.35	8.80	8.88	-21.42
VAT – Efficiency	-15.04	-6.39	9.79	9.06	-24.36
ITC	-14.13	-4.65	10.71	9.12	-24.20
ITC – Efficiency	-10.28	2.12	16.26	9.30	-24.37
Carbon Tax	-14.36	-5.72	10.79	9.10	-24.32

Table 6.5 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

	GDP	Consumption	Investment	Employment	Public Debt	Foreign Debt
VAT	-3.45	-0.71	-1.72	-1.15	5.08	7.38
VAT – Efficiency	-3.40	0.46	-1.56	-0.92	5.85	6.75
ITC	-1.41	-3.48	11.78	0.20	5.69	4.31
ITC – Efficiency	3.78	-1.98	14.23	2.36	-16.34	-21.53
Carbon Tax	-4.28	-2.37	-2.89	-2.07	-12.58	5.32

Table 6.6 Long Run [2050] Distributional Effects – Equivalent Variations

(Percent change relative to the reference scenario)

	VAT	VAT - Efficiency	ITC	ITC - Efficiency	Carbon Tax
First Quintile (Lowest Income)	-1.45	-0.08	-3.34	-0.80	-3.34
Second Quintile	-1.18	0.16	-3.64	-1.71	-3.05
Third Quintile	-0.81	0.44	-3.65	-2.21	-2.51
Fourth Quintile	-0.65	0.52	-3.53	-2.12	-2.28
Fifth Quintile (Highest Income)	-0.34	0.68	-3.33	-2.17	-1.84

6.3 Environmental Tax Reform: Mixed Revenue Recycling Strategies

The effects of the reducing taxes at the different margins suggests that multiple policy objectives may be achievable with an environmental tax reform based on mixed recycling strategies. In the simulations that follow we consider the application of carbon tax revenue to reducing the effective tax rates on direct and indirect taxes in combination. The revenues generated from carbon taxation are used to finance a reduction in the personal income tax rate, the corporate income tax rate, the value added tax rate and to provide corporate income tax credits for private investment.

We first consider a direct tax channel: a combination of reductions in the personal income tax and the corporate income tax margins; second, we consider an indirect tax channel, a combination of reductions in the VAT and an increase in investment tax credits; finally, we consider a case of mixing reductions in the personal income tax, with increases in the investment tax credits. In all cases, we consider the use of part of the revenues generated to provide income tax credits, VAT rate reductions and investment tax credit for the purchase of energy efficient technologies.

In each case, we consider a detailed grid of alternatives for the share of CO_2 tax revenues allocated to reductions in each tax margin to determine the most desirable outcome with respect to economic performance and distributional considerations. This approach allows us to understand in detail the nature of the trade-offs we are facing along the efficiency and equity fronts. For example, in the case of the direct tax replacements, the more the share of the personal income tax and the less the share of the corporate income tax the better the distributional effects and the less desirable the efficiency effects. The same is true for the case of indirect taxes. The greater the investment tax credit and the less the value added tax the better the efficiency effects and the more the welfare loss although also with an increased level of progressivity. So less ITC and more VAT lead to lower aggregate welfare outcomes which are nevertheless more regressive outcomes. From this it also follows the interest in considering a case with reductions in the personal income tax to help with positive welfare effects and progressivity and investment tax credits to help with efficiency.

Let's consider first the PIT/CIT grid. The reduction in energy demand and in CO_2 emissions increases in the share of the CO_2 revenues allocated towards reductions in the PIT, relative to the CIT. This however comes at the cost of less desirable economic effects on output and employment. The macroeconomic effects on GDP become positive around the 50/50 mixed case. Finally, greater welfare gains and more progressive outcomes are possible with a greater allocation of the revenues from the carbon tax to reductions in the PIT, relative to the CIT. All things considered, an equal allocation of revenues to reductions in the PIT rate and the CIT rate, the 50/50 case, seems to be a good compromise.

Table 6.7 Long Run [2050] Energy and Environmental Effects

(Percent change relative to the reference scenario)

PIT/CIT Shares	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
1.0/0.0	-15.738	-5.669	11.574	9.076	-25.769
0.9/0.1	-15.169	-4.837	12.116	9.188	-25.648
0.8/0.2	-14.595	-3.997	12.656	9.300	-25.524
0.7/0.3	-14.014	-3.150	13.196	9.414	-25.396
0.6/0.4	-13.428	-2.294	13.736	9.529	-25.264
0.5/0.5	-12.835	-1.429	14.276	9.645	-25.130
0.4/0.6	-12.235	-0.555	14.815	9.762	-24.991
0.3/0.7	-11.629	0.329	15.356	9.880	-24.850
0.2/0.8	-11.016	1.222	15.897	9.999	-24.704
0.1/0.8	-10.395	2.127	16.439	10.120	-24.555
0.0/1.0	-9.767	3.042	16.983	10.242	-24.402

Table 6.8 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

PIT/CIT Shares	GDP	Consumption	Investment	Employment	Public Debt	Foreign Debt
1.0/0.0	-3.003	0.804	-0.798	-0.366	4.606	7.089
0.9/0.1	-2.420	0.682	-0.140	-0.202	2.102	4.054
0.8/0.2	-1.825	0.551	0.542	-0.031	-0.427	0.980
0.7/0.3	-1.217	0.409	1.251	0.148	-2.983	-2.135
0.6/0.4	-0.596	0.257	1.987	0.335	-5.568	-5.293
0.5/0.5	0.039	0.093	2.752	0.530	-8.184	-8.498
0.4/0.6	0.690	-0.082	3.547	0.735	-10.832	-11.752
0.3/0.7	1.356	-0.268	4.374	0.949	-13.516	-15.058
0.2/0.8	2.039	-0.468	5.235	1.174	-16.237	-18.420
0.1/0.8	2.740	-0.681	6.131	1.410	-18.999	-21.840
0.0/1.0	3.460	-0.907	7.066	1.657	-21.803	-25.324

Table 6.9 Long Run [2050] Distributional Effects – Equivalent Variations

(Percent change relative to the reference scenario)

PIT/CIT Shares	First Quintile (Lowest Income Level)	Second Quintile	Third Quintile	Fourth Quintile	Fifth Quintile (Highest Income Level)
1.0/0.0	1.691	1.443	1.094	0.611	0.318
0.9/0.1	1.533	1.253	0.919	0.503	0.250
0.8/0.2	1.369	1.056	0.733	0.386	0.170
0.7/0.3	1.199	0.851	0.538	0.257	0.078
0.6/0.4	1.023	0.637	0.333	0.117	-0.026
0.5/0.5	0.842	0.416	0.116	-0.034	-0.144
0.4/0.6	0.654	0.186	-0.111	-0.198	-0.275
0.3/0.7	0.460	-0.053	-0.351	-0.375	-0.420
0.2/0.8	0.259	-0.301	-0.602	-0.564	-0.581
0.1/0.8	0.051	-0.558	-0.867	-0.768	-0.758
0.0/1.0	-0.163	-0.825	-1.145	-0.987	-0.951

Second, we consider the VAT/ITC grid. In this case, a greater reduction in energy demand is associated with a larger share of revenues allocated to reductions in the VAT rate and a smaller allocation to financing for an increase in the ITC. CO_2 emissions reductions, however, reach a maximum around a balanced allocation in which half of the revenues are directed towards reductions in the VAT rate and half

Table 6.10 Long Run [2050] Energy and Environmental Effects

(Percent change relative to the reference scenario)

VAT/ITC Shares	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
1.0/0.0	-15.035	-6.389	9.788	9.061	-24.358
0.9/0.1	-14.589	-5.574	10.441	9.080	-24.379
0.8/0.2	-14.137	-4.753	11.092	9.100	-24.395
0.7/0.3	-13.678	-3.923	11.742	9.121	-24.407
0.6/0.4	-13.213	-3.086	12.390	9.143	-24.415
0.5/0.5	-12.741	-2.240	13.036	9.166	-24.418
0.4/0.6	-12.261	-1.386	13.681	9.190	-24.418
0.3/0.7	-11.775	-0.523	14.326	9.215	-24.414
0.2/0.8	-11.282	0.349	14.970	9.241	-24.406
0.1/0.8	-10.782	1.231	15.613	9.269	-24.393
0.0/1.0	-10.275	2.123	16.257	9.298	-24.377

are directed towards an increase in the ITC, the 50/50 case. In addition, we observe more desirable macroeconomic effects on output and employment with a larger share of the revenues allocated towards financing an increase in investment tax credits, with positive GDP effects observed around the 50/50 mixed case. Finally, we observe greater welfare gains with a larger allocation of revenues to reductions in the VAT although the effects are regressive. These effects highlight a trade-off suggested that we are faced with a choice between positive welfare effects that are regressive and negative welfare effects which are progressive. Again the choice of the 50/50 mixed case is a good compromise.

Table 6.11 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

VAT/ITC Shares	GDP	Consumption	Investment	Employment	Public Debt	Foreign Debt
1.0/0.0	-3.399	0.459	-1.557	-0.923	5.849	6.750
0.9/0.1	-2.737	0.250	-0.007	-0.619	3.796	4.135
0.8/0.2	-2.065	0.036	1.543	-0.311	1.709	1.480
0.7/0.3	-1.382	-0.185	3.095	0.002	-0.413	-1.219
0.6/0.4	-0.686	-0.414	4.652	0.319	-2.572	-3.963
0.5/0.5	0.021	-0.650	6.216	0.642	-4.767	-6.755
0.4/0.6	0.742	-0.896	7.791	0.972	-7.000	-9.597
0.3/0.7	1.477	-1.151	9.377	1.308	-9.272	-12.492
0.2/0.8	2.227	-1.417	10.978	1.651	-11.585	-15.443
0.1/0.8	2.992	-1.694	12.596	2.002	-13.940	-18.454
0.0/1.0	3.775	-1.983	14.233	2.362	-16.339	-21.528

Table 6.12 Long Run [2050] Distributional Effects – Equivalent Variations

(Percent change relative to the reference scenario)

VAT/ITC Shares	First Quintile (Lowest Income Level)	Second Quintile	Third Quintile	Fourth Quintile	Fifth Quintile (Highest Income Level)
1.0/0.0	-0.081	0.158	0.438	0.517	0.681
0.9/0.1	-0.140	-0.005	0.208	0.292	0.439
0.8/0.2	-0.201	-0.171	-0.027	0.061	0.190
0.7/0.3	-0.264	-0.343	-0.269	-0.177	-0.067
0.6/0.4	-0.330	-0.519	-0.519	-0.424	-0.334
0.5/0.5	-0.399	-0.700	-0.777	-0.680	-0.610
0.4/0.6	-0.471	-0.887	-1.043	-0.945	-0.898
0.3/0.7	-0.547	-1.081	-1.319	-1.221	-1.197
0.2/0.8	-0.627	-1.282	-1.606	-1.509	-1.508
0.1/0.8	-0.712	-1.491	-1.903	-1.809	-1.834
0.0/1.0	-0.801	-1.707	-2.212	-2.122	-2.174

Third, and finally, we consider the PIT/ITC grid, which explores the desirable distributional effects of reductions in the PIT and the desirable economic effects of the increase in ITC. A larger reduction in energy demand and in CO_2 is possible with a greater allocation of revenues to reductions in the PIT rate. At the same time, this leads to less desirable economic effects on output and employment. Again, the macroeconomic GDP effects become positive around the 50/50 allocation. Finally, greater and more progressive welfare gains are possible with a larger allocation of the revenues from the carbon tax to

Table 6.13 Long Run [2050] Energy and Environmental Effects

(Percent change relative to the reference scenario)

PIT/ITC Shares	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
1.0/0.0	-15.738	-5.669	11.574	9.076	-25.769
0.9/0.1	-15.216	-4.924	12.041	9.094	-25.643
0.8/0.2	-14.689	-4.172	12.508	9.113	-25.515
0.7/0.3	-14.157	-3.413	12.974	9.133	-25.384
0.6/0.4	-13.620	-2.646	13.440	9.153	-25.249
0.5/0.5	-13.077	-1.934	13.907	9.175	-25.112
0.4/0.6	-12.529	-1.091	14.375	9.197	-24.971
0.3/0.7	-11.975	-0.301	14.843	9.221	-24.828
0.2/0.8	-11.414	0.498	15.313	9.245	-24.681
0.1/0.8	-10.848	1.306	15.784	9.271	-24.531
0.0/1.0	-10.275	2.123	16.257	9.298	-24.377

Table 6.14 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

PIT/ITC Shares	GDP	Consumption	Investment	Employment	Public Debt	Foreign Debt
1.0/0.0	-3.003	0.804	-0.798	-0.366	4.606	7.089
0.9/0.1	-2.385	0.559	0.645	-0.123	2.686	4.429
0.8/0.2	-1.757	0.309	2.090	0.123	0.736	1.737
0.7/0.3	-1.117	0.053	3.547	0.376	-1.251	-0.996
0.6/0.4	-0.464	-0.211	5.017	0.635	-3.277	-3.773
0.5/0.5	0.203	-0.482	6.502	0.901	-5.343	-6.598
0.4/0.6	0.885	-0.763	8.005	1.176	-7.451	-9.472
0.3/0.7	1.582	-1.052	9.528	1.458	-9.603	-12.399
0.2/0.8	2.296	-1.352	11.073	1.750	-11.801	-15.382
0.1/0.8	3.027	-1.662	12.643	2.051	-14.047	-18.426
0.0/1.0	3.775	-1.983	14.233	2.362	-16.349	-21.528

Table 6.15 Long Run [2050] Distributional Effects – Equivalent Variations

(Percent change relative to the reference scenario)

PIT/ITC Shares	First Quintile (Lowest Income Level)	Second Quintile	Third Quintile	Fourth Quintile	Fifth Quintile (Highest Income Level)
1.0/0.0	1.691	1.443	1.094	0.611	0.318
0.9/0.1	1.457	1.149	0.795	0.374	0.112
0.8/0.2	1.221	0.853	0.492	0.132	-0.101
0.7/0.3	0.982	0.552	0.182	-0.118	-0.322
0.6/0.4	0.740	0.246	-0.135	-0.375	-0.552
0.5/0.5	0.494	-0.064	-0.459	-0.641	-0.793
0.4/0.6	0.244	-0.381	-0.791	-0.916	-1.044
0.3/0.7	-0.011	-0.703	-1.132	-1.201	-1.307
0.2/0.8	-0.269	-1.031	-1.482	-1.497	-1.583
0.1/0.8	-0.533	-1.366	-1.842	-1.804	-1.872
0.0/1.0	-0.801	-1.707	-2.212	-2.122	-2.174

reductions in the PIT. Once again, 50/50 is a good compromise: It yields substantive economic gains and progressive welfare effects with positive outcomes for households in the lowest income group while the largest welfare losses, accruing to households in the highest income group, are less than half of what those associated with a simple tax on carbon.

6.4 Recycling Strategies: Concluding Remarks

We conclude that a balanced 50/50 mixed direct channel strategy of personal income tax and corporate income tax reductions, a balanced 50/50 mixed indirect channel of reductions to the value added tax and financing for investment tax credits, as well as a 50/50 mixed reduction in the personal income tax and increase in investment tax credits are among the strategies that can each yields all of the desirable policy outcomes: reductions in CO_2 emissions, positive macro-economic effects, progressive distributional effects, reductions to the public sector debt, and positive effects on international competitiveness.

Finally, it should be noted that our objective here is to provide evidence for the existence of recycling alternatives that lead to a carbon tax with all of the desirable outcomes. We did not intend to find the best possible outcome. First, a finer grid is possible that would lead to finer tuned results. Second, and more substantially, it is quite likely that our results could be further improved in all relevant directions: efficiency, fairness, and environment, by using a combination with a higher share of investment tax credits, larger shares of the recycling allocated to energy efficiency for the firms and a smaller personal income tax component but with a more aggressive progressive approach to the recycling.

7 Carbon Taxation with Balanced Recycling Strategies and Energy Efficiency

7.1 Introduction

We consider now in details the results from three different policies. First, a 50-50 reduction in direct taxes, the PIT and the CIT. Second, the application of half of the carbon tax revenue to reduce the value added tax rate and half for the provision of corporate income tax credits for private investment. Third, the use of half of the revenue from the tax on carbon to reduce the personal income tax and half for the provision of private investment tax credits.

In the discussion that follows, we consider more explicitly the results for 2030 in addition to results for 2050 we have been highlighting. Since these are the most important set of results, we want to also highlight the temporal patterns before reaching 2050. In general environmental effects are much smaller in 2030, and the economic and welfare effects much more desirable. The discussion in this chapter is based on the results reported in Tables 7.1 to 7.12 and in more detail in Appendices 1, 4, 5, and 6.

7.2 Energy and Environmental Effects

The three fiscal reform policies we consider, each have a very small effect on the price of energy products overall relative to the carbon tax alone. The notable exception to this rule, however, is the somewhat smaller price effects driven by lower VAT rates. In addition, policies which lower the corporate income tax rate or provide for a corporate income tax credit for private investment have a more important effect on prices in capital intensive industries and allow for a reduction in the price of electricity in the short run. In the long run, however, the substantial tax on carbon contributes to an increase in electricity prices, albeit a smaller increase than that associated with a carbon tax alone.

The relatively small differences in price for these tax reform policies relative to the carbon tax and individual revenue recycling policies considered above naturally leads to relatively small changes in final demand for energy relative to the cases discussed above. In all cases, aggregate final demand for energy falls by a smaller amount in the context of the fiscal reforms considered than in the reference scenario. These differences are largely due to short-run increases in the demand for electricity which further contributes towards electrification of the Portuguese economy and follows the price effects observed above. Final demand for electricity increases by 1.1% in 2040 with the PIT/CIT reform, 0.5% with the VAT/ITC reform and 0.7% with the PIT/ITC reform. Over the long run, the final demand for each type of energy, with the exception of biomass, is lower than in the reference scenario though the reduction in demand is smaller than that associated with a tax on carbon.

Table 7.1 Environmental tax reform: Effect on Final Energy Prices

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Composite Energy Price	2.666	12.745	19.868	57.523
Coal	19.774	86.345	135.623	392.032
Natural Gas	2.326	9.949	15.240	43.061
Butane, Propane and LPG	0.632	5.952	9.722	27.607
Fuel Oil	2.252	5.450	7.763	18.747
Gasoline	1.306	6.545	10.281	29.066
Diesel	2.313	9.885	15.434	44.510
Electricity	-0.011	1.690	2.770	9.192
Biomass	-0.336	-0.042	-0.378	1.969
PIT/CIT (50-50)				
Composite Energy Price	2.391	11.948	18.345	55.314
Coal	19.774	86.345	135.623	392.032
Natural Gas	2.326	9.949	15.240	43.061
Butane, Propane and LPG	0.327	4.989	7.817	24.903
Fuel Oil	2.087	4.757	6.354	16.475
Gasoline	1.093	5.961	9.293	27.668
Diesel	2.211	9.537	14.822	43.596
Electricity	-0.781	-0.654	-1.535	2.766
Biomass	-0.939	-1.502	-3.276	-1.744
VAT/ITC (50-50)				
Composite Energy Price	1.946	9.819	15.932	47.856
Coal	19.496	84.573	133.096	379.868
Natural Gas	2.092	8.906	14.021	39.530
Butane, Propane and LPG	-0.060	3.145	5.772	18.749
Fuel Oil	1.189	1.529	2.636	7.324
Gasoline	0.456	2.969	5.875	18.015
Diesel	1.471	6.311	11.039	32.501
Electricity	-0.812	-0.791	-1.506	2.324
Biomass	-0.577	-1.222	-2.432	-2.205
PIT/ITC (50-50)				
Composite Energy Price	2.443	12.054	18.513	55.431
Coal	19.774	86.345	135.623	392.032
Natural Gas	2.326	9.949	15.240	43.061
Butane, Propane and LPG	0.411	5.196	8.104	25.087
Fuel Oil	1.982	4.857	6.427	17.003
Gasoline	1.152	6.013	9.381	27.617
Diesel	2.210	9.586	14.873	43.671
Electricity	-0.723	-0.405	-1.113	3.402
Biomass	-0.588	-1.062	-2.537	-1.648

As a result, we observe much greater gains in terms of electrification, even over the long run. The long term increase in electrification stems from the smaller relative reduction in final demand for electricity relative to carbon intensive fossil fuels. The PIT/CIT reform contributes towards a 14.3% in the share of electricity in final energy demand, the largest effect among the reforms considered and reflective of the larger short term reduction in electricity prices together with the more moderate long term increase noted above. The gains in electrification are substantial also for the other reforms considered. The share of electricity in final energy demand increases 13.0% with the VAT/ITC policy and 13.9% with the PIT/ITC policy. Each policy contributes to a greater than three percentage points larger increase in the share of electricity in final demand than the effects observed when the revenues from these tax instruments reverted to the general fund.

Final demand for energy among firms is now largely influence by a greater incentive to substitute electricity for other types of energy. Final demand for energy among firms falls by 10.4% with the PIT/CIT policy, 10.7% with the VAT/ITC policy and 10.5% with the PIT/ITC policy, somewhat less than the 13.2% reduction in final energy demand stemming from the tax alone. In all cases, we observe notable reductions in energy demand in petroleum refining [a1], construction [a6], and transportation [a7]. With the tax reforms, final energy demand declines across all sectors of economic activity with particularly large effects also noted for agriculture [a4], chemicals [a10], rubber, plastics and ceramics [a11], and other goods and services [a13].

Household demand for energy is also affected by the change in prices, particularly those for electricity. In the simple decarbonization policy, household energy demand declined by 8.5% with a tax on carbon. Now, with the fiscal reforms considered, we observe a reduction in final demand of 9.4% with the PIT/CIT policy, 9.1% with the VAT/ITC policy and 10.0% with the PIT/ITC policy.

Environmental tax reform is effective in encouraging the electrification of the Portuguese economy. The incentives provided by the tax on carbon also have the intended effect of increasing the share of renewable energy in electricity production. The reductions to the CIT as well as the incentives for private capital investment contribute towards providing a stronger incentive for an increased penetration of renewable energy than the tax alone. The share of renewables in total electricity production increases by 9.1% with the tax on carbon, 9.6% with the PIT/CIT reductions, 9.2% with the VAT/ITC policy and 9.2% with the PIT/ITC policy. We continue to observe significant reductions in the production of electricity from fossil fuels and a larger expansion in production from renewable energy sources than in observed with the tax policies alone. The increase in electricity production and the improvement in the terms of trade for electricity translates also into an increase in exports of in the short run and more moderate reductions in exports in the long run.

Table 7.2 Environmental tax reform: Effect on Final Energy Demand

(Percent change relative to the reference scenario)

		2020	2030	2040	2050
Carbon tax					
Total		-0.230	-3.550	-5.698	-14.351
	Coal	-3.046	-31.844	-43.232	-67.820
	Natural Gas	-0.549	-7.345	-11.371	-27.373
	Butane, Propane and LPG	-0.351	-4.528	-7.214	-17.946
	Gasoline	-0.267	-3.527	-5.658	-14.511
	Diesel	-0.452	-6.187	-9.868	-24.520
	Electricity	0.012	-1.146	-1.795	-5.717
	Biomass	0.320	1.207	2.153	3.472
PIT/CIT (50-50)					
Total		-0.099	-2.952	-4.821	-12.835
	Coal	-3.824	-33.087	-45.041	-68.964
	Natural Gas	-0.317	-6.682	-10.570	-26.509
	Butane, Propane and LPG	-0.364	-4.429	-7.157	-17.741
	Gasoline	-0.624	-4.295	-7.044	-16.039
	Diesel	-0.605	-6.512	-10.555	-25.282
	Electricity	0.514	0.577	1.108	-1.389
	Biomass	0.216	1.085	2.149	3.979
VAT/ITC (50-50)					
Total		-0.099	-2.923	-4.851	-12.741
	Coal	-3.563	-32.945	-44.828	-68.989
	Natural Gas	-0.531	-6.863	-10.840	-26.393
	Butane, Propane and LPG	-0.302	-4.134	-6.836	-16.949
	Gasoline	-0.400	-3.664	-6.308	-14.627
	Diesel	-0.544	-6.114	-10.141	-24.286
	Electricity	0.431	0.173	0.515	-2.410
	Biomass	-0.012	0.350	0.996	2.417
PIT/ITC (50-50)					
Total		-0.143	-3.088	-5.013	-13.077
	Coal	-3.616	-33.039	-44.915	-69.055
	Natural Gas	-0.520	-6.860	-10.812	-26.381
	Butane, Propane and LPG	-0.393	-4.498	-7.235	-17.791
	Gasoline	-0.563	-4.310	-7.019	-16.201
	Diesel	-0.649	-6.546	-10.607	-25.271
	Electricity	0.467	0.333	0.739	-1.934
	Biomass	0.115	0.795	1.734	3.650

Table 7.3 Environmental tax reform: Effect on the Electric Power Industry

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Electricity Production	0.007	-0.991	-1.535	-4.840
Renewable Energy Share	0.333	2.290	4.213	9.095
Final Demand for Electricity	0.012	-1.146	-1.795	-5.717
Electricity Demand by Households	0.055	-0.080	-0.230	-1.637
Electricity Demand by Firms	-0.007	-1.264	-1.944	-5.865
Electricity Share in Final Demand	0.254	2.742	4.437	10.785
PIT/CIT (50-50)				
Electricity Production	0.416	0.380	0.765	-1.451
Renewable Energy Share	0.326	2.267	4.655	9.645
Final Demand for Electricity	0.514	0.577	1.108	-1.389
Electricity Demand by Households	-0.142	-0.078	-0.069	-0.480
Electricity Demand by Firms	0.565	0.523	1.015	-1.697
Electricity Share in Final Demand	0.660	4.028	6.779	14.276
VAT/ITC (50-50)				
Electricity Production	0.355	0.093	0.338	-2.167
Renewable Energy Share	0.250	1.994	4.268	9.166
Final Demand for Electricity	0.431	0.173	0.515	-2.410
Electricity Demand by Households	-0.009	-0.471	-0.497	-2.085
Electricity Demand by Firms	0.443	0.215	0.528	-2.284
Electricity Share in Final Demand	0.605	3.613	6.258	13.036
PIT/ITC (50-50)				
Electricity Production	0.379	0.195	0.484	-1.869
Renewable Energy Share	0.261	2.022	4.305	9.175
Final Demand for Electricity				
Electricity Demand by Households	0.035	-0.204	-0.178	-1.270
Electricity Demand by Firms	0.467	0.299	0.661	-2.043
Electricity Share in Final Demand	0.676	30.925	60.617	13.907

Provisions for tax credits and incentives for the adoption of energy efficiency technologies in the framework of an environmental tax reform allows for a small increase in the environmental effectiveness of the decarbonization policies. Carbon dioxide emissions reductions are greater with the environmental tax reforms made possible by the energy efficiency provisions they contain. Carbon dioxide emissions decline by 24.3% with the tax on carbon, 25.1% with the PIT/CIT policy, 24.4% with the VAT/ITC policy and 25.1% with the PIT/ITC policy.

Emissions among firms decline by 26.0% with the tax on carbon, 25.8% with the PIT/CIT policy, 25.7% with the VAT/ITC policy and 25.6% with the PIT/ITC policy. The sectors of economic activity with the greatest reductions in emissions with financing from a tax on carbon are petroleum refining [a1], agriculture [a4], textiles [a8], and rubber, plastics and ceramics [a12], though all sectors have make a substantial contribution towards emissions reductions efforts. These emissions reductions stem from both

Table 7.4 Environmental tax reform: Effect on Carbon Dioxide Emissions

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Carbon Dioxide Emissions	-0.394	-5.036	-10.355	-24.322
Households	-0.534	-6.298	-9.682	-21.083
Residential	-1.373	-14.885	-21.108	-37.549
Transportation	-0.281	-3.708	-6.070	-15.841
Firms	-0.348	-4.613	-10.694	-25.987
PIT/CIT (50-50)				
Carbon Dioxide Emissions	-0.531	-5.312	-11.128	-25.130
Households	-1.359	-8.034	-12.481	-23.911
Residential	-2.133	-16.342	-23.453	-39.580
Transportation	-1.125	-5.527	-9.012	-18.923
Firms	-0.258	-4.400	-10.448	-25.756
VAT/ITC (50-50)				
Carbon Dioxide Emissions	-0.496	-5.103	-10.829	-24.418
Households	-0.865	-6.972	-11.247	-21.957
Residential	-1.847	-16.061	-23.051	-39.343
Transportation	-0.568	-4.230	-7.515	-16.422
Firms	-0.375	-4.477	-10.620	-25.683
PIT/ITC (50-50)				
Carbon Dioxide Emissions	-0.554	-5.335	-11.155	-25.112
Households	-1.148	-8.028	-12.368	-24.256
Residential	-1.931	-16.301	-23.304	-39.770
Transportation	-0.912	-5.532	-8.911	-19.318
Firms	-0.357	-4.434	-10.545	-25.552

changes in the production process consistent with substitution towards fuels with a lower carbon content, substitution towards capital and labor inputs in production as well as reductions in output levels consistent with the increase in prices arising from the environmental policies and the demand responses by households.

Household emissions reductions, particular those associated with residential energy demand, are larger for the environmental tax reform policies than for the simple decarbonization policies. Households reduce emissions by 21.0% with the tax on carbon, 23.9% with the PIT/CIT policy, 24.4% with the VAT/ITC policy and 24.3% with the PIT/ITC policy. The lower price for electricity coupled with greater substitution possibilities in residential energy demand means that these reductions in household emissions are driven by reductions in emissions associated with residential energy consumption. Emissions associated with residential energy consumption fall by 37.5% with the tax on carbon and by upto two percentage points more with the environmental tax reforms, the largest effect observed for the PIT/ITC policy with a 39.8% reduction in emissions associated with residential energy demand. Emissions associated with demand for transportation services declines by 15.8% with the tax on carbon, 18.9% with the PIT/CIT policy, 16.4% with the VAT/ITC policy and 19.3% with the PIT/ITC policy. Accordingly, the reductions in emissions come primarily from reductions in residential energy demand.

Table 7.5 Long Run [2050] Energy and Environmental Effects

(Percent change relative to the reference scenario)

	Energy Demand		**Electricity Demand**		**Electricity Share**		**RES**		**CO_2 Emissions**	
	2030	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Carbon tax	-3.55	-14.36	-1.15	-5.72	2.74	10.79	2.29	9.10	-5.04	-24.32
PIT – CIT (50/50)	-2.95	-12.83	0.58	-1.45	4.03	14.28	2.27	9.64	-5.31	-25.13
VAT – ITC (50/50)	-2.92	-12.74	0.17	-2.17	3.61	13.04	1.99	9.17	-5.10	-24.42
PIT – ITC (50/50)	-3.09	-13.08	0.33	-1.93	3.83	13.91	2.02	9.18	-5.34	-25.11

7.3 Macroeconomic Effects

Environmental tax reform has the potential to produces a strong double dividend, reducing carbon dioxide emissions while encouraging job creation and promoting stronger macroeconomic performance. Environmental tax reform contributes towards a reduction in emissions without any significant long-run effects on GDP for both the PIT/CIT and the VAT/ITC tax reform policies. These policies have a positive short-run effect on economic output, increasing GDP by 0.3% in 2030 with the PIT/CIT tax policy and by 0.02% with the VAT/ITC policy. The environmental tax reform focused on reducing the PIT coupled with financing for corporate income tax credits for private investment, with provisions in each for investments in energy efficiency, provides the largest positive effects on economic performance, increasing GDP by 0.2% relative to the reference scenario in 2050. This represents an increase of 350 million euros.

These neutral to positive effects on macroeconomic performance reverse the adverse macroeconomic impacts associated with the carbon tax alone in which the tax on carbon would lead to a 4.3% reduction in GDP relative to the reference scenario.. These tax reform policies encourage production by providing a direct increase in income with reductions to the PIT, incentives for increases in investment with reductions to the CIT and financing for the ITC and lower the cost of consumption by reducing the VAT. Reductions to taxes on income appear to have a large impact on output in large part due to the larger distortions present in the tax system associated with these tax margins.

The sectoral incidence of these climate policies reflect the effects noted for the individual tax policies. Petroleum refining [a1], transportation [a7], chemicals [a10], and rubber, plastics and ceramics [a11] are affected the most by the decarbonization policies. The tax reforms yield positive outcomes for construction [a6], equipment manufacturing [a5] and primary metals [a12], due in large part to their importance in investment activities, as well as biomass [a3].

These policies generate positive effects on investment. Despite the overall increase in investment, we still observe sharp declines on investment in the three recycling cases for petroleum refining [a1]. These are the same sectors that lose the most in the non-recycling cases. We observe now – virtually by design – large increases in investment and the industries that support investment activities.

Environmental tax reform can encourage employment and job creation. Employment declines by 2.1% with the tax on carbon. Each of the proposed tax reforms increases employment. Employment increases by 0.5% with the PIT/CIT policy, 0.0% with the VAT/ITC policy and 0.9% with the PIT/ITC policy, which is equivalent to 41,000 permanent jobs. The revenue-recycling policies lead to job creation in construction [a6] and equipment manufacturing [a5]. In turn, the sectors that lose the most are the same as those in the simple decarbonization policies: petroleum refineries [a1], transportation [a7] and chemicals [a10], and rubber, plastics and ceramics [a11].

Table 7.6 Environmental tax reform: Effect on Macroeconomic Performance

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
GDP	-0.055	-0.976	-1.621	-4.284
Consumption	-0.032	-0.412	-0.774	-2.370
Gross Fixed Capital Formation	0.155	-0.434	-0.691	-2.890
Exports	-0.212	-2.220	-3.759	-9.180
Imports	-0.070	-0.979	-1.475	-3.459
Foreign Debt	0.042	0.792	2.501	5.324
Trade Deficit	0.488	3.607	5.785	13.151
Public Debt	-0.011	-1.441	-4.784	-12.578
PIT/CIT (50-50)				
GDP	0.520	0.758	1.378	0.039
Consumption	0.063	0.290	0.422	0.093
Gross Fixed Capital Formation	1.767	2.520	4.061	2.752
Exports	0.788	1.066	2.143	-0.897
Imports	0.249	-0.196	-0.323	-1.743
Foreign Debt	-0.097	-1.664	-4.989	-8.498
Trade Deficit	-1.879	-4.857	-8.179	-4.206
Public Debt	0.154	-0.124	-1.306	-4.846
VAT/ITC (50-50)				
GDP	0.220	0.390	0.788	0.021
Consumption	0.271	0.177	0.388	-0.650
Gross Fixed Capital Formation	-0.301	1.956	2.263	6.216
Exports	0.521	0.460	1.322	-1.162
Imports	-0.049	-0.301	-0.614	-1.325
Foreign Debt	-0.267	-1.492	-4.177	-6.755
Trade Deficit	-2.305	-3.114	-6.782	-1.796
Public Debt	0.092	-0.631	-2.668	-8.334
PIT/ITC (50-50)				
GDP	0.253	0.467	0.917	0.203
Consumption	0.257	0.207	0.433	-0.482
Gross Fixed Capital Formation	-0.077	2.236	2.689	6.502
Exports	0.529	0.477	1.395	-1.139
Imports	-0.018	-0.252	-0.531	-1.187
Foreign Debt	-0.239	-1.415	-4.069	-6.597
Trade Deficit	-2.181	-2.945	-6.669	-1.325
Public Debt	0.281	0.149	-1.627	-5.343

Table 7.7 Environmental tax reform: Industry Effects – Output

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.055	-0.976	-1.621	-4.284
A1. Petroleum Refining	-0.351	-4.528	-7.214	-17.946
A2. Electricity Production	0.007	-0.991	-1.535	-4.840
A3. Biomass	0.320	1.207	2.153	3.472
A4. Agriculture	-0.059	-0.854	-1.501	-4.039
A5. Equipment Manufacturing	-0.501	-2.776	-5.051	-10.177
A6. Construction	0.122	-0.465	-0.747	-2.848
A7. Transportation	-0.115	-2.567	-4.027	-10.914
A8. Textiles	-0.091	-1.106	-1.949	-5.078
A9. Wood, pulp and paper	-0.225	-1.771	-3.103	-7.148
A10. Chemicals and pharmaceuticals	-0.155	-2.081	-3.409	-8.684
A11. Rubber, plastic and ceramics	-0.289	-3.055	-5.011	-12.035
A12. Primary metals	-0.319	-2.184	-3.872	-8.466
A13. Other	-0.012	-0.477	-0.848	-2.461
PIT/CIT (50-50)				
Total	0.520	0.758	1.378	0.039
A1. Petroleum Refining	-0.364	-4.429	-7.157	-17.741
A2. Electricity Production	0.416	0.380	0.765	-1.451
A3. Biomass	0.216	1.085	2.149	3.979
A4. Agriculture	0.471	0.933	1.659	0.742
A5. Equipment Manufacturing	1.298	2.964	5.233	4.141
A6. Construction	1.505	2.161	3.476	2.215
A7. Transportation	0.399	-0.927	-1.263	-7.283
A8. Textiles	0.524	1.135	2.131	1.079
A9. Wood, pulp and paper	0.896	1.809	3.227	1.755
A10. Chemicals and pharmaceuticals	0.584	0.366	0.876	-2.798
A11. Rubber, plastic and ceramics	0.913	0.435	0.949	-4.251
A12. Primary metals	1.053	2.106	3.703	2.027
A13. Other	0.379	0.807	1.415	1.016
VAT/ITC (50-50)				
Total	0.220	0.390	0.788	0.021
A1. Petroleum Refining	-0.302	-4.134	-6.836	-16.949
A2. Electricity Production	0.355	0.093	0.338	-2.167
A3. Biomass	-0.012	0.350	0.996	2.417
A4. Agriculture	0.297	0.485	1.043	0.206
A5. Equipment Manufacturing	0.798	2.190	4.249	4.681
A6. Construction	-0.204	1.656	1.984	5.062
A7. Transportation	0.211	-1.451	-1.948	-8.009
A8. Textiles	0.484	0.721	1.589	0.466
A9. Wood, pulp and paper	0.596	1.211	2.400	1.542
A10. Chemicals and pharmaceuticals	0.452	-0.047	0.332	-3.100
A11. Rubber, plastic and ceramics	0.414	-0.135	0.082	-3.960
A12. Primary metals	0.628	1.448	2.827	2.252
A13. Other	0.196	0.486	0.933	0.767

PIT/ITC (50-50)				
Total	0.253	0.467	0.917	0.203
A1. Petroleum Refining	-0.393	-4.498	-7.235	-17.791
A2. Electricity Production	0.379	0.195	0.484	-1.869
A3. Biomass	0.115	0.795	1.734	3.650
A4. Agriculture	0.329	0.610	1.231	0.553
A5. Equipment Manufacturing	0.816	2.201	4.309	4.626
A6. Construction	-0.017	1.898	2.349	5.318
A7. Transportation	0.267	-1.238	-1.650	-7.452
A8. Textiles	0.462	0.681	1.569	0.421
A9. Wood, pulp and paper	0.610	1.240	2.478	1.590
A10. Chemicals and pharmaceuticals	0.442	-0.074	0.340	-3.150
A11. Rubber, plastic and ceramics	0.455	-0.066	0.213	-3.859
A12. Primary metals	0.653	1.488	2.919	2.282
A13. Other	0.220	0.564	1.057	0.978

Table 7.7 Environmental tax reform: Industry Effects – Investment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	0.155	-0.434	-0.691	-2.890
A1. Petroleum Refining	-5.723	-8.875	-12.759	-16.136
A2. Electricity Production	3.011	3.941	5.853	4.565
A3. Biomass	4.163	5.341	7.830	6.238
A4. Agriculture	-0.472	-1.576	-2.609	-5.617
A5. Equipment Manufacturing	-7.692	-12.823	-18.459	-23.090
A6. Construction	0.539	-0.127	-0.565	-2.310
A7. Transportation	2.371	2.993	4.578	2.562
A8. Textiles	-0.915	-2.279	-3.736	-7.072
A9. Wood, pulp and paper	-3.233	-5.759	-8.507	-12.187
A10. Chemicals and pharmaceuticals	-0.856	-2.029	-3.052	-6.181
A11. Rubber, plastic and ceramics	-3.634	-6.216	-8.926	-12.173
A12. Primary metals	-4.474	-7.656	-11.173	-14.875
A13. Other	0.209	-0.355	-0.593	-2.715
PIT/CIT (50-50)				
Total	1.767	2.520	4.061	2.752
A1. Petroleum Refining	-7.890	-10.578	-13.520	-16.394
A2. Electricity Production	1.081	2.240	4.863	4.066
A3. Biomass	0.279	1.668	5.091	3.988
A4. Agriculture	3.016	4.308	6.173	5.115
A5. Equipment Manufacturing	8.970	11.551	12.643	11.106
A6. Construction	6.074	6.875	7.663	4.715
A7. Transportation	4.042	6.291	9.849	9.356
A8. Textiles	2.647	3.954	5.725	4.920
A9. Wood, pulp and paper	4.642	6.075	7.310	6.125
A10. Chemicals and pharmaceuticals	3.726	5.242	7.216	6.335
A11. Rubber, plastic and ceramics	4.121	5.032	5.602	3.928
A12. Primary metals	5.701	7.062	7.711	6.041
A13. Other	1.171	1.769	3.228	1.937

VAT/ITC (50-50)				
Total	0.220	0.390	0.788	0.021
A1. Petroleum Refining	-0.302	-4.134	-6.836	-16.949
A2. Electricity Production	0.355	0.093	0.338	-2.167
A3. Biomass	-0.012	0.350	0.996	2.417
A4. Agriculture	0.297	0.485	1.043	0.206
A5. Equipment Manufacturing	0.798	2.190	4.249	4.681
A6. Construction	-0.204	1.656	1.984	5.062
A7. Transportation	0.211	-1.451	-1.948	-8.009
A8. Textiles	0.484	0.721	1.589	0.466
A9. Wood, pulp and paper	0.596	1.211	2.400	1.542
A10. Chemicals and pharmaceuticals	0.452	-0.047	0.332	-3.100
A11. Rubber, plastic and ceramics	0.414	-0.135	0.082	-3.960
A12. Primary metals	0.628	1.448	2.827	2.252
A13. Other	0.196	0.486	0.933	0.767
PIT/ITC (50-50)				
Total	-0.077	2.236	2.689	6.502
A1. Petroleum Refining	-10.020	-10.976	-15.019	-12.338
A2. Electricity Production	-0.071	0.528	2.731	1.878
A3. Biomass	-1.494	1.263	3.195	7.444
A4. Agriculture	0.559	3.640	4.553	10.106
A5. Equipment Manufacturing	5.202	11.039	13.266	22.857
A6. Construction	3.258	7.366	9.974	13.326
A7. Transportation	1.606	5.595	8.209	14.211
A8. Textiles	0.111	3.034	3.499	9.719
A9. Wood, pulp and paper	1.594	5.239	6.054	12.877
A10. Chemicals and pharmaceuticals	1.037	4.472	5.736	12.075
A11. Rubber, plastic and ceramics	1.038	4.492	5.103	11.270
A12. Primary metals	2.404	6.494	7.524	14.607
A13. Other	-0.490	1.617	1.688	5.390

Environmental tax reform can contribute to an improvement in the terms of trade and an increase in the competitiveness of domestic industry, leading to a reduction in the trade deficit and foreign debt. Foreign debt increases by 5.3% with the tax on carbon. In contrast, the environmental tax reforms contribute towards a 8.5% reduction in foreign debt with the PIT/CIT policy, 6.8% reduction in foreign debt with the VAT/ITC policy and a 6.6% reduction in foreign debt with the PIT/ITC policy. These increases in foreign indebtedness in the simple decarbonization policy accompany a deterioration in the trade deficit of 13.2% relative to the reference scenario. The improvements in the foreign account associated with the tax reforms are accompanied by a 4.2% reduction in the trade deficit for the PIT/CIT policy, a 1.8% reduction in the trade deficit for the VAT/ITC policy and 1.3% with the PIT/ITC policy. Although both exports and imports decline in the long run both the non-recycling and recycling cases, the

Table 7.8 Environmental tax reform: Industry Effects – Employment

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
Total	-0.015	-0.458	-0.755	-2.065
A1. Petroleum Refining	-0.325	-4.223	-6.704	-16.724
A2. Electricity Production	0.014	-0.087	-0.038	-0.231
A3. Biomass	0.185	1.190	1.999	4.282
A4. Agriculture	-0.028	-0.423	-0.731	-1.981
A5. Equipment Manufacturing	-0.460	-2.510	-4.561	-9.101
A6. Construction	0.172	-0.118	-0.115	-1.301
A7. Transportation	-0.080	-1.785	-2.731	-7.254
A8. Textiles	-0.071	-0.790	-1.390	-3.600
A9. Wood, pulp and paper	-0.171	-1.337	-2.319	-5.297
A10. Chemicals and pharmaceuticals	-0.133	-1.673	-2.703	-6.780
A11. Rubber, plastic and ceramics	-0.236	-2.483	-4.031	-9.607
A12. Primary metals	-0.284	-1.897	-3.359	-7.246
A13. Other	-0.003	-0.251	-0.436	-1.295
PIT/CIT (50-50)				
Total	0.388	0.634	0.999	0.530
A1. Petroleum Refining	-0.414	-4.374	-7.108	-17.113
A2. Electricity Production	0.024	0.018	-0.107	-0.130
A3. Biomass	-0.162	0.475	0.797	3.250
A4. Agriculture	0.289	0.617	0.955	0.738
A5. Equipment Manufacturing	1.241	2.816	4.904	4.067
A6. Construction	1.546	2.046	3.166	2.316
A7. Transportation	0.262	-0.724	-1.056	-5.058
A8. Textiles	0.362	0.846	1.507	0.940
A9. Wood, pulp and paper	0.747	1.521	2.620	1.673
A10. Chemicals and pharmaceuticals	0.441	0.184	0.428	-2.452
A11. Rubber, plastic and ceramics	0.823	0.480	0.927	-3.132
A12. Primary metals	0.982	1.975	3.403	2.127
A13. Other	0.250	0.519	0.796	0.713
VAT/ITC (50-50)				
Total	0.220	0.390	0.788	0.021
A1. Petroleum Refining	-0.302	-4.134	-6.836	-16.949
A2. Electricity Production	0.355	0.093	0.338	-2.167
A3. Biomass	-0.012	0.350	0.996	2.417
A4. Agriculture	0.297	0.485	1.043	0.206
A5. Equipment Manufacturing	0.798	2.190	4.249	4.681
A6. Construction	-0.204	1.656	1.984	5.062
A7. Transportation	0.211	-1.451	-1.948	-8.009
A8. Textiles	0.484	0.721	1.589	0.466
A9. Wood, pulp and paper	0.596	1.211	2.400	1.542
A10. Chemicals and pharmaceuticals	0.452	-0.047	0.332	-3.100
A11. Rubber, plastic and ceramics	0.414	-0.135	0.082	-3.960
A12. Primary metals	0.628	1.448	2.827	2.252
A13. Other	0.196	0.486	0.933	0.767

PIT/ITC (50-50)				
Total	0.133	0.501	0.711	0.901
A1. Petroleum Refining	-0.435	-4.394	-7.129	-17.106
A2. Electricity Production	0.018	0.020	-0.120	-0.191
A3. Biomass	-0.120	0.365	0.693	2.963
A4. Agriculture	0.196	0.484	0.762	0.738
A5. Equipment Manufacturing	0.733	2.137	4.046	4.717
A6. Construction	-0.228	1.930	1.962	6.060
A7. Transportation	0.154	-0.908	-1.296	-5.096
A8. Textiles	0.360	0.543	1.153	0.401
A9. Wood, pulp and paper	0.475	1.094	2.030	1.687
A10. Chemicals and pharmaceuticals	0.330	-0.107	0.074	-2.639
A11. Rubber, plastic and ceramics	0.357	0.089	0.295	-2.560
A12. Primary metals	0.567	1.448	2.701	2.541
A13. Other	0.124	0.424	0.619	0.841

change in imports is of a larger absolute magnitude in the recycling cases, thereby effecting a greater reduction in the trade deficit.

Exports decline by 9.2% with the tax on carbon, 0.9% with the PIT/CIT policy, 1.2% with the VAT/ITC policy and 1.1% with the PIT/ITC policy. For each policy, the reduction in exports is driven by lower exports of refined energy products, transportation services, chemicals and rubber. Exports of electricity are also lower over the long-run.

Finally, **environmental tax reform can contribute towards fiscal consolidation efforts.** The tax on carbon contributes towards a 12.6% reduction in the public debt to GDP ratio relative to the reference scenario. The fiscal reforms we consider produce more modest improvements in the public sector budgetary position, those these effects are notably positive. The environmental tax reform policies can reduce public debt by 8.2% for the PIT/CIT policy, 4.8% for the VAT/ITC policy and 5.3% for the PIT/ITC policy. These policies are each revenue neutral by design with the effects on public debt determined by second order effects on the tax bases for the Portuguese economy.

7.4 Household Effects

Environmental tax reform alleviates some of the pressure on electricity prices associated with carbon and energy pricing policies and allows for electrification and decarbonization of the Portuguese economy to yield less regressive outcomes through both income and price channels. The negative welfare effects of the simple decarbonization policy, measured by the equivalent variation in income associated with the policy, are largely eliminated in the PIT/CIT tax reform and greatly mitigated with the VAT/ITC policy and the PIT/ITC policy. In fact, the PIT/ITC can be designed to produce positive outcomes for low-income households. For both policies involved targeted reductions to the

Table 7.8 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

	GDP		Consumption		Investment		Employment		Public debt		Foreign debt	
	2030	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Carbon Tax	-0.98	-4.28	-0.41	-2.37	-0.44	-2.89	-0.46	-2.07	-1.44	-12.58	0.79	5.32
PIT – CIT (50/50)	0.76	0.04	0.29	0.09	2.52	2.75	0.63	0.53	-0.12	-8.18	-1.66	-8.50
VAT – ITC (50/50)	0.39	0.02	0.18	-0.65	1.96	6.22	0.40	0.64	0.22	-4.77	-1.49	-6.75
PIT – ITC (50/50)	0.47	0.20	0.21	-0.48	2.24	-0.48	0.50	0.90	0.45	-5.34	-1.42	-6.60

Table 7.9 Environmental tax reform: Distributional Effects on Households – Employment

(Percent change relative to the reference scenario)

	2020	**2030**	**2040**	**2050**
Carbon tax				
First Quintile (Lowest Income)	-0.009	-0.219	-0.365	-1.005
Second Quintile	-0.013	-0.354	-0.593	-1.645
Third Quintile	-0.016	-0.467	-0.776	-2.130
Fourth Quintile	-0.015	-0.471	-0.778	-2.129
Fifth Quintile (Highest Income)	-0.016	-0.515	-0.846	-2.302
PIT/CIT (50-50)				
First Quintile (Lowest Income)	0.170	0.281	0.426	0.176
Second Quintile	0.298	0.512	0.784	0.451
Third Quintile	0.390	0.649	1.021	0.560
Fourth Quintile	0.404	0.666	1.050	0.591
Fifth Quintile (Highest Income)	0.439	0.696	1.115	0.551
VAT/ITC (50-50)				
First Quintile (Lowest Income)	0.055	0.148	0.220	0.106
Second Quintile	0.074	0.274	0.398	0.353
Third Quintile	0.093	0.384	0.555	0.588
Fourth Quintile	0.091	0.416	0.591	0.702
Fifth Quintile (Highest Income)	0.099	0.469	0.661	0.819
PIT/ITC (50-50)				
First Quintile (Lowest Income)	0.077	0.213	0.305	0.274
Second Quintile	0.118	0.405	0.568	0.691
Third Quintile	0.140	0.513	0.731	0.916
Fourth Quintile	0.138	0.531	0.751	0.988
Fifth Quintile (Highest Income)	0.139	0.549	0.784	1.003

Table 7.10 Environmental tax reform Distributional: Effects on Households – After-Tax Income
(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.004	-0.134	-0.200	-0.539
Second Quintile	-0.013	-0.385	-0.590	-1.583
Third Quintile	-0.019	-0.550	-0.846	-2.261
Fourth Quintile	-0.023	-0.625	-0.966	-2.573
Fifth Quintile (Highest Income)	-0.024	-0.660	-1.019	-2.706
PIT/CIT (50-50)				
First Quintile (Lowest Income)	0.243	0.872	1.129	2.651
Second Quintile	0.375	1.043	1.507	2.966
Third Quintile	0.448	1.085	1.681	2.971
Fourth Quintile	0.465	1.039	1.679	2.740
Fifth Quintile (Highest Income)	0.458	0.970	1.628	2.557
VAT/ITC (50-50)				
First Quintile (Lowest Income)	0.055	0.148	0.220	0.106
Second Quintile	0.074	0.274	0.398	0.353
Third Quintile	0.093	0.384	0.555	0.588
Fourth Quintile	0.091	0.416	0.591	0.702
Fifth Quintile (Highest Income)	0.099	0.469	0.661	0.819
PIT/ITC (50-50)				
First Quintile (Lowest Income)	0.200	0.879	1.100	2.744
Second Quintile	0.240	1.025	1.385	3.212
Third Quintile	0.247	1.048	1.492	3.323
Fourth Quintile	0.239	0.986	1.457	3.117
Fifth Quintile (Highest Income)	0.223	0.915	1.397	2.946

personal income tax, the **environmental tax reform yields progressive policy outcomes** reversing the regressive pattern observed for the tax on carbon.

The increase in consumer prices is smaller with the environmental tax reform policies than with the simple decarbonization policies. As a result, the reduction in real incomes and employment is clearly smaller for these environmental tax reforms than in the simple decarbonization policies. As with the decarbonization policies, we observe that the relative change in employment increases with income. Thus, increases in employment tend to be concentrated among those households that are more responsive to relative wage and price changes. These results highlight a larger positive effect on employment among higher income households. These effects are largely mirrored in the after-tax income of households although the adjustments to the personal income tax rates coupled with the greater importance of capital

Table 7.11 Environmental tax reform: Distributional Effects on Households – Consumer Prices

(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	0.044	0.837	1.459	4.290
Second Quintile	0.046	0.858	1.498	4.393
Third Quintile	0.045	0.820	1.434	4.207
Fourth Quintile	0.042	0.766	1.343	3.945
Fifth Quintile (Highest Income)	0.039	0.709	1.246	3.658
PIT/CIT (50-50)				
First Quintile (Lowest Income)	-0.282	-0.229	-0.562	1.295
Second Quintile	-0.276	-0.201	-0.513	1.407
Third Quintile	-0.268	-0.214	-0.533	1.286
Fourth Quintile	-0.261	-0.242	-0.577	1.095
Fifth Quintile (Highest Income)	-0.251	-0.261	-0.607	0.915
VAT/ITC (50-50)				
First Quintile (Lowest Income)	0.055	0.148	0.220	0.106
Second Quintile	0.074	0.274	0.398	0.353
Third Quintile	0.093	0.384	0.555	0.588
Fourth Quintile	0.091	0.416	0.591	0.702
Fifth Quintile (Highest Income)	0.099	0.469	0.661	0.819
PIT/ITC (50-50)				
First Quintile (Lowest Income)	-0.234	-0.040	-0.325	1.512
Second Quintile	-0.228	-0.010	-0.274	1.623
Third Quintile	-0.221	-0.024	-0.296	1.501
Fourth Quintile	-0.214	-0.050	-0.340	1.309
Fifth Quintile (Highest Income)	-0.203	-0.070	-0.370	1.125

income among higher income households leads generally to a more progressive outcome with respect to income, particularly among those households in the highest income brackets.

7.5 Environmental Tax Reform: Concluding Remarks

We conclude that the case of 50/50 mixed personal income tax and investment tax credit dominates the other two 50/50 mixed cases along the relevant fronts. Energy market effects and emissions reductions are more pronounced than under the other two mixed cases and more pronounced than with the carbon tax alone. Output and employment effects are also clearly better. Finally, welfare effects are clearly progressive and with magnitudes between the other two mixed cases.

Table 7.12 Environmental tax reform: Distributional Effects on Households – Equivalent Variation
(Percent change relative to the reference scenario)

	2020	2030	2040	2050
Carbon tax				
First Quintile (Lowest Income)	-0.039	-0.682	-1.187	-3.427
Second Quintile	-0.038	-0.582	-1.037	-3.046
Third Quintile	-0.033	-0.440	-0.822	-2.511
Fourth Quintile	-0.031	-0.381	-0.732	-2.275
Fifth Quintile (Highest Income)	-0.027	-0.278	-0.567	-1.836
PIT/CIT (50-50)				
First Quintile (Lowest Income)	0.332	0.802	1.144	0.842
Second Quintile	0.201	0.548	0.752	0.416
Third Quintile	0.075	0.317	0.434	0.116
Fourth Quintile	0.027	0.217	0.330	-0.034
Fifth Quintile (Highest Income)	-0.048	0.085	0.163	-0.144
VAT/ITC (50-50)				
First Quintile (Lowest Income)	0.321	0.383	0.658	-0.399
Second Quintile	0.300	0.248	0.462	-0.700
Third Quintile	0.274	0.159	0.348	-0.777
Fourth Quintile	0.267	0.155	0.365	-0.680
Fifth Quintile (Highest Income)	0.246	0.118	0.325	-0.610
PIT/ITC (50-50)				
First Quintile (Lowest Income)	0.376	0.665	1.013	0.494
Second Quintile	0.330	0.446	0.707	-0.064
Third Quintile	0.273	0.241	0.454	-0.459
Fourth Quintile	0.241	0.138	0.355	-0.641
Fifth Quintile (Highest Income)	0.198	0.019	0.218	-0.793

8 Summary and Concluding Remarks

The report focuses on the environmental, economic, and distribution effects of carbon taxation and carbon tax revenue recycling policies in Portugal. Decarbonization of the Portuguese economy will necessarily be based on an increasing electrification of energy demand and the production of electricity from renewable energy resources. These policies can decisively contribute towards the decarbonization of the Portuguese economy and an increase in the use of renewable energy resources in the production of electric power while at the same time generating virtuous economic and distributional outcomes.

8.1 Summary

The analysis of the role of the electricity in the decarbonization of the Portuguese economy is based on a soft-link between the energy technology systems model TIMES_PT and the dynamic multi-sector general equilibrium model of the Portuguese economy, DGEP. The two models bring together two complementary approaches to energy and climate policy analysis, an energy systems approach and an economic approach, providing a comprehensive view of the issues at stake.

The reference scenario was defined as a pathway for the energy sector and the economy that explicitly considers the energy and climate policy targets for 2020 and extended through 2050 with the objective of identifying the role of electricity in the energy system given the expected evolution of the costs and characteristics of the various energy technologies absent further policy objectives.

The energy system and economic models were integrated using a harmonization process designed to ensure that modeling approach provides a complementary and coherent analysis of the energy, environmental, macroeconomic, budgetary and distributional effects of electrification and decarbonization policies in Portugal. The soft-link between the energy technology systems model and the dynamic multi-sector general equilibrium model of the Portuguese economy process is depicted in Figure 2 and is based on key indicators for the energy system: carbon dioxide emissions, final demand for electricity, and share of renewables in the electricity production. The endogenously generated trajectories for these key energy system indicators in 2020, 2030, 2040 and 2050 iterated under the reference scenario until the difference in the model reference scenario converged to within 10% for each time period under consideration. In addition, selected energy drivers generated by TIMES_PT model were adopted by the DGEP model (e.g. energy efficiency), while economic drivers generated by DGEP were used by the TIMES_PT model (e.g. household private consumption, GDP.

The reference scenario adopted by the TIMES_PT and the DGEP models — the starting point for the analysis of the macroeconomic effects of decarbonization policies — incorporates sizable reduction in CO_2 emissions and advances in electrification and the use of renewable energy sources relative to a business as usual scenario. More importantly, the TIMES_PT model provides a wide variety of cost-effective strategies for reducing CO_2 emissions in 2050 by 60% relative to 1990 levels. The shadow price of the emissions constraint defined in the TIMES_PT model for the CO_2-60% scenario provides the marginal cost of emissions abatement and is implemented as a tax on carbon dioxide emissions to assess the macro-economic impact of decarbonization policies for the Portuguese economy. The emissions constraint suggests that the tax on CO_2 emissions will need to increase from its current level of 5€/tCO_2 to 33€/tCO_2 in 2030, 49€/tCO_2 in 2040 and 183 €/tCO_2 in 2050.

We start from the reference scenario to define a whole array of counterfactual scenarios divided in two groups. First, we consider decarbonization policies based on a tax on carbon, a broader-based energy tax and an increase in the value added tax on private consumption. Second, we consider carbon taxation in the context of a broader environmental tax reform policies with revenues from the tax on carbon recycled by a reduction in distortionary tax margins and together with credits and incentives for energy efficiency improvements. All counterfactual results are presented as percentage deviations from the reference scenario. All results reported here refer to long-term effects in 2050.

Comparisons among the different decarbonization policies based on carbon taxes, energy taxes and consumption taxes are possible and are based on the design of these policy instruments to raise the same level of revenue for the public sector and the use of these revenues to reduce the public deficit. To have a sense of the magnitude of these policies, given the marginal cost implied by the TIMES_PT model, these pricing policies would generate revenues for the public sector equal to approximately 0.1% of 2015 GDP in 2020; 1% in 2030, 1.1% in 2040 and 2.5% in 2050.

To benchmark our results, we now focus on the most direct economic counterpart to the TIMES_PT decarbonization policies in defining the marginal costs of emissions reductions as a tax on CO_2 emissions.

A carbon tax designed to meet the 60% reduction in emissions in 2050 with revenues reverting to the public budget would lead to adverse economic effects in terms of GDP, private consumption and investment and a deterioration of the trade balance. In addition, the labor market effects of this policy would be negative. A tax on carbon dioxide emissions would be regressive and thereby produce undesirable distributional effects. The welfare effects of the tax on carbon are larger for lower income households than for higher income households which raises concerns about social justice emerging from these policies. These negative distributional effects are driven by labor supply responses, lower after-tax incomes and higher consumer prices. The carbon tax would significantly improve the public budgetary situation. This is to be expected because the proceeds from the tax are directed towards the public account by design.

A tax on CO_2 emissions would lead to adverse effects on macro-economic performance in terms of GDP (-4.28%), private consumption (-2.37%) and investment, reductions (-2.89%), as well as a deterioration of the trade balance and a 5.32% increase in foreign debt. The tax would similarly produce adverse labor market effects and reduce employment by 2.07% relative to the reference scenario in 2050. Naturally, and by design, **the tax on carbon would contribute to significant improvements in the public budgetary situation**, allowing for a 12.58% reduction in the public debt to GDP ratio in the long run. This is to be expected because the carbon tax revenues are allocated to general budgetary purposes by design.

A tax on CO_2 emissions would also lead to adverse distributional effects and is regressive in nature. Indeed, the equivalent variation in income to the tax on carbon is substantially larger for lower income households than for wealthier households which raises social justify concerns. These larger welfare effects stem from labor supply responses, lower after-tax incomes and higher consumer prices which impose a substantially larger burden on lower-income households. Households in the lowest income quintile are expected to see a 3.34% reduction in welfare with the tax on carbon while the loss in income for those in the highest income quintile is substantially less –a 1.84% reduction in welfare.

The tax is effective in reducing CO_2 emissions and allows for a substantial reduction in emissions. The underlying economic mechanisms, however, suggest a more conservative reduction in emissions than that implied by the TIMES_PT model. The more limited efficacy of the tax in the context of the economic system stems from a greater reliance on output reductions to reduce emissions relative to changes to process and activities given the substitution possibilities for carbon intensive goods and services for both households and firms and the electrification options that are technological feasible within the scope of the TIMES_PT model.

The economic mechanisms underlying decarbonization strategies imply a somewhat less environmentally effective policy in reducing emissions. The more limited substation possibilities coupled with more substantial demand responses suggest that behavioral responses may limit the overall effectiveness of policies to reduce emissions and suggest greater marginal costs of control. Total energy demand decreases by 14.36%, substantially more than the 5.72% reduction in the demand for electricity which suggests some substitution towards electricity and increase in electrification of the Portuguese economy. This translates to an increase of 10.79% increase in the share of electricity in final energy demand. The higher costs for carbon increases energy system costs and reduces the resources available for expenditure on other goods, services and inputs to production. This lowers demand while simultaneously encouraging substitution towards lower carbon energy vectors and inputs. These scale and substitution effects provide the incentives and mechanisms for households and firms to respond to higher prices for carbon. This is reflected also in a relative shift in production towards labor and capital inputs and within the energy sector to fuels with a lower carbon content and to renewable energies. The production of electricity from renewable sources increases by 9.10%. Overall, the economic mechanisms behind the reductions in emissions suggest a greater reliance on output reductions due to more limited substitution possibilities for fossil fuels and for electrification.

Overall, the tax on carbon tax alone can produce favorable budgetary outcomes but with serious and severe costs reflected in the adverse economic and distributional implications of the decarbonization policy.

Two alternative sources of revenue to finance deficit reduction the same magnitude as the carbon tax were considered as simple decarbonization strategies: a broad tax on energy consumption and a tax on all products, an extension of the VAT. In both alternative cases, the **broader tax bases contribute towards smaller adverse macro-economic and distributional effects** although these continue to produce negative and regressive effects on economic performance. Both of these tax scenarios, but particularly the VAT lead to a much more severe pattern of regressivity.

These two alternative pricing policies lead to dramatically lower reductions in CO_2 emissions. **The carbon tax provides a direct incentive for reducing emissions that is superior to a more general tax on energy and on consumer goods as a strategy for reducing emissions**. As two alternatives to a simple tax on carbon we consider an increase in the tax on energy products and the value added tax that generates the same level of revenue. The additional tax revenues is allocated to the general public sector account. In both alternative cases, the economic effects are substantially smaller although the smaller economic effects are just a reflection of a much less effective policy in reducing emissions. Clearly, a carbon tax, being a much more focused instrument, is much more effective in curtailing emissions.

The adverse macro-economic and distributional effects of the tax on CO_2 emissions motivate the need to consider a more comprehensive environmental tax reform that has the potential to reduce emissions, promote economic growth and job creation and address public sector budgetary concerns.

The negative economic and distributional effects of the tax on carbon motivate the need to search for tax reforms that can address the adverse effects of the policy while reaching environmental objectives. The proceeds from the carbon tax open up the possibility of a more comprehensive tax reform in which the revenues generated can be carefully allocated to reducing distortions at the major tax margins of the Portuguese tax system, in isolation and together with energy efficiency objectives. Reductions to the personal income tax (PIT) can be designed to promote progressive policy outcomes. Reform to the value added tax (VAT) can also be used to address the adverse distributional effects of the carbon tax. Reductions to the corporate income tax (CIT) and financing for an investment tax credit (ITC) margins are particularly effective in reducing the adverse economic effects of the policy.

Table 8.1 Long Run [2050] Environmental Effects

(Percent change relative to the reference scenario)

	Energy Demand	Electricity Demand	Electricity Share	RES	CO_2 Emissions
Carbon Tax	-14.36	-5.72	10.79	9.10	-24.32
Energy Tax	-7.58	-4.51	3.64	1.79	-9.42
Value Added Tax	-3.92	-2.51	1.32	0.61	-4.37

Table 8.2 Long Run [2050] Macroeconomic Effects

(Percent change relative to the reference scenario)

	GDP	Consumption	Investment	Employment	Public debt	Foreign debt
Carbon tax	-4.28	-2.37	-2.89	-2.07	-12.58	5.32
Energy tax	-2.28	-1.11	-1.64	-1.08	-4.85	2.96
Value Added Tax	-2.36	-0.67	-3.17	-1.30	-8.33	2.98

Table 8.3 Long Run [2050] Distributional Effects: Equivalent Variation in Income

(Percent change relative to the reference scenario)

	Carbon Tax	Energy Tax	Value Added Tax
First quintile (lowest income)	-3.34	-1.66	-1.26
Second quintile	-3.05	-1.41	-0.92
Third quintile	-2.51	-1.15	-0.64
Fourth quintile	-2.28	-1.06	-0.61
Fifth quintile (highest income)	-1.84	-0.87	-0.49

Comprehensive environmental tax reform provides for a politically feasible mechanism to address environmental, economic, industry and social concerns associated with decarbonization policies and promote positive and progressive economic outcomes. Environmental tax reform is made possible through the proceeds generated by the tax on CO_2 emissions. These revenues can be used to finance reductions in the personal income tax (PIT), corporate income tax (CIT), value added taxes (VAT) and to finance investment tax credits (ITC) for private capital, renewable energy, and for energy efficient equipment.

We now focus on the tax on carbon, in the context of a broader fiscal reform in which the revenues generated are judiciously allocated to reducing distortions at the other major tax margins of the

Portuguese tax system, in isolation and together with incentives for the purchase of energy efficient equipment and technologies, including selected reduction in the VAT and personal income tax credits for energy efficiency appliances as well as corporate income tax deductions and investment tax credits for the purchase of energy efficiency equipment and technologies.

We start by considering policy options in which the revenues from the tax are used to reduce individual tax margins with and without incentives for energy efficiency improvements. Progressive changes to the personal income taxes can always produce progressive distributional effects for the decarbonization policies. Generally, the use of carbon tax revenues to reduce the personal income tax rate and VAT rates are particularly effective in reducing the adverse distributional effects of the carbon tax. In turn, reductions to the corporate income tax and financing for private investment tax credits are particularly effective in reducing the adverse economic effects and can, in some instances, encourage economic growth and job creation.

The effects of the reducing taxes at the different margins suggests that multiple policy objectives may be achievable with a environmental tax reform based on mixed recycling strategies. We first consider a direct tax channel: a combination of reductions in the PIT and the CIT tax margins; we then consider an indirect tax channel, a combination of reductions in the VAT and increases in the ITC; finally, we consider a combination of reductions in the PIT and increases in the ITC. In all cases, we consider a detailed grid of alternatives for the share of CO_2 tax revenues allocated to reductions in each tax margin to determine the most desirable outcome with respect to economic performance and distributional considerations. In each case, we consider the use of part of the revenues generated to provide PIT and CIT credits, VAT rate reductions and increases in the ITC for the purchase of energy efficient technologies.

A balanced 50/50 mixed revenue recycling policy yield all of the desirable results: economic growth and job creation, progressive distributional outcomes, and a reduction in CO_2 emissions. We conclude that a balanced 50/50 mixed direct channel strategy of personal income tax and corporate income tax reductions, a balanced 50/50 mixed indirect channel of reductions to the value added tax and financing for investment tax credits and a balanced 50/50 mixed of reductions to the personal income tax and financing for investment tax credits can each yields all of the desirable policy outcomes: reductions in GHG emissions, positive macro-economic effects, progressive distributional effects, reductions to the public sector debt, and positive effects on international competitiveness.

First**, environmental tax reform is effective in reducing CO_2 emissions**. Overall, these policies tend to be more effective when part of the reduction in the PIT and the VAT are specific to energy efficiency improvements. Carbon pricing policies with revenues used to reduce the rate of direct income taxation have the technical capacity to reduce CO_2 emissions by 25.13% in 2050 relative to the

Table 8.4 Long Run Environmental Effects

(Percent change relative to the reference scenario)

	Energy Demand		Electricity Demand		Electricity Share		RES		CO_2 Emissions	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Carbon tax	-3.55	-14.36	-1.15	-5.72	2.74	10.79	2.29	9.10	-5.04	-24.32
PIT – CIT (50/50)	-2.95	-12.83	0.58	-1.45	4.03	14.28	2.27	9.64	-5.31	-25.13
VAT – ITC (50/50)	-2.92	-12.74	0.17	-2.17	3.61	13.04	1.99	9.17	-5.10	-24.42
PIT – ITC (50/50)	-3.09	-13.08	0.33	-1.93	3.83	13.91	2.02	9.18	-5.34	-25.11

Table 8.5 Long Run Macroeconomic Effects

(Percent change relative to the reference scenario)

	GDP		Consumption		Investment		Employment		Public debt		Foreign debt	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Carbon Tax	-0.98	-4.28	-0.41	-2.37	-0.44	-2.89	-0.46	-2.07	-1.44	-12.58	0.79	5.32
PIT – CIT (50/50)	0.76	0.04	0.29	0.09	2.52	2.75	0.63	0.53	-0.12	-8.18	-1.66	-8.50
VAT – ITC (50/50)	0.39	0.02	0.18	-0.65	1.96	6.22	0.40	0.64	0.22	-4.77	-1.49	-6.75
PIT – ITC (50/50)	0.47	0.20	0.21	-0.48	2.24	-0.48	0.50	0.90	0.45	-5.34	-1.42	-6.60

Table 8.6 Long Run Distributional Effects – Equivalent Variation

(Percent change relative to the reference scenario)

	Carbon Tax		PIT – CIT (50/50)		VAT – ITC (50/50)		PIT – ITC (50/50)	
	2030	2050	2030	2050	2030	2050	2030	2050
First quintile (lowest income)	-0.68	-3.34	0.80	0.84	0.38	-0.40	0.67	0.49
Second quintile	-0.58	-3.05	0.55	0.42	0.25	-0.70	0.45	-0.06
Third quintile	-0.44	-2.51	0.32	0.12	0.16	-0.78	0.24	-0.46
Fourth quintile	-0.38	-2.28	0.22	-0.03	0.15	-0.68	0.14	-0.64
Fifth quintile (highest income)	-0.28	-1.84	0.09	-0.14	0.12	-0.61	0.02	-0.79

reference scenario with provisions for income tax credits for energy efficiency improvements. Reductions to the indirect tax rates in the context of an environmental tax reform allow for a 24.42% reduction in emissions. Reductions to the personal income tax coupled with increased investment tax credits yield a 25.11% reduction. These are slightly greater than the 24.32% reduction in emissions with the tax alone suggesting an increase in the efficacy of the policy within the scope of a broader environmental tax reform due to the provisions for efficient technologies.

Second, **environmental tax reform with mixed revenue recycling strategies can promote positive economic outcomes**: GDP gains and more substantial gains in employment. Reform can promote a significant improvement of the long term foreign debt position by encouraging exports. **These policies also yield an improvement in the long-term public debt position for the public sector**, despite the revenue neutral implementation, due to expanding tax bases in response to the positive economic outcomes.

Finally, **environmental tax reform with mixed revenue recycling strategies has the potential to produce positive and progressive distributional effects**. Environmental tax reform may significantly reduce the welfare losses associated with decarbonization policies and yield positive and progressive distributional effects. With appropriate adjustments to the personal income tax rates for lower income households, environmental tax reform can allow for positive welfare effects and address existing social justice concerns.

Environmental tax reform provides a politically and economically feasible mechanisms for realistically implementing the technologically feasible options identified with the TIMES CO_2-60% scenario. They lead to the desired environmental outcomes while at the same time encouraging positive and progressive economic outcomes, contributing towards public debt reduction and promoting the international competitiveness of the Portuguese economy. **These mixed recycling strategies provide for a comprehensive package of policy instruments capable of addressing the environmental, social and economic dimensions of policy concerns facing the country and provide mechanisms for reducing CO_2 emissions by 60% relative to 1990 levels by 2050**.

8.2 Some Final Considerations on Policy Design

As we analyze the results of these simulations, there are some important economic and political economy caveats to be mentioned.

First, from an economics perspective it can easily be argued that the reference scenario adopted is in some dimensions overly optimistic. This is important because, given the highly non-linear nature of the economic modelling, a less ambitious reference scenario with respect to the penetration of renewable energy in electricity production in Portugal and with respect to the trajectory for carbon dioxide emissions through 2050 would likely contribute to less adverse economic and distributional effects of a carbon tax without necessarily affecting adversely the environmental targets. The point is that a less ambitious reference scenario would conceivably allow for marginal changes from the different policies to achieve any given environmental targets at a lower marginal cost for the economy. As a corollary, positive outcomes from recycling would even be easier to identify.

Second, the starting point from the whole exercise, the path of marginal carbon abatement costs suggested by the TIMES_PT model for the 60% reductions in CO_2 emissions in 2050 compared to the 1990 levels, which is adopted in the DGEP model, postulates an extremely rapidly increasing path for carbon pricing. This is particularly true between 2040 and 2050, when the carbon marginal abatement costs increase from 49 euros per ton to 183 euros per ton, after increasing from 5 to just 49 euros in the previous two decades. This is understandable from a technological perspective as reaching high emission reductions may ultimately lead to rather steep costs. Form an economics perspective, however, and again given the highly non-linear nature of the economic system, the rapid increase in carbon pricing in a relatively short period of time greatly increases the economic costs of the carbon policies and limits the capacity of the economy system to compensate for the adverse economic and distributional effects of the policies. From this perspective, a smoother trajectory of the carbon pricing would be desirable.

A necessary follow up on these points is the sharp differences in the economic results we observe comparing 2030 versus 2050. All of the effects of a carbon tax are rather subdued by 2030 with environmental effects to match – a mere 5.0% reduction in CO_2 emissions compared to the reference case. This being the case, invariably, the different recycling mechanisms yield much more favorable economic outcomes by 2030 than they do by 2050. All of these patterns are a direct consequence of the sharp increase in the carbon taxation towards the end of the model horizon and the highly non-linear nature of the economic modelling.

8.3 Some Final Considerations on Modelling Approaches

As final remarks, the joint implementation of the TIMES energy system model and the DGEP dynamic general equilibrium model and a careful analysis of the results for the policy simulations to meet our climate policy objectives highlights important differences between the two analytical approaches and contribute to the richness of our results.

The TIMES energy system model permits a great degree of substitution among different technological alternatives which can be adopted in a cost-effective manner without consideration of financial constraints to investment behavior and individual preferences. This decision making structure contributes towards a very optimistic view of the technologically available and feasible choices that can contribute towards a substantial reduction in emissions absent additional policy measures. In turn, the

DGEP dynamic general equilibrium model considered behavioral responses constrained by individual preferences, financial constraints and the opportunity cost associated with individual choices. A more pessimistic view of the feasible emissions reductions potential of the economy stems from substantial inertia in the system based on its behavior over the past decades and a rather dim view and consideration of new technologies that are more insipient in nature.

These differences highlight the different mechanisms in place to reduce carbon dioxide emissions. Reductions in emissions are possible through a reduction in the level of activity and through a change in the technologies employed that can contribute towards an efficient use of energy inputs or through inter-fuel substitution to reduce emissions by relying on energy sources with a smaller environmental footprint. The more limited substitution possibilities and the consideration of emissions abatement channels through output reductions in the DGEP general equilibrium model of the Portuguese economy contributes towards model results that suggest a smaller degree of emissions reductions at the costs considered than those suggested by the TIMES_PT energy system model.

From a practical perspective, the greater incentive for substitution among fuels producing an alignment of the results between the DGEP dynamic general equilibrium model and the TIMES energy system model associated with a 60% reduction in emissions relative to 1990 levels in 2050 as a climate policy objective. In this context, indicators for the energy sector with respect to emissions, electrification and electricity demand, as well as renewable energy are closely aligned with the TIMES energy system results. At the same time, there is a reduction in the environmental effectiveness of the carbon pricing, Indeed, under the same carbon pricing path postulated by the TIMES_PT model, we simulate a reduction in CO_2 emissions reductions of around 50% compared to the 1990 levels as opposed to the 60% [which result from the TIMES_PT simulations.

From this standpoint the TIMES_PT and DGEP environmental results mark the goals posts that straddle the optimist of the engineering approach which focuses on technological possibilities and ignores economic constraints and the pessimism of the economic approach which highlights economic constraints while ignoring the full length of technological possibilities. The reality will likely be in between the two.

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