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Energy Taxation Reform with an Environmental Focus (*)

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Abstract

In this paper, we address the issue of energy taxation reform with an environmental focus. We do so using a multi-sector and multi-household dynamic computable general equilibrium model of the Portuguese economy. We analyze the environmental, macroeconomic, and distributional effects of different policies allowing for energy taxation to be replaced with carbon taxation while at the same time allowing for the IPCC 2018 emissions reduction targets to be achieved. Our analysis indicates a clear path in the quest for decarbonization. First, replace energy taxes with a carbon tax; second, adopt the levels of carbon taxation necessary to achieve the emissions goals; third, use extra tax revenues from the carbon tax to reverse any potential adverse macroeconomic and distributional effects of the carbon taxation. In the process, this would be a way around the pervasive problem of perverse fossil fuel subsidies, which would effectively disappear and as such would improve the efficiency of the tax system.

JEL Classification: Energy taxes; Perverse Fossil Fuel Subsidies; CO2 Taxation; Macroeconomic Effects; Distributional Effects; Dynamic Computable General Equilibrium; Portugal.

Keywords: C68, E62, H23, Q43, Q48.

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1. Introduction

Recently, the IPCC (2018) report indicated that limiting global warming to 1.5°C would require “rapid and far-reaching” transitions in land, energy, industry, buildings, transport, and cities. Global emissions of CO2 would need to fall by about 45% from 2010 levels by 2030, reaching ‘net zero’ around 2050, and neutrality of the remaining greenhouse gases would need to be achieved soon thereafter. In turn, the European Union legislative package "Clean Energy for All Europeans" (2019) includes, among others measures, requirements for each Member State to draw up National Integrated Energy and Climate Plans, setting out the objectives, targets and contributions of each Member State by 2030.

There is a wide gap between intentions and actions when it comes to environmental policies. This is mostly due to the difficulty in getting “fossil fuel prices right”, i.e., having fossil fuel prices reflect also the environmental externalities they generate [see, for example, Parry et al. (2014), Parry (2015), Coady et al. (2018)].

In the path toward getting “fossil fuel prices right” that are of critical importance. The first is the inadequacy of current energy taxation systems to do this job due to the focus on energy content and not emissions and even more so the widespread existence of environmentally perverse fossil fuel subsidies that actually make fossil fuels even cheaper than the market mechanisms would dictate. [See, for example, Sovacool (2017), Rentschler and Bazilian (2017), Coady et al. (2017), Gelan (2018), and Monasterolo and Raberto (2019)].

The second are the mechanisms to get “fossil fuel prices right” by environmental standards, in particular, through carbon taxation. [See, for example, OECD (2011), Marron and Toder (2014), Williams (2016), and High-Level Commission on Carbon Prices (2017)]. In this context, there is strong evidence that carbon taxation without countervailing measures would lead to macroeconomic losses, loss of international competitiveness, and would have adverse distributional effects. [See, for example, Carbone and Rivers (2017), Renner et al. (2018), Zachman et al. (2018), Fremstad and Paul (2019), Pizer and Sexton (2019)]. This brings the issue of carbon tax revenue recycling to the forefront and to the notion of revenue neutral decarbonization policies. [See, for example, Carbone et al. (2014), Jorgenson (2014), Jorgenson et al, (2015), Marron and Morris (2016), Metcalf (2019), and Kirchner et al. (2019)].

In Portugal, the main energy taxation exists under the so-called ISP, a broad tax on petroleum and other energy products, which represents about 1.8% of the GDP. This tax has three main components: a basic unit tax; a road contribution component; and, an add-on based on the carbon content of the products, more on which below. For the most part, the current energy tax system is designed mostly to reflect the energy content of fuels – rather than their emissions content – and is based on the need to raise funds for the public budget. In addition, it provides a large number of exemptions and subsidies on the use of different fossil fuels in transportation, agriculture, industrial processes, electricity generation, etc. In 2018, such exemptions and subsidies amounted to 430 million euros or about 0.22% of the GDP or 12% of the ISP revenues. Accordingly, such environmentally perverse subsidies are substantial and pervasive.

In turn, in 2015 a carbon tax indexed to the carbon price in the EU-ETS was introduced as an add-on to the ISP tax. As such, this carbon tax has several serious shortcoming that make it a rather ineffective tool in desperate need of reform. In a nutshell, the existing carbon tax is hopelessly too low, it is far from universal as it inherited all of the exemptions under energy taxation in Portugal, and contemplates no recycling mechanisms which would make it rather harmful for the economy and social justice should it be of a significant magnitude.

Faced with the IPCC 2018 targets and the EU 2019 directives, Portugal, has recently approved the Roadmap for Carbon Neutrality [RNC2050, hereafter]. In the RNC2050, these different environmental and decarbonization targets are duly incorporated and specific pathways presented to achieve such targets. And yet, there is no clear guidance on how to actual proceed in the direction of decarbonization given the current state of affairs in energy taxation and carbon taxation. Indeed, the pathways towards decarbonization may be clearly formulated in the RNC2050. The specific public policy mechanisms necessary to get the country started in such pathways, however, are not. In this paper, we suggest a first strong step in the direction of decarbonization in the form of energy taxation reform.

The reality of energy and carbon taxation coupled with the need to achieve specific environmental goals, fully justifies the need in Portugal for energy taxation reform. In this research we focus on energy taxation reform with an environmental focus with the objective of getting fossil fuel prices right – allowing these prices to reflect the full costs of fossil fuel combustion activities. We analyze the effects of replacing the tax on energy products with a carbon tax directly linked to the different environmental damages associated with fossil fuel combustion. Then, we discuss how energy-environmental taxes can be structured in the context of a broader revenue neutral fiscal reform to improve economic performance in the country while at the same time achieving the international targets towards decarbonization.

This paper uses a multi-sector, multi-household dynamic computable general equilibrium model of the Portuguese. Previous versions of this model are documented in Pereira and Pereira (2014c), and were used to address several energy and climate policy issues [see Pereira and Pereira (2014a, 2014b, 2017a, 2017b, 2017c) and Pereira et al. (2016)]. The current version of the model has a detailed description of the tax system including energy taxation. It features a fine differentiation of consumer and producer goods, particularly energy products. It captures the heterogeneity in income and consumption patterns by considering five differentiated household groups.

General equilibrium models have been used extensively in energy and environmental studies. Our approach follows in the tradition of the early models developed by Borges and Goulder (1984) and Ballard et al. (2009). In its specifics, however, it is more directly linked to the recent contributions of, for example, Fullerton et al (2012), Goulder and Hafstead (2013), Bhattarai et al. (2016), Tran and Wende (2017), and Annicchiarico et al. (2017). In turn, thematically, this research is closer to Jorgenson et al. (2015), Williams (2016), Gelan (2018), Kirchner et al. (2019).

This paper is organized as follows. In Section 2, we present in very general terms the DGEP model and discuss some implementation issues. In Section 3, we highlight some of the areas that were upgraded in this version of the model with direct relevant for this research. Sections 4 present the simulation results for a simple replacement of the ISP with a CO2 tax. Section 5 does the same but includes the extra CO2 taxation necessary to achieve IPCC goals. Finally, Section 6 offers a summary of the results, policy recommendations and some thoughts about future research.

2. The Dynamic Computable General Equilibrium Model

What follows is a very brief description of the dynamic computable general equilibrium model of the Portuguese economy [see Pereira and Pereira (2017d) for further details]. In Section 3 we provide detailed information about some of the new features directly relevant for this research.

2.1 The General Features

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

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 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.

Firms maximize the net present value of their cash flow, subject to the equation of motion for capital stock to yield optimal output, labor demand, and investment demand. 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 EU-ETS sectors, such as transportation, textiles, wood pulp and paper, chemicals and pharmaceuticals, rubber, plastic and ceramics, and primary metals, as well as sectors not in the EU-ETS such as agriculture, basic manufacturing and construction. 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. The public sector and the foreign sector evolve in a way that is determined by the economic conditions and their respective financial constraints.

All economic agents interact in different markets. The general market equilibrium is defined by market clearing in product markets, labor markets, financial markets, and the market for investment goods. The equilibrium of the product market reflects the national income accounting identity and the different expenditure allocations of the output by sector of economic activity. 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 demand by households, by the public sector, its use as an intermediate demand, and its application as an investment good.

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 obviously differ by quartile of income. 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 equal the value of domestic investment plus the budget deficit.

The evolution of the economy is described by the optimal change in the stock variables – household-specific financial wealth and sector-specific private capital stock, as well as their respective shadow prices. 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 link between subsequent periods. The model can be conceptualized as a large set of nonlinear difference equations, where flow variables are determined through optimal control rules.

The intertemporal path for the economy is described by the behavioral equations, the equations of motion for the stock and shadow price variables, and 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 and shadow prices are constant.

2.2 Calibration

The model is calibrated with data for the period 2005-2014 and stock values for 2015. The calibration of the model is 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's implementation will just replicate into the future such stylized economic trends. Counterfactual simulations thus allow us to identify marginal effects of any policy or exogenous change, as deviations from the base case.

The existence of a steady state imposes three types of calibration restrictions. First, it determines the value of critical production parameters, such as adjustment costs and depreciation rates, given the initial capital stocks. These stocks, in turn, are determined by assuming that the observed levels of investment 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 budget deficit and the current account deficit are a fraction of the respective stocks of debt equal to the steady-state growth rate. Finally, the exogenous variables, such as public or international transfers, have to grow at the steady-state growth rate.

2.3 Numerical 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, on account 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 is then solved using a quasi-Newton algorithm to select a search direction and step length.

2.4 The Reference Scenario

The reference scenario provides a trajectory for the economy through 2050. The reference scenario embodies several assumptions regarding climate policy, which are super-imposed on the steady state trajectory used in the calibration of the model. The main assumptions in our reference scenario are as follows. First, we assume that the current levels of carbon taxation persist through 2050. Second, we assume that the major coal fired power plants cease operations at the end of their life span and no additional coal capacity is installed. Third, we assume that fossil fuel prices follow forecasts given by the IEA (2018).

3. Some Extensions to the DGEP Model

3.1 A Detailed Disaggregation of Production Sectors and Energy Inputs

We consider 24 sectors of economic activity encompassing all areas of economic activity. See Table 1 for the list of sectors as well as for some basic descriptive statistics.

This disaggregation allows us to identify the sectors of economic activity that produce goods that are internationally traded and those that do not. The sectors engaged in significant international trade include petroleum refining, food, textiles, wood, chemicals, rubber, basic metals, equipment, and transportation. These sectors account for 90% of exports. Yet, they represent just 28.5% of total output and 17.9% of total employment. Equally important, they are very highly energy intensive sectors, which are responsible for 45.7% of total energy expenditures.

[Table 1]

In turn, we consider eleven types of energy inputs: crude oil; coal; natural gas; butane; propane; LPG; fuel oil; gasoline; diesel; electricity, and biomass.

3.2 A Detailed Specification of the Energy Taxation

The tax on petroleum products raised 3.086 billion Euros in 2015, approximately 1.8% of GDP and 5% of total public sector receipts including tax revenues and social contributions.

The final sale price of energy products includes the following components: the base price per physical unit; the tax on petroleum products; and an additional value tax that is levied as a fraction of the base price plus the unit tax. Specifically, the tax on petroleum products, the ISP, includes: a basic unit tax; the contribution for road service design to finance maintenance of the national road network; an add-on tax on emissions of CO2. Table 2 includes details about these three components for a whole variety of fuels.

[Table 2]

3.3 A Detailed Specification of GHG Emissions and of other Air Pollutants

We incorporate in the model GHG emissions considered within the common reporting framework of the IPCC framework [see, for example, IPCC (2019)] and which represent the whole universe of GHG pollutants in Portugal: Carbon Dioxide (CO2); Methane (CH4); Nitrous Oxide (N2O); Hydrofluorocarbons (HFC); Perfluorocarbons (PFC); and Sulfur Hexafluoride (SF6).

[Figure 1]

Of the GHG considered, carbon dioxide, and in a small part methane, are directly related to the combustion of fossil fuels. In turn, the bulk of emissions from methane and remaining GHG derive mostly from agriculture and a variety of industrial processes.

In turn, we incorporate in the model the air pollutants considered within the National Emission Ceiling Directive of the EEA (2016, 2019): Nitrogen Oxides (NOx); Sulfur Dioxide (SO2), Particulate Matter (PM) 10 micrometers diameter and 2.5 micrometers diameter; Volatile Organic Compounds (VOC); Carbon Monoxide (CO); and Ammonia (NH3).

[Figure 2]

These air pollutants are induced by the combustion of fossil fuels, either directly as is the case of nitrogen oxide and sulfur dioxide or indirectly by road transportation activities such as particulate matter, volatile organic matter and carbon monoxide. These are the relevant co-pollutants when we consider policies designed to reduce carbon dioxide emissions.

We model emissions of the different GHG and air pollutants in two different ways. For emissions that are generated by fossil fuel combustion, i.e., the co-pollutants with carbon dioxide, we model emissions as direct function of the amount of the fossil fuel used in the corresponding activities. For emissions that are induced by agriculture of industrial processes we modelled them as a fixed function of the output of each of the different production sector or activities.

From a conceptual perspective, for fossil fuel based emissions, carbon dioxide and its co-pollutants, we capture the following three effects: effects due to fossil fuel switching; effects due to changes in the level of economic activity; and effects due to changes in the composition of economic activity. For process-based emissions, we capture only the last two effects.

4. Energy Taxation Reform with an Environmental Focus

To establish the effects of replacing the ISP with an equivalent CO2 tax we start by analyzing the effects, in isolation, of a CO2 tax of the magnitude necessary to replace the current ISP energy taxation. In this case, CF1, the CO2 tax is levied in addition to the current ISP taxation. Then, we compare this scenario with a revenue neutral experiment, CF2, in which the CO2 tax replaces the ISP taxation. We present summary simulation results in Tables 3 -8.

[Tables 3 - 8]

4.1 On the Effects of a CO2 Tax under the Current Energy Taxation Framework

The CF1 scenario corresponds to the implementation, in isolation, of a CO2 tax of the magnitude necessary to replace the ISP without actually doing so. The magnitude of the carbon tax is 114 euros per ton of CO2 and generates tax revenues that are approximately 1.85% of the GDP.

4.1.1 Effects on the Energy Markets and on Emissions

The introduction of this CO2 tax leads to an increase in energy prices of 13.91%, which leads to a decrease of energy demand by 12.40%. The price of domestic electricity generation increases by 12.59%, which leads to a 10.17% decrease in domestic production and a 12.81% increase in imports. Overall electricity demand declines by 9.80%. Accordingly, the share of electricity in final energy demand increases by 2.97%.

The introduction of this CO2 tax leads to a reduction in CO2 emissions of 36.02%, which represents 53.8% of the 2010 levels. Significant reductions are also induced in other GHG emissions, in particular CH4 and in N2O emissions with smaller reductions in emissions are observed for HP, PF, and SF6. In turn, the emissions of air pollutants are reduced greatly as well. This is true particularly for emissions of NOx, SO2, VOC, and less so for emissions of CO and PM.

4.1.2. Macroeconomic and Distributional Effects

The macroeconomic effects of the CO2 tax are naturally adverse. GDP declines by 5.21% linked directly on the supply side to the reduction in investment by 1.33% and of employment by 2.71% and on the demand side by a reduction in private consumption of 1.21%. The CPI increases by 2.32%. In turn, foreign debt increases by 3.70% with greater reliance of relatively cheaper foreign goods. Finally, there is, by construction, a reduction of 12.66% in the public debt.

The industries that are the most adversely affected in terms of their output are petroleum refining and electricity generation as expected as well as rubber, plastic and ceramics, basic metals, equipment, and transportation as well as textiles, wood and chemicals. These are all energy-intensive sectors that produce internationally traded goods.

Overall, there is an aggregate household welfare loss of 1.34%. Across the different household income groups, this loss is felt in a regressive manner. Indeed, the lowest income group suffers a loss of 1.85% while the highest income group loses just 1.02%. Accordingly, the factor of regressivity is 1.8.

4.2 On the Effects of Replacing the ISP with a CO2 Tax

In simulation CF2, we use the proceedings of the 114 euros per ton of CO2 tax discussed above to replace the ISP in a revenue neutral manner. Effectively, this experiment consists in transforming the ISP from a tax based on the energy content of the different fuels into an environmental tax based on the CO2 emissions content.

4.2.1 Effects on Energy Markets and on Emissions

Energy prices increase marginally by 0.55% and energy demand declines by just 4.36%. The price of electricity generation increases by 7.31%, which leads to a reduction of 5.37% in production. The production from renewables increases 7.83% while imports increase by 9.20%. Overall, the share of electricity in final energy demand declines by 0.80%. Compared to CF1, all results under CF2 are smaller. The most important differences in CF2 are the increase in electricity production from renewable sources and the relative decline in the share of electricity in final demand.

Under CF2, CO2 emissions decline by 28.26%. This means that emissions by 2030 represent 60.2% of emissions in 2010. The remaining emissions of both GHG and air pollution are also less pronounced but maintain the patterns observed before. The lower reductions compared to CF1 are due to the replacement on the energy taxes as opposed to the mere addition of a CO2 tax.

4.2.2. Macroeconomic and Distributional Effects

The substitution of the energy taxes with a CO2 tax leads to a decline in GDP of 1.19% with private investment remaining essentially unchanged and employment declining by just 0.56%. The CPI shows a small increase of 0.38% and private consumptions a marginal decline of 0.12%. Foreign debt increases but just by 2.26% while naturally the public debt by definition is just marginally affected. Overall compared to CF1 we observe smaller adverse macroeconomic effects.

The reduction in economic activity observed at the aggregate level hides some interesting industry effects. While electricity generation declines, the production of the refining sector increases, albeit only marginally. This reflects the switch in the focus of taxation of the sector but not a meaningful net increase of the tax burden on the sector. Along the same lines, transportation services show also an increase production. The remaining industries that are adversely affected are the same as under CF1 but with greatly reduced effects under CF2, in particular the cases of chemicals, basic metals, and equipment.

The adverse household welfare effects are now much smaller, just a loss of 0.10%. Yet, the same patterns of regressivity can be observed as the lowest household income group sees a loss of 0.22% and the highest income group of less than 0.08%. The factor of regressivity is 2.7.

5. On the Effects of Energy Taxation Reform while Reaching IPCC Targets

Having reached this point it is clear that there are benefits from energy taxation reform. It is also clear that there are adverse efficiency and distributional effects. More fundamentally, this reform does not generate the reductions in CO2 emissions necessary to reach the IPCC 2018 targets.

In this new set of experiments, we consider the effects of energy tax reform while at the same time increasing CO2 taxation to the levels necessary to reach IPCC emissions targets. The new levels of CO2 taxation are naturally much larger than what would be strictly necessary to replace the ISP. In terms of the experiments considered, we look first to a case in which the revenues from the CO2 taxation in excess to what is necessary to finance the energy taxation reform reverts to the general public budget, i.e., a non-recycling case – CF3. In turn, C4 considers the recycling of these extra CCO2 revenues in ways conducive to improving the economic and distributional outcomes. We present the simulation results in Tables 3-8 as before.

5.1 Effects of Energy Taxation Reform Without Recycling

To reach a reduction in CO2 emissions by 2030 of 45% relative to 2010 levels we need a CO2 tax rate that increases from 114 to 190 euros per ton of CO2. We consider an increasing level of taxation reflecting the increasing marginal costs of emissions abating.

5.1.1 Effects on Energy Markets and on Emissions

Under CF3, energy prices increase by 8.52% and energy demand decreases by 10.58%. The price of electricity generation increases by 12.66%, which leads to a 9.54% reduction of in production. Production of electricity from renewable energy resources increases by 5.89% while imports increase by 14.15%. Overall, the share of electricity in final energy demand increases by 1.59%.

Compared to CF2, results in CF3 are of a much greater magnitude, in some cases almost doubling the effect, which suggests rapidly increasing marginal abatement costs. Qualitatively, the most important difference is the increase in the relative role of electricity in final energy demand directly induced by a change in relative prices of electricity to fossil fuels.

Under CF3, CO2 emissions decrease by 37.64%. As such, emissions by 2030 will represent 52.7% of emissions in 2010, which marginally exceeds what is required under the IPCC target. GHG and air pollution emissions are much reduced compared to CF2 due to higher levels of CO2 taxation.

Reductions in emissions across the board are similar to the ones observed under CF1 – a case in which a CO2 tax of 114 euros per ton is imposed on top of the existing energy tax system. This suggests that from an environmental perspective a carbon tax of 114 per ton of CO2 added to the status quo, has the same environmental effects as a tax starting at 114 euros and increasing to 190 by 2030, which includes the replacement of current energy taxes.

5.1.2. Macroeconomic and Distributional Effects

Under CF3, there is a decrease in GDP of 3.97% with private investment decreasing by 0.61% and employment decreasing by 2.03%. The CPI increases by 1.65% and private consumption decreases by 0.78%. Foreign debt increases by 3.59% while public debt decreases by 1.53% due to the added CO2 tax revenues and despite a decreasing tax base.

Overall, compared to CF2 we observe significantly larger negative macroeconomic effects. This reinforces the evidence supporting sharply increasing marginal abatement costs for CO2 emissions. More importantly, compared to CF1 – a case with similar environmental effects – the adverse macroeconomic effects are now clearly smaller, although still sizeable.

Under CF3, the industries most affected include electricity production, petroleum refining, agriculture, mining, textiles, wood, chemicals, rubber, basic metals, equipment, trade and transportation. These are essentially the same industries that are most affected under CF2 although the adverse effects are now larger. In particular, the adverse effects on petroleum refining, trade, and transportation are significantly larger. In turn, compared to CF1 all of these adverse effects are smaller, in particular for sectors such as refining and transportation, sectors that are directly affected by the current energy taxation.

The adverse household welfare effects under CF3 are a loss of 0.86%. Yet, the same patterns of regressivity can be observed as the lowest income group sees a welfare loss of over 1.25% and the highest income group is 0.65%. The factor of regressivity is 1.9. Overall, the adverse distributional effects are also significantly larger under CF3 than under CF2. More importantly, again, the adverse distributional effects under CF3 compare favorably to the ones observed under CF1 while displaying a similar pattern of regressivity.

5.2 Effects of Energy Tax Reform with Revenue Recycling

In CF4 the extra tax revenues generated by the additional CO2 taxation over what is needed to finance the energy tax reform are recycled in the economy through lower taxation at other tax margins. This means that this case CF4 is strictly revenue neutral. Specifically, the recycling of additional revenue is done as follows: 50% for an investment tax credit applicable to the traded-goods sectors; 50% to reductions in the personal income tax divided in equal amounts across the different income groups; both mechanisms associated with broad energy efficiency gains.

5.2.1 Effects on Energy Markets and on Emissions

Under CF4, energy prices increase by 3.72% and energy demand decreases by 4.47%. The price of electricity generation increases by 3.65%, which leads to a reduction of 1.75% in production. The production of electricity from renewable energy increases 9.50% while electricity imports increase by 6.06%. Overall, the share of electricity in final energy demand increases by 2.99%. Compared to CF3, the adverse effects on energy prices and demand are much smaller under CF4. This is particularly true for electricity prices and demand, which contributes to a much larger increase in the share of electricity in final energy demand.

Under CF4, CO2 emissions decrease by 34.76%. This means that emissions by 2030 represent 55.1% of emissions in 2010, on target to meet the IPCC goal of 55% of 2010 levels. Emissions of the other GHG also decline substantially, except for HF and PF, which actually increase. Air pollutants emissions also fall significantly with the exception of NH3. Comparing with CF3, under CF4 we see less favorable emissions reductions across the board. This is normal and it is a manifestation of the rebound effect. We allowed for a greater than necessary reduction in CO2 emissions in CF3 exactly to account for the rebound effect under recycling.

5.2.2. Macroeconomic and Distributional Effects

Under CF4, there is a 1.46% increase in GDP, with private investment increasing 1.63% and employment 0.90%. The CPI increases by 0.53% and private consumption increases by 1.18%. Foreign debt decreases by 0.90% while public debt decreases by 3.59% due to the increase in economic activity. Compared to CF3, as desired, we observe a reversal of the adverse macroeconomic effects. Under CF4, there is an increase in production for most sectors. Electricity, mining, and rubber, however, are still affected adversely in a significant manner. This implies that while the recycling mechanisms have led to a reversion of the bulk of the adverse macroeconomic effects, there are still specific industries that need further consideration in terms of cost mitigation strategies.

Under CF4, household welfare gains are 1.09%. Furthermore, these effects are progressive in nature as the lower income group gains 2.51% while the highest income group gains just 0.53%. This means that under CF4, the adverse distributional effects both at the aggregate level and in terms of the regressive pattern that we observed under CF3 have been reversed.

5.2.3 On the Effects of Different Recycling Mechanisms

Scenarios CF4A and CF4B are just a decomposition of the CF4 case into its IRS replacements and ITC replacement components in order to identify the mechanisms behind the overall CF4 results.

Recycling the additional CO2 tax revenues after replacing the ISP at only the IRS level leads to reversal of the negative distributional and regressive effects of the policy without reversing the adverse economic effects. Indeed, for comparable emissions reductions leads to much greater welfare gains and much greater output losses. In turn, recycling the additional CO2 tax revenues with a corporate income tax credit for private investment, leads to reversal of the negative economic impact of the policy without eliminating the negative and regressive distributional effects of the policy. Overall, these results indicate the need of a multifaceted recycling approach if the adverse economic and distributive effects of decarbonizaztion are to be reversed.

6. Concluding Remarks

In this paper, we address the issue of energy taxation reform with an environmental focus in Portugal. We address this issue in the context of a dynamic disaggregated computable general equilibrium model of the Portuguese economy. We analyze the environmental, macroeconomic, and distributional effects of different policies allowing for current energy taxes to be replaced with a carbon tax while at the same time reaching the IPCC 2018 emissions reduction targets.

Our simulation results show, first, that a carbon tax of 114 euros per ton imposed on top of the current energy taxation is enough to achieve the IPCC 2030 targets. It does so, however, at a high macroeconomic and distributional cost. In turn, replacing energy taxes with such a carbon tax would lead to smaller although still significant environmental effects and much smaller adverse macroeconomic and distributional effects.

This suggest that just replacing energy taxation with a carbon tax may be a good second best alternative compared to the status quo. This is particularly so if political constraints do not allow for the implementation of a well-designed carbon tax with the proper recycling mechanisms. Just replacing the current energy taxes with a carbon tax would greatly mitigate the adverse economic and distributional effects of a stand-alone carbon tax, while still achieving important environmental goals in a context of strict tax revenue neutrality. In addition, this second best alternative, would improve the efficiency of the tax system by implicitly eliminating the myriad of perverse fossil fuel subsidies consigned in the current energy taxation system. Replacing the current energy taxation with a carbon tax completely sidesteps the politically charged issue of reducing or eliminating fossil fuel subsidies.

Our simulation results show, second, that to achieve the IPCC 2030 targets while replacing the current energy taxes ISP requires a carbon tax increasing to 190 by 2030. The marginal burden of the additional tax in terms of the economic and distributional impact sharply increases compared to the previous cases. This suggest a pattern of sharply increasing marginal abatement costs.

Significantly, the case of achieving the IPCC targets while replacing the ISP with carbon taxation has similar CO2 emissions effects compared to the case of adding carbon taxation to the ISP burden as in case. Yet the economic and distributional effect are less adverse when the current energy taxes are replaced. This means that from a policy perspective the strategy of replacing the current energy taxation with a carbon tax while at the same time reaching IPCC levels clearly dominates a strategy in which the IPCC levels are achieved by carbon taxation while maintaining the current patterns of energy taxation.

Finally, our simulation results show that proper recycling of revenues in excess to what is need to replace current energy taxes allows for positive economic and distributional outcomes while keeping the environmental benefits, thereby reverting the adverse effect observed. It is important to note that the recycling strategy presented in this paper is illustrative only. It is not the only way of achieving the multiple dividends or the most desirable way to do so.

In this vein, we also show that recycling of revenues through demand-side, personal income tax reductions, is fundamental to achieve the desirable distributional effects of these polices while recycling of revenues through supply-side, investment tax credits, is fundamental to achieve desirable macroeconomic outcomes.

Overall, our analysis indicates a clear specific path in the quest for decarbonization. First, replace current energy taxation with a carbon tax; second, target the carbon taxation levels necessary to achieve the relevant emissions goals; third, use extra tax revenues to reverse any potential adverse macroeconomic and distributional effects of carbon taxation. In the process, this would be a way around the fossil fuel subsidies, which would effectively disappear.

Furthermore, our analysis indicates a clear framework for the decarboniation efforts. There is no way to reach decarbonization without duly considering potential adverse macroeconomic, budgetary, international competitiveness, and distributional effects of such policies. These adverse effects if not addressed would likely make it impossible to reach a political consensus on such policies. In this context, revenue neutrality – with its reduction of other tax distortions and the achievement of desirable economic and welfare outcomes - has to be the central piece of any decarbonization policies. As a corollary, addressing the issue of decarbonization in a comprehensive manner is of paramount importance. This is so because only with a comprehensive reform will it be possible to neutralize such adverse effects. Piecewise measures are bound to lead to undesirable economic and welfare effects.

Finally, and although this is an energy policy paper applied to the Portuguese economy and its policy implications directly relevant for the Portuguese case, its interest is far from parochial. The quest for decarbonization is universal. The existence of inefficient energy taxation mechanisms incorporating fossil fuel subsidies widespread. The concerns over the macroeconomic and distributional effects of renewable energy finance and environmental policies in general unavoidable if there is some hope of meaningful policies ever being adopted.

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Table 1 - Sectors of Economic Activity: Definition and Basic Information

	Output	Employment	Exports	Energy
Total	**100.0**	**100.0**	**100.0**	**100.0**
Petroleum Refining	3.9	0.0	5.3	24.4
Electricity	4.2	0.2	0.2	28.9
Biomass	0.3	0.0	-	0.0
Agriculture	3.6	10.2	1.8	1.8
Mining	0.9	0.2	1.1	0.7
Food products, beverages and tobacco	5.6	2.2	7.8	2.0
Textiles	2.8	4.3	11.3	1.3
Wood, pulp and paper	2.1	1.2	6.6	1.4
Chemicals and pharmaceuticals	2.6	0.4	6.2	2.2
Rubber, plastics and ceramics	2.1	1.3	7.5	2.6
Basic metals and fabricated metal products	2.1	1.8	8.2	1.0
Equipment manufacturing	4.2	3.3	27.3	0.6
Water, sewage and waste management	1.2	0.8	0.7	0.7
Construction	6.9	5.8	1.1	1.6
Wholesale and retail trade	10.6	15.5	0.2	10.2
Transportation	4.8	3.4	9.7	9.9
Accommodation and food services	4.0	6.1	1.1	1.7
Information technology	3.6	1.8	2.2	0.5
Finance and insurance	4.8	1.8	1.1	0.5
Real estate	7.2	1.0	-	0.4
Professional services	6.6	13.0	0.7	1.4
Public administration	5.3	5.9	-	2.6
Education	3.7	6.9	-	0.7
Health	4.7	8.7	-	1.9

Table 2 - ISP and its components

	Units	Unit Tax	Road Contribution	CO2 Add-on	Total Tax Rate
Butane/Propane	kg	0.00799		0.01681	0.02480
Electricity	MWh	1.00000			1.00000
Fuel Oil	kg	0.01565		0.02121	0.03686
Natural Gas	GJ	0.30000		0.38429	0.68429
Natural Gas (vehicular)	GJ	2.84000		0.38429	3.22429
Diesel (Colored and Marked)	l	0.07751		0.01695	0.09446
Diesel Heating Oil	l	0.33000		0.01695	0.34695
Diesel	l	0.27841	0.11100	0.01695	0.40636
Gasoline	l	0.51895	0.08700	0.01556	0.62151
LPG Auto	l	0.12788	0.12300	0.01988	0.27076

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Figure 1 - Greenhouse Gas Emissions

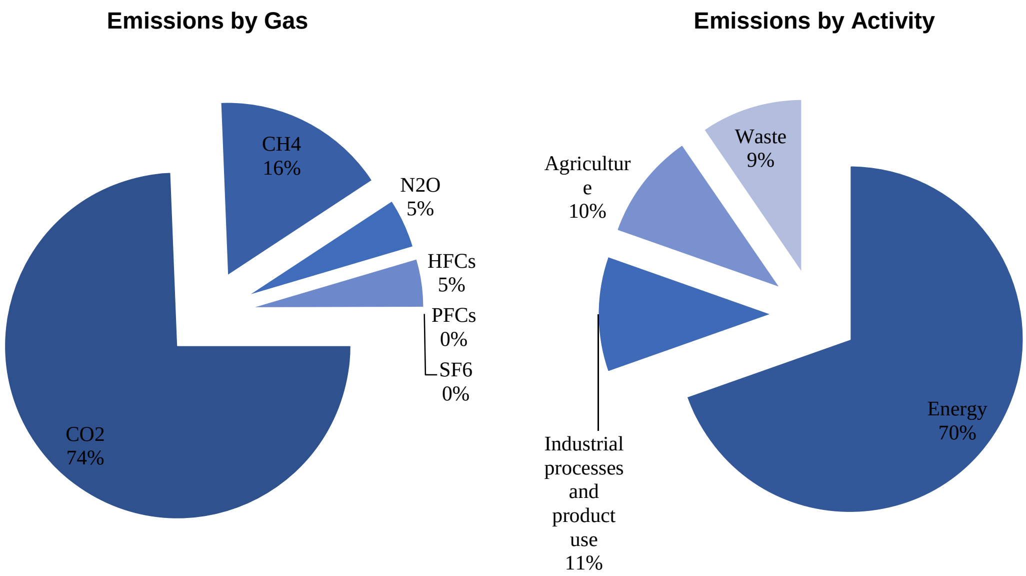

Figure 2 – Emissions of Air Pollutants

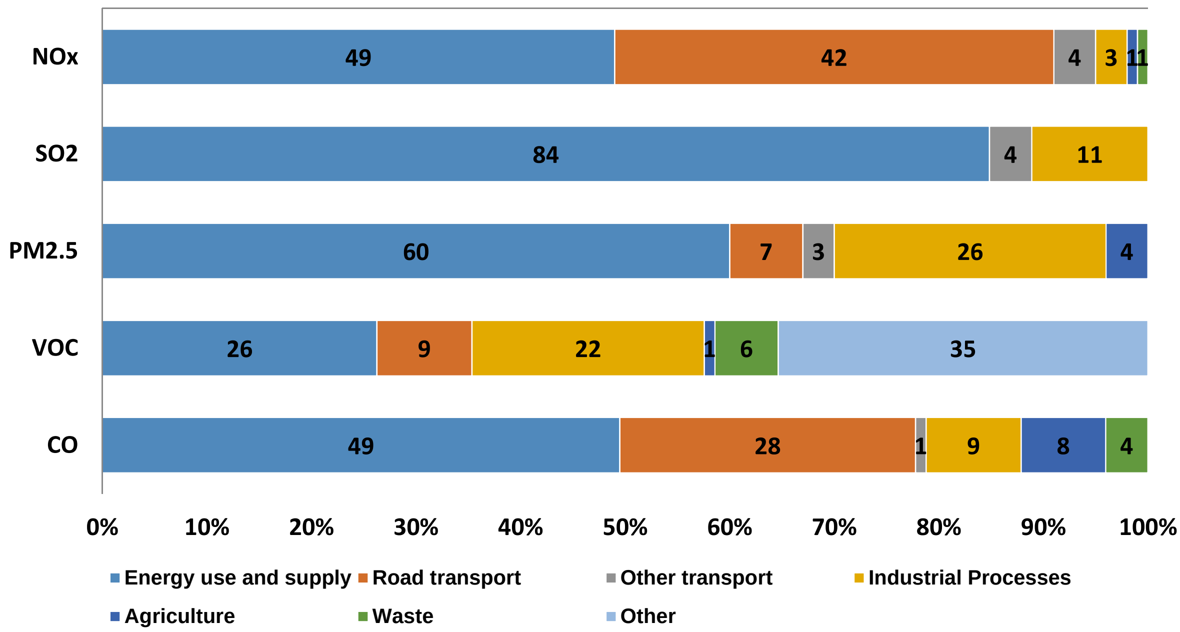

Table 3 Long Run [2030] Effects: Energy Markets

Percent Change from Baseline

	CF1	CF2	CF3	CF4	CF4A	CF4B
Carbon Tax	114	114	120-190	120-190	120-190	120-190
Energy Price	13.91	0.55	8.52	3.72	9.03	3.47
Electricity Price	12.59	7.31	12.66	3.65	13.59	3.30
Electricity Production	-10.17	-5.37	-9.54	-1.75	-7.65	-2.71
Thermal Generation	-25.61	-20.18	-29.31	-25.52	-27.83	-26.28
Renewable Energy Systems	-2.18	7.83	5.89	9.50	7.85	8.48
Net Electricity Imports	12.81	9.20	14.15	6.06	18.26	4.33
Energy Demand	-12.40	-4.36	-10.58	-4.47	-8.62	-5.36
Electricity Demand	-9.80	-5.13	-9.16	-1.62	-7.23	-2.59
% Electricity in Final Energy Demand	2.97	-0.80	1.59	2.99	1.52	2.92

Table 4 Long Run [2030] Effects: Greenhouse Gas and Air Pollutant Emissions

Percent Change from Baseline

	CF1	CF2	CF3	CF4	CF4A	CF4B
			Greenhouse Gas Emissions			
CO2 Emissions relative to 2010	53.8%	60.2%	52.7%	55.1%	53.6%	54.2%
Carbon Dioxide – CO_2	-36.02	-28.26	-37.64	-34.76	-36.16	-35.34
Methane – CH_4	-25.29	-16.57	-26.75	-23.39	-25.01	-24.04
Nitrous Oxide – N_2O	-30.73	-22.39	-32.16	-29.03	-30.56	-29.66
Hydrofluorocarbons – HFC	-5.66	-0.94	-4.07	2.56	-3.80	3.56
Perfluorocarbons – PFC	-4.96	-0.96	-3.69	2.02	-3.31	2.60
Sulfur Hexafluoride – SF_6	-10.17	-5.37	-9.54	-1.75	-7.65	-2.71
			Air Pollutant Emissions			
Nitrogen Oxides – NO_x	-37.22	-29.01	-37.90	-34.97	-36.44	-35.57
Sulfur Dioxide – SO_2	-43.13	-35.66	-44.14	-41.45	-42.82	-42.01
Volatile Org. Compounds – VOC	-23.67	-15.36	-26.37	-23.18	-24.65	-23.81
Carbon Monoxide – CO	-51.08	-45.62	-54.54	-52.74	-53.39	-53.20
Particulate Matter – PM	-71.71	-69.19	-77.22	-76.57	-76.59	-76.85
Ammonia – NH_3	-11.93	-1.44	-3.98	0.35	-3.17	0.37

Table 5 Long Run [2030] Effects: Macroeconomic Performance

Percent Change from Baseline

	CF1	CF2	CF3	CF4	CF4A	CF4B
GDP	-5.21	-1.19	-3.97	1.46	-3.06	1.72
Private Consumption	-1.21	-0.12	-0.78	1.18	2.34	-0.85
Investment	-1.33	0.02	-0.61	1.63	0.37	1.63
Employment	-2.71	-0.56	-2.03	0.90	-1.00	0.88
Foreign Debt	-12.66	0.64	-1.53	-3.59	-3.38	-0.79
Public Debt	3.70	2.26	3.59	-0.90	7.20	-2.98
CPI	2.32	0.38	1.65	0.53	2.49	0.03

Table 6 - Long Run [2030] Effects: Energy Taxes

% of GDP

	Reference	CF1	CF2	CF3	CF4	CF4A	CF4A
Unit Tax	2.28	3.90	2.30	3.22	3.37	3.30	3.34
CSR	0.22	0.21	0.23	0.22	0.22	0.22	0.22
ISP	1.90	1.84	0.00	0.00	0.00	0.00	0.00
CO2	0.16	1.85	2.07	3.01	3.15	3.08	3.12

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Table 7 Long Run [2030] Effects: Output by Industry

Percent Change from Baseline

	CF1	CF2	CF3	CF4	CF4A	CF4B
Total	-5.21	-1.19	-1.53	-3.59	-3.38	-0.79
Petroleum Refining	-11.16	0.64	-0.18	-0.21	-0.18	-0.07
Electricity	-10.17	-5.37	1.43	1.57	1.48	0.62
Biomass	2.04	2.29	-1.34	-3.63	-11.05	2.57
Agriculture	-4.39	-1.50	-1.40	-20.39	1.66	-44.25
Mining	-9.07	-0.96	-2.02	0.90	-1.01	0.88
Manufacture of food products, etc	-3.05	-0.28	0.59	1.53	4.60	-1.00
Textiles	-8.13	-5.04	40.21	46.50	43.65	45.05
Wood, pulp and paper	-7.81	-4.66	-1.53	-3.59	-3.38	-0.79
Chemicals and pharmaceuticals	-8.12	-2.67	-0.18	-0.21	-0.18	-0.07
Rubber, plastics and ceramics	-13.49	-9.09	1.43	1.57	1.48	0.62
Basic metals and fabricated metal products	-10.35	-4.12	-1.34	-3.63	-11.05	2.57
Equipment manufacturing	-16.91	-1.62	-1.40	-20.39	1.66	-44.25
Water, sewage and waste management	-2.02	-0.71	-2.02	0.90	-1.01	0.88
Construction	-1.80	-0.21	0.59	1.53	4.60	-1.00
Wholesale and retail trade	-5.86	-0.25	40.21	46.50	43.65	45.05
Transportation	-9.50	0.75	-1.53	-3.59	-3.38	-0.79
Accommodation and food services	-2.37	-0.41	-0.18	-0.21	-0.18	-0.07
Information technology	-1.95	-0.42	1.43	1.57	1.48	0.62
Finance and insurance	-2.61	-0.45	-1.34	-3.63	-11.05	2.57
Real estate	-0.82	-0.12	-1.40	-20.39	1.66	-44.25
Professional services	-3.48	-0.57	-2.02	0.90	-1.01	0.88
Public administration	-0.94	-0.42	0.59	1.53	4.60	-1.00
Education	-0.58	-0.18	40.21	46.50	43.65	45.05
Health	-1.32	-0.37	-1.53	-3.59	-3.38	-0.79
Other	-2.68	-0.43	-0.18	-0.21	-0.18	-0.07

Table 8 Long Run [2030] Effects: Welfare Effects

Percent Change from Baseline

	CF1	CF2	CF3	CF4	CF4A	CF4B
	Equivalent Variation in Income					
All Households	-1.34	-0.10	-0.86	1.09	2.26	-0.94
First Quintile (lowest income)	-1.85	-0.22	-1.25	2.51	4.84	-1.08
Second Quintile	-1.64	-0.12	-1.04	1.71	3.35	-0.99
Third Quintile	-1.45	-0.09	-0.92	1.25	2.56	-0.96
Fourth Quintile	-1.33	-0.09	-0.85	0.85	1.82	-0.94
Fifth Quintile (highest income)	-1.02	-0.08	-0.65	0.53	1.24	-0.86

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