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Research article

Financing a renewable energy feed-in tariff with a tax on carbon dioxide emissions: A dynamic multi-sector general equilibrium analysis for Portugal

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Abstract: Renewable energy production subsidies alleviate the pressure on electricity prices associated with carbon and energy pricing policies in the process of decarbonization and electrification of the Portuguese economy. Our simulation results show that a feed in tariff financed by a carbon tax leads to adverse macroeconomic as well as adverse and regressive distributional welfare effects. On the flip side, however, we show that use of the carbon tax revenues to finance a feed in tariff is an improvement over the simple carbon tax case along all the relevant policy dimensions. The feed in tariff mechanism when added to the carbon tax leads to better environmental outcomes at lower costs both in terms of the economic and social justice implications. The policy implications are clear. First, because of its adverse economic and distributional effects, a carbon tax should not be used in isolation. The use of the revenues to finance a feed in tariff dominates the simple carbon tax case in all dimensions. Second, the search for an appropriate recycling mechanisms beyond a feed in tariff is an issue as important as the carbon tax itself as it pertains to the potential reversal of the adverse effects of such a tax.

Keywords: dynamic general equilibrium; renewable energy; feed-in tariff; carbon taxation; macroeconomic effects; distributional effects; environmental effects; Portugal

JEL Codes: C68, E62, H23, Q43, Q48

1. Introduction

Policies to encourage the adoption of renewable energies are at the center of efforts to address climate change in Portugal and around the world (IEA, 2018). This focus is justifiable as decarbonization of the Portuguese economy will necessarily be based on an increasing electrification of energy demand coupled with the production of electricity from green energy.

Renewable energy has made strong progress in Portugal over the past decade and the country has become one of Europe's leaders in the use of renewable energy sources (RES). Since 2005, installed capacity for wind energy grew from 3058 MW in 2008 to 5,313 MW in 2017 and installed capacity for electricity production from solar cells grew from 62 MW in 2008 to 585 MW in 2017 (DGEG, 2019).

These trends are expected to continue over the coming decades. Projections within the context of the National Program for Climate and Energy (PNEC) indicate that renewable energies will grow to dominate the production of electricity through 2030 with 33–35% of electricity generated in the country produced from wind turbines, 24–28% from hydroelectric generating units and 22–27% from solar power (PNEC, 2019). This expansive growth will require significant investment in infrastructures. The national program for investment (PNI) estimates investment volume of 4,930 million Euros through 2030 while the national program for climate and energy estimates investment volumes between 17,100 million Euros and 18,700 million Euros in the energy sector overall.

Support mechanisms for renewable energy sources are based on feed-in tariff systems, tax benefits and small levels of investment subsidies. The principal instrument for promoting renewable electricity in Portugal is the special production regime, whereby electricity produced from renewable energy benefit from a feed-in tariff. Support costs for renewable energy amount to 781.15 million EUR in 2012 and 977.71 million EUR in 2013 (IEA, 2018).

The objective of this paper is to examine the environmental, economic, and distribution effects of initiatives to support the use of renewable energy resources in the production of electric power. In this paper we consider using auction revenues for permits issued within the context of the European Union Emission Trading System (EU-ETS) in Portugal and a tax on carbon dioxide emissions from fossil fuel combustion activities not covered within the EU-ETS to finance green energy in the production of electricity. This is consistent with the carbon pricing policies in place in Portugal; In 2015, Portugal introduced a tax on carbon dioxide emissions indexed to the price of carbon permits in the EU-ETS (IEA, 2018).

Climate and energy policies that increase the price of fossil fuels or provide funding for the development and deployment of renewable energies raise a number of concerns. On one hand, consumer and producer groups are concerned about the potentially higher costs associated with energy goods in the presence of carbon pricing policies. On the other hand, funding mechanisms needs to be efficiently and fairly designed to support renewable energies.

Both of these concerns are then compounded by social justice concerns surrounding the effects of these policies on lower income households and on industry sectors that are particularly vulnerable. The distributional impact of carbon pricing policies across households is determined by heterogeneity in spending patterns as well as heterogeneity in factor income patterns across income groups and the precise formulation of the policy, i.e., how the revenue from the carbon pricing policy are distributed [see, for example Fullerton and Heutel (2010), Rausch et al. (2011), Dissou and Siddiqui (2014), Beck et al. (2015), and Parry and Williams (2011)].

When policies that mandate the use of renewable energies in the production of electric power are financed by surcharges on the power bills of utility customers, renewable energy support policies may also increase the price of electricity (see Bhattacharya et al., 2017, among others). Rausch and Mowers (2014) find that renewable energy support policies yield highly regressive distributional effects stemming from this increase in electricity prices.

Higher electricity prices also increase input costs for firms and, when coupled with the loss in revenue due to lower demand for the firms' products at higher prices, results in losses in profits for firms. Proença and Aubyn (2013) find that feed-in tariffs in Portugal were effective in increasing the share of renewable energy sources in electricity production from 19.2% to 45% of electricity supply and reducing carbon dioxide emissions by 31% at a cost of 0.18% of GDP.

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. 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 et al., 2011). In fact, carbon taxation in Washington State failed to gain sufficient support because it was unpopular with groups concerns about social justice and divided environmental activists, many arguing it did not go far enough in promoting clean energy (Inside Climate News, 2016).

The regressive aspects of renewable energy promotion stemming 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). 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 large energy price increases. These concerns highlight the need to design a politically feasible package of policy instruments to encourage the adoption of green energies and to appropriately price fossil fuels to reflect the external costs these generate.

2. The dynamic multi-sector general equilibrium model of the Portuguese economy

What follows is necessarily a very brief and general description of the design and implementation of the new multi-sector, multi-household dynamic general equilibrium model. We provide detailed information in the Appendix. See also Pereira and Pereira (2017), which focuses on the impact of energy taxes and carbon taxation on decarbonization, for further details.

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 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 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 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 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 European Trading System 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, 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 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. 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 quintile. 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 change in the stock variables—five household-specific financial wealth variables and thirteen sector-specific private capital stock variables, 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.

2.2. Calibration

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'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 model is calibrated with data for the period 2005–2015 and stock values for 2015. The model is calibrated to reflect the long-term trajectory of the Portuguese economy. For this reason, rather than focus on calibrating the model using only a single year of data, we use a ten-year interval, which roughly capture an entire business cycle and reflects the most recently available performance of the economy. Although more recent data was available for some economic indicators, data on a variety of energy indicators has only been validated for Portugal through 2015 at the time calibration.

There are three types of calibration restrictions imposed by the existence of a steady state. 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 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 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 transfers 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 as each of the individual problems (the household, firm and public sector) are defined by the first order and Hamiltonian conditions necessary for an optimal solution. 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. This scenario serves as a reference for evaluating the impact of policies that follow. 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 6.85 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. Third, we assume that fossil 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 marginal improvements thereafter.

These assumptions imply a reference scenario in which greenhouse gas emissions fall 36.8% from 2015 levels, from 64.6 Mt CO$_2$e in 2015 to 44.3 Mt CO$_2$e 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 closings of Sines and Pego are 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.

3. Simulation results

3.1. The simulation design

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. This emissions constraint is introduced to the TIMES energy system model and the energy sector adjusts to meet this constraint in a cost-effective manner, minimizing the cost of the energy system. The shadow price of the emissions constraint identified by the TIMES model measures the marginal cost of carbon dioxide emissions reductions associated with the emissions constraint. Specifically, the marginal costs of CO$_2$ abatement considered in the central counterfactual scenario grow from current levels to 33 Euro/tCO$_2$ in 2030, 49 Euro/tCO$_2$ by 2040 and 183 Euro/tCO$_2$ by 2050.

In our simulations, 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) is indexed to prices in the EU-ETS, thereby generating a single, economy-wide price for carbon.

The carbon tax yields tax revenues that result from a sharply increasing tax rate applied to a less sharply declining tax base. Accordingly, the tax revenues generated are marginal in the early years of the simulations but reaches about 0.8% of the GDP by 2040 and about 1.7% by 2050. The proceeds from this carbon tax are used to finance a renewable energy feed-in tariff for wind and solar power supplied to the national electric power grid. In these simulations, hydroelectric power facilities are not provided this support.

The revenues from the carbon tax are used to finance electricity production from renewable sources. In practical terms, this means that the power-generating sector now benefits from a subsidy on use of installed renewable energy electric power generating capacity. We model the feed-in tariff for the different renewable installations as an additional payment to providers based on the size of the stock of renewable energy capital used in the production of electricity. Consistent with the nature of the exercise, the magnitude of the subsidy is determined by the available revenues from carbon taxation and not by the difference between the production costs and market prices of electricity from renewable sources. [See, for example, Timilsina and Landis (2014) and Johanson and Kristrom (2019).]

In the tables summarizing the policy experiments we report two sets of results—the effects of financing a renewable energy feed-in tariff with a tax on carbon dioxide emissions and the effects of an equivalent carbon tax without any revenue recycling. Our main purpose is to identify the effects of financing a renewable energy feed-in tariff with a tax on carbon dioxide emissions from the different relevant perspectives—environmental, macroeconomic, and distributional. These results are reported on the top panel of the different tables. In addition, by comparing the results of the carbon tax without revenue recycling to the effects of the carbon tax financing renewable energy feed in tariff we can ascertain the marginal contribution of the feed in tariffs. These results are reported in the bottom panel of all of the tables, Finally, and for the sake of simplicity although we report the simulation results for 2020, 2030, 2040, and 2050, we focus our discussion on the effects by 2050, which we refer to as the long-term effects of the policies. All results are presented as percent change deviations relative to the Reference Scenario.

3.2. The effects on the energy sector and on CO_2 emissions

Table 1 presents the effects on final energy prices. Overall, final energy prices increase by 57.5% in 2050 relative to the reference scenario.

The prices of coal and natural gas are determined in world commodity markets and the increase in prices for domestic consumers reflects the carbon pricing policies in place. As a result, in the long term the increasing tax on carbon will increase the price of coal by 379.0% and the price of natural gas by 40.6% relative to the reference scenario.

The price of petroleum products reflects both the price of oil set in international markets but also the technical details of the refining process and the amount of each refined petroleum product produced at the refineries in Sines and in Matosinhos. The yield of each product from the refining process together with domestic demand for those specific products and international trade in refined products will ultimately define the prices for the refined products. The dominance of diesel products in transportation demand and in agriculture and fisheries ultimately means that prices for these products grow substantially, by 45.2% by 2050. Gasoline prices are expected to grow by 29.7% relative to the reference scenario reflecting both the relatively higher price of gasoline in place as well as the lower levels of demand for gasoline in transportation and domestic production levels in the refineries in Portugal defined by the technical requirements of the distillate towers.

Heating oils (butane, propane and LPG) can be relatively easily replaced for home space heating with centralized heating units running on electric power. This dampens the increase in prices for heating oils given supply conditions.

Electricity prices decrease over the long run by 1.2% relative to the reference scenario due to the substantial subsidies provided by the significant tax on carbon. The feed-in tariff financed by broader based pricing policies for fossil fuels in function of their carbon content allows for a significant reduction in the levelized costs of producing energy from renewable sources and thereby lowers the costs and prices of electric power. Given the substitution possibilities available to residential and commercial consumers for heating, demand responses to the lower electricity prices provide the basis for the equilibrium price responses observed.

Table 1. Effects on final energy prices. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Composite Energy Price Index	3.163	18.915	23.054	57.564
Coal	23.695	131.692	157.499	379.031
Natural Gas	2.669	14.661	17.202	40.638
Butane, Propane and LPG	1.636	9.350	11.271	26.887
Gasoline	1.690	9.852	12.202	29.710
Diesel	2.521	14.453	18.015	45.197
Electricity	−0.719	−0.796	−2.978	−1.174
Biomass	−0.264	0.478	−0.015	1.626
Carbon Tax w/o Revenue Recycling				
Composite Energy Price Index	3.350	19.410	23.912	58.863
Coal	23.695	131.692	157.499	379.031
Natural Gas	2.669	14.661	17.202	40.638
Butane, Propane and LPG	1.777	9.799	12.070	28.155
Gasoline	1.744	9.910	12.260	29.752
Diesel	2.482	14.408	17.968	45.134
Electricity	0.541	3.006	3.483	8.273
Biomass	0.062	0.929	0.621	2.427

Note: Source: Authors’ Calculations.

Table 2 presents the effects on final energy demand. The increase in energy prices stemming from financing a renewable energy feed in tariff with a tax on carbon dioxide emissions decreases the final demand for energy products relative to the reference scenario. Overall, final energy demand decreases by 10.4% in 2050 relative to the reference scenario.

The pattern of reduced demand reflects the observed increase in prices for each energy product reflecting the carbon content of the fuel as well as domestic supply and demand constraints. Naturally, final demand for coal by households, in industry and in services decreases significantly by nearly 70.6% relative to the reference scenario in 2050. This is possible because of the relatively easily available substitutes for coal products and the substantial increase in the price of coal relative to electricity and, to a lesser extent, natural gas. By 2050, natural gas demand decreases by 27.7% relative to the reference scenario. In contrast, the lower prices for electricity allow for an increase in electricity demand of 1.3% relative to the reference scenario reflective of an increasing electrification of energy demand in Portugal over the long run as part of a pathway to decarbonization.

Reductions to the final demand for transportation fuels reflect the increase in prices and domestic refinery supply constraints. Over the long run, the final demand for diesel fuel decreases by 26.1% relative to the reference scenario and the demand for gasoline falls by 15.9%. Adjustments within the transportation sector reflect an increasing use of transportation services, public transportation, improvements to fuel efficiency, and increased adoption of electric vehicles for passenger transport.

Table 2. Effects on final energy demand. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Final Energy Demand	−0.717	−4.267	−4.281	−10.398
Coal	−15.406	−48.417	−52.797	−70.622
Natural Gas	−2.417	−12.330	−14.225	−27.649
Butane, Propane and LPG	−1.474	−7.535	−9.101	−18.741
Gasoline	−1.264	−6.338	−7.602	−15.860
Diesel	−1.967	−10.582	−12.721	−26.059
Electricity	0.606	0.781	2.683	1.262
Biomass	0.060	0.334	0.429	0.747
Share of Electricity in Final Energy Demand	1.570	6.389	8.751	15.624
Carbon Tax w/o Revenue Recycling				
Final Energy Demand	−1.157	−5.866	−6.927	−14.126
Coal	−14.859	−47.698	−51.804	−69.764
Natural Gas	−2.496	−12.239	−13.952	−27.121
Butane, Propane and LPG	−1.456	−7.494	−9.043	−18.589
Gasoline	−1.146	−6.207	−7.462	−15.671
Diesel	−2.010	−10.643	−12.798	−26.090
Electricity	−0.390	−2.339	−2.653	−6.028
Biomass	0.341	1.126	1.718	2.536
Share of Electricity in Final Energy Demand	0.902	4.404	5.245	10.707

Note: Source: Authors' Calculations.

Table 3 presents the effects on the electric power industry. Over the long run, domestic electricity production increases by 0.8% relative to the reference scenario. The feed-in tariff, coupled with increased costs associated with fossil fuel generation units, naturally increases investment in and the use of renewable energies in the production of electric power. The share of renewable energy in electricity production increases 13.8% percent in 2050 relative to the reference scenario. This increase in the employment of renewable energies reflects the costs of these energies to the utilities but also technological constraints on further deployment of specific technologies. The increase in wind energy is constrained by the fact that the most productive areas for the placement of wind turbines are the first developed and that additional turbines placed in less productive areas will yield a diminishing marginal product for these capital stocks.

The lower prices for electricity for households, commercial applications in services and in industry, together with the available substitutes in home space heating and in industrial applications, allow for an increase in the final demand for electricity. Electricity demand by households increases by 3.3% in the long run and the demand for electricity by firms increases more marginally by 0.1% relative to the reference scenario.

Table 4 presents the effects on carbon dioxide emissions. Carbon dioxide emissions decrease by 25.9% relative to the reference scenario in 2050. Both firms and households reduce their emissions in response to the pricing policies in place for carbon as well as the incentives in place for use of renewable energies in electricity production. Firms reduce their carbon dioxide emissions by 27.1% relative to the reference scenario. The long run 23.4% reduction in carbon dioxide emissions by household are driven by emissions reductions associated with residential demand for fossil fuels. Residential demand for fossil fuels, especially heating oil and natural gas used for space heating as well as in cooking, can be relatively easily replaced by electric power and biomass used in wood-fired heating units and fireplaces. Carbon dioxide emissions from residential fossil fuel demand decreases by 40.9% relative to the reference scenario.

Table 3. Effects on the electric power industry. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Electricity Production	0.494	0.544	2.133	0.786
Thermal	−1.373	−5.584	−12.883	−23.665
Hydroelectric	−0.119	−0.401	−0.735	−1.128
On-shore Wind	5.431	17.328	30.175	44.161
Solar Photovoltaic	2.453	8.158	14.873	22.735
Percent of RES in Electricity Production	2.073	6.902	8.962	13.774
Net Imports of Electricity	−1.204	−2.118	−5.489	−1.961
Exports	1.384	1.525	5.966	2.249
Imports	−0.400	−0.449	−1.621	−0.677
Electricity Demand by Household	0.324	1.418	2.810	3.292
Electricity Demand by Sector	0.521	0.322	1.941	0.144
Carbon Tax w/o Revenue Recycling				
Electricity Production	−0.351	−2.083	−2.347	−5.311
Thermal	−1.080	−5.006	−10.826	−21.123
Hydroelectric	0.233	0.686	1.098	1.455
On-shore Wind	0.217	0.646	1.044	1.393
Solar Photovoltaic	0.117	0.377	0.654	0.927
Percent of RES in Electricity Production	0.756	3.148	4.503	8.220
Net Imports of Electricity	0.844	5.869	5.046	10.805
Exports	−0.996	−5.578	−6.355	−14.161
Imports	0.308	1.606	1.888	4.573
Electricity Demand by Household	−0.002	−0.194	−0.241	−1.179
Electricity Demand by Sector	−0.438	−2.513	−2.853	−6.336

Source: Authors' Calculations.

In contrast, reductions in transportation demand for energy are more limited due to the lack of easily accessible substitutes for fossil fuels in these applications. In the long run, carbon dioxide emissions associated with transportation demand for energy decrease by 16.9% relative to reference scenario.

Comparing the results in the top and bottom panels of Tables 1–4 we can highlight the contribution of the feed in tariff to decarbonization and the energy markets. Overall, the feed in tariff allow for a slightly deeper level of emissions reductions. This is true for both households and producers, with reductions of emissions of 2.9% and 1.0% respectively, greater in the long-term with a feed in tariff, for an aggregate improvement of 1.6%. Residential emissions are the most affected with a larger reduction of just under 4%.

Table 4. Effects on carbon dioxide emissions. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Carbon Dioxide Emissions	−1.862	−8.546	−13.583	−25.923
Carbon Dioxide Emissions by Households	−3.073	−11.720	−13.533	−23.365
Residential	−7.532	−24.967	−27.867	−40.897
Transportation	−1.525	−6.663	−8.099	−16.930
Carbon Dioxide Emissions by Firms	−1.480	−7.632	−13.606	−27.116
Carbon Tax w/o Revenue Recycling				
Carbon Dioxide Emissions	−1.806	−8.457	−13.278	−25.525
Carbon Dioxide Emissions by Households	−2.665	−11.221	−12.906	−22.710
Residential	−6.953	−23.996	−26.463	−39.324
Transportation	−1.165	−6.247	−7.656	−16.478
Carbon Dioxide Emissions by Firms	−1.534	−7.655	−13.445	−26.841

Note: Source: Authors' Calculations.

These improved outcomes in terms of emissions mirror the effects of the feed in tariffs on final energy prices, final energy demand and the electricity sector. Feed in tariffs lead to slightly lower overall final energy prices led by a decline in electricity prices and an easing of the reduction in final energy demand, with the share of electricity in final energy demand demand increasing substantially. With the feed in tariff, electricity demand increases particularly for households while the share of renewables in electricity production also increases substantially.

Overall, we can say that the use of the revenues from the carbon tax to finance a renewable energy feed in tariff deepens the level of emissions reductions while at the same time mitigates the adverse effects on energy demand associated with the carbon tax itself.

3.3. The macroeconomic and budgetary effects

Table 5 presents the macroeconomic and budgetary effects of the feed-in tariff financing mechanism under consideration. The increasing costs of energy—with the notable exception of electric power—limits the ability of households to purchase consumer goods and increases production costs, both of which contribute to decreased domestic demand and consumption. By 2050, private consumption decreases 2.9% relative to the reference scenario. The feed-in tariff, however, facilitates the large scale investment in and deployment of new renewable energy infrastructures which increases private investment by 0.7%.

The increase in domestic production costs due to the higher prices for energy products makes domestically produced goods less attractive in international markets and thereby worsens the current account balance in Portugal. Foreign debt increases by 4.0% over the long run relative to the reference scenario led by a 6.1% deterioration in the trade balance due to a close to 8.0% decrease in exports, though weaker domestic demand also contributes to a 2.5% decrease in imports by 2050.

Table 5. Effect on macroeconomic performance. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Gross Domestic Product	−0.019	−0.937	−1.092	−2.782
Private Consumption	−0.484	−1.112	−1.361	−2.827
Gross Fixed Capital Formation	2.566	2.029	2.195	0.655
Exports	−0.609	−3.103	−3.772	−7.974
Imports	0.056	−0.967	−1.086	−2.508
GDP Deflator	0.178	0.560	0.597	1.373
Employment	0.216	−0.244	−0.313	−1.173
Foreign Debt	0.446	1.504	2.778	3.995
Current Account Deficit	14.214	19.545	16.661	12.466
Trade Deficit	1.197	2.785	3.348	6.056
Public Debt	0.416	1.238	2.341	3.853
Carbon Tax w/o Revenue Recycling				
Gross Domestic Product	−0.276	−1.436	−1.784	−3.732
Private Consumption	−0.114	−0.708	−0.961	−2.442
Gross Fixed Capital Formation	−0.222	−1.300	−1.610	−3.588
Exports	−0.723	−3.545	−4.527	−9.060
Imports	−0.308	−1.422	−1.625	−3.111
GDP Deflator	0.120	0.652	0.820	1.801
Employment	−0.137	−0.717	−0.891	−1.874
Foreign Debt	0.086	0.842	2.361	4.405
Current Account Deficit	3.334	14.673	14.233	18.381
Trade Deficit	0.395	2.199	3.011	5.889
Public Debt	−0.280	−2.846	−7.111	−12.874

Source: Authors' Calculations.

The overall effect of reduced domestic demand and a worsening of the trade balance—despite the moderate uptick in private investment—is overall weaker economic performance. By 2050, GDP is 2.8% lower than the reference scenario.

By design, the financing policy itself is revenue neutral as the increase in revenues associated with the tax on carbon is used exclusively to promote the use of renewable energy in the electric power industry by financing a feed-in tariff. As a result, the overall effects on the public sector account are driven by second order effects on tax revenues due to economy-wide responses and tax interaction effects. The net result is an increase in public debt levels by 3.9% percent by 2050 relative to the reference scenario.

Comparing the results in the top and bottom panels of Table 5 we are able to examine the contribution of the feed in tariff to the macroeconomic performance. Overall, the allocation of the revenues from the carbon tax to a feed in tariff significantly mitigates the adverse macroeconomic effects of the carbon tax. Naturally, the most direct effect is on private investment, which now increases by 0.7% vis-à-vis the reference scenario while with the simple carbon tax private investment would decrease by 3.6%. This brings with itself a substantial reduction of the adverse effects on employment. As a consequence, GDP now falls by 2.8% in the long term relative to the reference scenario as opposed 3.7% in the simple carbon tax case, a 32% decline in the magnitude of the adverse effect of the carbon tax. Naturally, these marginal effects also reach private consumption, the trade balance, and the CPI, all of which show clearly better outcomes with the feed in tariff.

Overall, we can say that the use of the revenues from the carbon tax to finance a feed in tariff, greatly mitigates the adverse macroeconomic effects of the carbon tax itself.

3.4. The industry-specific effects

Table 6 presents the industry output effects. The overall output decline in the long-term relative to the reference scenario is 0.8%. The specific industry output effects depend on the types of energy used in the production process, the energy intensity of the production process, the industries exposure to international markets and the response of domestic consumers to increasing costs and prices.

Table 6. Output effects by sector of economic activity. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
Total	−0.019	−0.937	−1.092	−2.782
Petroleum Refining	−1.474	−7.535	−9.101	−18.741
Electricity Production	0.494	0.544	2.133	0.786
Biomass	0.060	0.334	0.429	0.747
Agriculture	−0.220	−1.144	−1.454	−3.216
Equipment Manufacturing	−0.334	−2.189	−3.110	−6.209
Construction	2.046	1.478	1.598	0.075
Transportation	−0.780	−4.281	−4.964	−10.884
Textiles	−0.464	−1.699	−2.061	−4.260
Wood, pulp and paper	−0.237	−1.620	−1.953	−4.439
Chemicals and pharmaceuticals	−0.606	−3.007	−3.474	−7.575
Rubber, plastic and ceramics	−0.412	−3.611	−4.239	−9.434
Primary metals	−0.213	−1.831	−2.350	−5.201
Other	−0.054	−0.489	−0.635	−1.517
Carbon Tax w/o Revenue Recycling				
Total	−0.276	−1.436	−1.784	−3.732
Petroleum Refining	−1.456	−7.494	−9.043	−18.589
Electricity Production	−0.351	−2.083	−2.347	−5.311
Biomass	0.341	1.126	1.718	2.536
Agriculture	−0.236	−1.239	−1.641	−3.507
Equipment Manufacturing	−0.747	−3.118	−4.549	−8.131
Construction	−0.218	−1.257	−1.548	−3.427
Transportation	−0.778	−4.320	−5.056	−11.001
Textiles	−0.340	−1.712	−2.240	−4.639
Wood, pulp and paper	−0.509	−2.349	−3.155	−6.084
Chemicals and pharmaceuticals	−0.648	−3.317	−4.066	−8.398
Rubber, plastic and ceramics	−0.949	−4.593	−5.666	−11.192
Primary metals	−0.627	−2.778	−3.833	−7.162
Other	−0.109	−0.625	−0.820	−1.837

Note: Source: Authors’ Calculations.

Naturally, because the feed-in tariff provides additional revenues to electric utilities and provides a strong incentive to expand production capacity for renewable energy sources, output of the electric power industry increases by 0.8% relative to the reference scenario by 2050. The capacity expansion encourages construction activities and marginally offsets some of the losses to equipment manufacturers. The most significant decreases in output levels are in transportation services for which few alternatives are commercially and technologically viable with a decline of 10.9%, as well as energy intensive industry, notably non-metallic mineral products—rubber, plastic and ceramics with a 9.4% decrease and chemical and pharmaceutical products with a 7.6% reduction relative to the reference scenario.

Comparing the results in the top and bottom panels of Table 6 we are able to ascertain the contribution of the feed in tariff to the economic performance at the industry level. Although one can say that the adverse effects of the carbon tax are mitigated with a feed in tariff across basically all sectors of activity, clearly the electric power industry and construction benefit the most. In both cases, feed in tariffs translate into positive output, employment and investment effects in these sectors while they both would see a decline along all of these dimensions under a simple carbon tax. Other sectors that benefit significantly from the feed in tariff compared to the simple carbon tax case, include, equipment, wood and related, rubber and related, and primary metals, all sectors clearly linked to investment activities.

Overall, we can say that the use of the revenues from the carbon tax to finance a feed in tariff greatly mitigates the adverse economic effects of the carbon tax itself across all sectors of activity. Clearly, the electric power industry and investment-related sectors stand to benefit the most.

3.5. Household welfare effects

Table 7 presents the policy’s distributional effects by quintile of income. The reduction in national income reflected in weaker GDP figures for 2050 is further reflected in reductions to the after-tax income for households. As the sources of income vary across income brackets the overall effects are felt in a rather unequal fashion among households. Lower income household groups tend to earn a more substantial amount of their income from labor while wealthier households have additional sources of capital income. As such, the increase in corporate income made possible due to gains among electric utilities and construction firms, both of which feature heavily in the PSI-20 the Portuguese stock market, translate to increases in income among the higher income groups offset by losses in income for the lower income groups.

Changes to household specific consumer price indices reflect the importance of energy products in the households’ basket of consumer goods. As noted above, energy products broadly and electricity in particular are generally normal and necessary goods which implies that lower income household groups tend to spend a larger fraction of their income on electricity than do wealther household groups – though these higher income groups do tend have higher power bills reflective of the larger home energy requirements for these household groups. The lower prices for electricity therefore contribute to greater gains for households in the lower income quintiles that marginally offsets increases in energy costs among the remaining energy products consumed by households.

Personal automobiles, however, are less prevalent among households at the lowest income group who tend to rely more on public transportation services. As a result, consumer prices for households in the lowest income quintile increase by 3.7% over the long run, just less than those in the second income quintile who are expected to see a 3.9% increase in consumer prices relative to the reference scenario. After this level of income, a more traditional pattern of consumer price increases reflecting a decreasing expenditure share for energy products in the household budget emerges.

Table 7. Distributional effects on households: equivalent variation in income. (Percent Change Relative to the Reference Scenario).

	2020	2030	2040	2050
Green Energy Feed-in Tariff Financed by Carbon Tax				
First Quintile (Lowest Income)	−0.370	−1.457	−1.727	−3.986
Second Quintile	−0.389	−1.452	−1.748	−3.972
Third Quintile	−0.493	−1.195	−1.454	−3.060
Fourth Quintile	−0.564	−1.010	−1.246	−2.414
Fifth Quintile (Highest Income)	−0.495	−0.906	−1.137	−2.221
Carbon Tax w/o Revenue Recycling				
First Quintile (Lowest Income)	−0.263	−1.498	−1.910	−4.358
Second Quintile	−0.247	−1.425	−1.828	−4.207
Third Quintile	−0.124	−0.834	−1.121	−2.797
Fourth Quintile	−0.034	−0.395	−0.602	−1.755
Fifth Quintile (Highest Income)	−0.032	−0.367	−0.559	−1.627

Note: Source: Authors' Calculations.

The effects of a feed-in tariff financed by a tax on carbon on the after-tax income of households and on the costs of a typical basket of goods and services paid for by each household group contributes towards a regressive effect of the policy; this effect is reflected in equivalent variations in income for the policy that decrease with income level. Households in the lowest income group experience a welfare loss equivalent to a 4.0% percent reduction in well-being relative to the reference scenario while those in wealthiest households see a 2.2% reduction in welfare relative to the reference scenario by 2050.

We can ascertain the contribution of the feed in tariff at the household distributional level by comparing the results in the top and bottom panels of Table 7. Overall, the feed in tariff reduce the welfare losses induced by the carbon tax for the three lowest income groups despite a greater loss by the two highest income groups. This also implies that the feed in tariff make the distributional effects of the carbon tax less regressive. The factor of regressivity—the adverse effects of the lowest income group over the adverse effects of the highest income groups—is 2.7 in the simple carbon tax case and it is 1.8 under the feed in tariff scheme.

4. Concluding remarks

The quest for the decarbonization in Portugal requires a dual path. On one hand, it requires mechanisms toward pricing the environmental costs associated with fossil fuels. In this context, a carbon tax is a prime candidate. On the other hand, it requires the electrification of the economy. Necessarily, and to be an effective component of a strategy of decarbonization of the economy, such electrification needs to be based on the widespread use of electricity generated from renewable sources. In this context, incentives for the use of renewable electric power capacity is critical. It is, therefore, only natural to assume that the use of the revenues from a carbon tax to finance renewable electricity production would lead the most desirable outcomes.

In this paper, we evaluate the environmental, economic and distributional effects of such a policy in Portugal in the context of a multi-sectoral dynamic general equilibrium model. We show that a carbon tax eventually growing by 2050 to 183 euros per ton of CO_2 emissions couple with the use of the corresponding revenues as a feed-in tariff for the production of electricity from renewable sources allows indeed for a sharp decline in CO_2 emissions. In this sense, this is an effective policy with environmental concerns as the overriding consideration.

Our simulation results also show that the macroeconomic effects of such policy are less than innocuous, leading to a weakening in economic performance—measured by GDP, consumption, investment, employment, and the trade balance—while at the same time financing a feed in tariff with a tax on carbon leads to adverse negative welfare effects across the broad which are regressive. This means that a carbon tax with revenues recycled to finance a feed in tariff, as appealing as it may be from an environmental perspective, fails to deliver a win-win outcome for environmental policy—it has adverse effects in terms of macroeconomic efficiency and social justice.

On the flip side however, we show that use of the carbon tax revenues to finance a feed in tariff is an improvement over the simple carbon tax case along all the relevant policy dimensions. The feed in tariff mechanism leads to better environmental outcomes at lower costs both in terms of the economic and social justice implications.

From a policy perspective, these results highlight two very important facts. First, the use of the revenues of a carbon tax to finance feed in tariffs represents an improvement over a simple carbon tax. In this sense, a carbon tax should not be implemented in isolation. Rather, at the very least, it should be combined with a green energy financing mechanism like a feed in tariff. Second, the effects of the combined policies of a carbon tax and feed in tariffs still yield potentially adverse macroeconomic and distributional effects that may be enough to jeopardize support among voters and from political actors thereby sowing the seeds of inertia. In this sense, the quest for recycling mechanisms for the carbon tax revenues that may reverse the adverse macroeconomic and distributional effects is wide open.

Overall, our results show that the idea that, given the necessary paths toward decarbonization, using the revenues from a carbon tax to finance renewable electricity production would lead the most desirable outcomes is only very partially correct. It is correct from an environmental perspective in that it leads to a faster path to decarbonization. At the same time, by not eliminating the adverse macroeconomic and distributional effects of the carbon tax, this strategy falls short of creating the political economy context conducive to the adoption of decarbonization policies. In this sense, it really falls short on the macroeconomic and distributional fronts. This is the missing piece.

Conflict of interests

The Author declares no conflict of interest.

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