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On the Spillover Effects of CO2 Taxation on the Emissions of other Air Pollutants (*)

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Abstract

In this paper, we compare and contrast the environmental, macroeconomic and distributive effects of CO2 taxation with the effects of taxing a variety of air pollutants at their external costs. We do so using a multi-sector and multi-household dynamic computable general equilibrium model of the Portuguese economy. We find that a carbon tax of 114 euros per ton of CO2 is necessary to achieve the IPCC 2030 targets. It does so, however, at a high macroeconomic and distributional cost. In turn, the macroeconomic and distributional effects of taxing different pollutants at their external costs in line both qualitatively and quantitatively with the effects of the CO2 taxation. In absolute terms, however, better environmental results in terms of GHG and air pollutants emissions are achieved through the level of CO2 taxation necessary to achieve the IPCC targets than through direct taxation of such emissions at their external costs. Ultimately, the benefits of complementing the CO2 taxation with the taxation of other air pollutants at their external costs does not seem significant from either efficiency, fairness, or environmental perspectives to justify the practical complexity of considering it.

JEL Classification: CO2 Taxation; Taxation of Air Pollutants; Co-Pollutants; Spillover Effects of CO2 taxation; IPCC Targets; General Equilibrium; Portugal.

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

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1. Introduction

The purpose of this paper is to identify the environmental, macroeconomic and distributional effects of carbon taxation and of the taxation of a multiplicity of air pollution at their external costs. The practical objective is to determine whether the use of a myriad of policy instruments to correct air pollution externalities is necessary in the presence of the carbon taxation necessary to achieve IPCC targets and when we account for co-pollution from fossil fuel combustion.

Recently, the IPCC (2018) special report concluded that limiting global warming to 1.5°C would require “rapid and far-reaching” transitions in land, energy, industry, buildings, transport, and cities. Global net anthropogenic emissions of CO2 would need to fall by about 45% from 2010 levels by 2030, reaching ‘net zero’ around 2050, with neutrality of the remaining greenhouse gases to be achieved soon thereafter. Special attention has to be paid to the consumption of fossil fuels as the primary contributor to greenhouse gas emissions and the leading anthropogenic cause of climate change.

In Portugal, the Roadmap for Carbon Neutrality [RNC2050, hereafter] was presented to the public in late 2018 and was approved by the government in middle 2019 [see MATE (2019)]. In the RNC2050, these different environmental and decarbonization targets were duly incorporated and specific pathways presented to achieve such targets. There is now a lively policy debate on the specific public policy mechanisms to be adopted to implement such pathways. A centerpiece of such mechanisms is carbon pricing in particular carbon taxation.

While decarbonization is the central issue in environmental policy in Portugal, it is not the only one. Indeed, great concern exists with air quality, for example. Despite substantial improvements over the last few of decades, there remain persistent problems with air pollution affecting human health and the ecosystems. To revert the situation important reduction in emissions of sulphur dioxide, nitrogen oxides, volatile organic matter, particulate matter, carbon monoxide and ammonia have to be achieved in the next couple of decades [See, for example, the national strategy for achieving air quality in Portugal, APA (2018)]

This is a critical issue. Fossil fuel combustion leads directly to global carbon dioxide emissions. In addition, it also leads to the emission of local air pollutants, either directly in the form of sulphur dioxide and nitrogen oxides, or indirectly through road transportation, such as particulate matter, volatile organic matter and carbon monoxide. These local air pollutants are exactly the cause of the damage to human settlements and the natural environment [see IPCC (2014)]. These local air pollutants are exactly the focus of the domestic policies on the matter.

The tax system in Portugal provides a broad range of incentives that influence choices made by consumers and producers in the energy system. The current tax system is designed based, in part, on the energy content of fuels and the need to raise funds for the public budget and not on the emissions content of the fuels. This fully justifies the need for energy taxation reform bringing the energy taxation more in line with the emissions content of the different pollutants and/or their external costs. Accordingly, reform to the current tax on energy products based on the environmental costs associated with the consumption of fossil fuels can help to internalize the external environmental costs associated with fossil fuel use and create a more focused fiscal policy instrument with the ability to address inefficiencies in energy markets while raising revenue for the public sector.

A key political economy question is the concern with the existence of multiple environmental objectives and the potential need for a large number of policy instruments. This is an issue conceptually because as argued above the emissions of many of these pollutants are connected and in practical terms because the political environment is not particularly conducive to the introduction on multiple taxes and/or fees. This raises the question of identifying the effects of an overarching policy to reach the IPCC goals through proper pricing of carbon emissions on the emissions of the co-pollutants and the other greenhouse gases. Specifically, the question is to determine how much taxing carbon emissions at a level necessary to achieve IPCC goals affects the other emissions and how it compares with taxing such emissions at their own external costs.

In this paper, we compare the environmental, macroeconomic and distributive effects of a CO2 tax with the effects of taxing a variety of air pollutants at their external costs. To do so, we use the most recent version of the DGEP, the dynamic general equilibrium model of the Portuguese economy. Previous versions of this model have been used recently to address energy and climate policy issues [see Pereira and Pereira (2014a, 2014b, 2017a, 2017b, 2017c) and Pereira et al. (2016)]. This model has a detailed description of the tax system and a relatively fine differentiation of consumer and producer goods, particularly those with a focus on energy products. We consider twenty-two sectors spanning the all spectrum of economic activity. Household heterogeneity in income and consumption patterns is captured by differentiating among five household groups based on income levels.

This paper builds upon a well-established literature on co-pollutants and the co-benefits of environmental policies. Parry (2015) and Coady et al (2018), provide overall reviews of the conceptual issues for the design of fiscal policies to address the external costs of energy use. Fullerton and Karney (2018) and Ambec and Coria (2018) Stranlund and Son (2019) provide conceptual discussions of the co-benefits of policies to address GHG emissions and local air pollutant emissions under different situations. Finally, Fichtner et al (2003), Jiang et al. (2103) Lott et al. (2017), Li et al. (2019) for applied discussions with more of a technological focus.

This paper is organized as follows. In Section 2, we present the DGEP model and discuss data and implementation issues. In Section 3, we briefly present the modelling of the different greenhouse gases and different pollutants. In Section 4, we present and discuss the simulation results. Finally, In Section 5, we offer 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 and general description of the design and implementation of the new multi-sector, multi-household dynamic general equilibrium model. Detailed information is provided in Pereira and Pereira (2017d).

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 given by the behavioral equations, the equations of motion of 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 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. As calibration is designed to reflect the long-term trajectory of the economy, rather than focusing on a single year of data, we use a ten-year interval. This reflects the most recently available performance of the economy and it roughly captures an entire business cycle thereby avoiding contaminating the calibrated model with business cycle effects. 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, 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. 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, which are superimposed on the steady state trajectory used in the calibration of the model.

The principal climate policy considerations present in our reference scenario are first, that the tax of 6.85 Euro/tCO2 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. 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 developed by the International Energy Agency (2018).

3. On the Modelling of Greenhouse Gases and Air Pollutants

3.1. Greenhouse Gases

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.

3.2 Air Pollutants

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.

3.3. On the Modelling of the Different 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 of the different policies: 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 two following effects of policies: effects due to changes in the level of economic activity; and effects due to changes in the composition of economic activity. Accordingly, in this work, the effects of the different policies on process-based emissions are underestimated by the amount of process switching the policies may generate.

It should be noted that, given the focus and level of aggregation of the analysis, we implicitly assume that the different co-pollutants are complements with carbon dioxide. Although there is a debate in the literature on whether one should observe complementary of substitution among co-pollutants our approach is consistent with the arguments and evidence in Fullerton and Karney (2018) to the effect that under the most plausible parameter specifications emissions of CO2 and co-pollutants are complements.

3.4 Benefits Table Database (BeTa) for Air Pollutants

Of the air pollutants considered above we consider taxation of sulphur dioxide, oxides of nitrogen, particulate matter, volatile organic compounds and carbon monoxide – all in some way related to combustion or closely related activities - at their external costs.

The assessment of the externalities from emissions SO2, NOx, PM, and VOC are based on the calculation of the estimated damages from air pollution follow the ExternE methodology, ExternE (2019). In turn, the data for the external costs of carbon monoxide (CO) is from the Israel Ministry of Environmental Protection (2018).

[Table 1]

The external effects included in these figures are as follows: acute effects of PM and SO2 on mortality and morbidity; chronic effects of PM on mortality and morbidity; effects of SO2 and acidity on materials used in buildings and other structures; and effects on arable crop yield. Among the effects that are not included we should mention: non-ozone effects on agriculture; change in visibility; impacts on ecosystems through eutrophication of waterways; and damage to cultural heritage.

As one can observe in Table 1, the external costs of the different pollutants for Portugal are in general substantially below the EU-15 average. This is due to differences in purchasing power vis-à-vis the other countries and to the fact that some of measured externalities depend critically on standards of living, population density, etc.

4. Simulation Results

We start by analyzing the environmental, macroeconomic, and distributional effects of a CO2 tax of the magnitude necessary to reach IPCC 2018 goal of a 45% reduction in CO2 emissions by 2030 relative to the 2010 levels. Then, we consider the corresponding effects of taxing the different air pollutants at their external costs. We present the simulation results in Tables 2 - 8.

[Tables 2 - 8]

4.1. On the Effects of CO2 Taxation

The magnitude of the carbon tax necessary to reach IPCC 2018 CO2 reduction goals is 114 euros per ton of CO2. This tax generates tax revenues that are approximately 1.85% of the GDP.

Effects on Energy Markets and Emissions

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

The introduction of the CO2 tax leads to a reduction in CO2 emissions of 36.02% which represents 53.8% of the 2010 levels. The CO2 tax induces significant reductions in other GHG emissions, in particular CH4 and in N2O emissions, which decline by 25.29% and 30.73%. It induces smaller reductions for emissions of HFC, PFC, and SF6.

The CO2 tax leads also to significant reductions of emissions of air pollutants. This is true particularly for emissions of NOx, SO2, CO, and PM, which decline by 37.22%, 43.13%, 51.08%, and 71.71%, respectively and less so for emissions of VOC and NH3.

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 increased 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, basic metals, equipment, and transportation as well as textiles, wood and chemicals. These are all internationally traded goods.

Overall, there is an aggregate welfare loss of 1.34%. Across the different 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 Taxing other Pollutants at their External Costs

In counterfactual simulation CF2, we consider the results of taxing air pollutants at their external costs as detailed in Table 1. The corresponding tax revenues are 0.67% of the GDP and therefore about 36% of the CO2 tax revenues considered in CF1.

Effects on Energy Markets and Emissions

The effects on the energy market essentially mirror the effects induced by the CO2 tax. Quantitatively, they are in line with the relative magnitude of the two policies. Qualitatively, there are no significant changes in the observed patterns of results.

In turn, CO2 emissions decrease by 21.38%, which means that they reach 73.2% of the 2010 levels. This compares to 36.02% reduction and 53.8% of 2010 levels under the CO2 tax. Therefore, the reduction in CO2 emissions are now about 60% of what was simulated under CF1. Accordingly, there is a substantial cross effect on CO2 emissions coming from the reduction in economic activity but also from the fact that that the pollutants being taxed are directly or indirectly related to the combustion of fossil fuels.

The cross effects on emissions of other GHG are quite in line with the relative magnitude of the two policies except for N2O, in which case the reduction is now 15.50% or about 50% of what observed under the CO2 tax.

In turn, reductions in air pollutants are enhanced greatly under the direct taxation of their external costs. The largest reductions occur with emissions NOx, SO2, CO, and PM, which decline by 25.45%, 31.57%, 34.14%, and 55.69%, respectively and less so for emissions of VOC and NH3.

Overall, with an overall tax levy just over one third of the CF1 case, under direct taxation of their external costs emissions of air pollutants decrease by about two-thirds of what is observed under CF1. Naturally, the individual tax levy on each of the different air pollutants is much smaller. This indicates that direct taxation of these air pollutants is substantially more effective in terms of the tax costs involved than indirect reductions through CO2 taxation.

Interestingly enough, however, the reductions in emissions of air pollutants we observe under direct taxation of their external costs are, across the board, lower than what is achieved though taxation of CO2. This means that in absolute terms we achieve better environmental results in terms of the air pollutants through the CO2 taxation necessary to reach IPCC targets. The same is true for all of the GHG emissions. Just taxing carbon emissions at a level necessary to reach IPCC targets leads to greater reductions of air pollution emissions than what would be accomplished through their taxation at the level of their external costs.

Economic and Distributional Effects

The macroeconomic effects under CF2 are, broadly speaking, about one-third of the effects observed under CF1. Therefore, they are in line with the relative magnitude of the two policies. Qualitatively, there are no changes.

The sectors affected under CF2 are essentially the same as under CF1 although there are some small differences in the relative importance of the outputs reductions across sectors compared to CF1. Petroleum refining, electricity generations, and transportation are clearly affected more than proportionally to the relative magnitude of the two policies, while textiles, wood, chemicals, and rubber are clearly affected less than proportionally.

Overall, the welfare losses are 0.49%, which is in line with the relative magnitude of the two policies. The same pattern of regressivity is observed under both policies.

5. Concluding Remarks

In this paper, we compare the environmental, macroeconomic and distributive effects of a CO2 tax with the effects of taxing a variety of air pollutants at their external costs. We do so using the recent version of the DGEP, the dynamic general equilibrium model of the Portuguese economy. Our objective is to identify the relevance of the environmental spillovers of CO2 taxation.

We can summarize our simulation results as follows. A carbon tax of 114 euros per ton imposed on top of the current energy taxation is enough to achieve the IPCC 2030 targets as well as significant reductions in other GHG emissions as well as emissions of air pollutants. It does so, however, at a high macroeconomic and distributional cost. The macroeconomic and distributional effects of taxing different pollutants at their external costs are closely aligned with the effects of carbon taxation. They show the same qualitative patterns and the different in magnitude is in line with the relative magnitude of the two policies. Yet, under the taxation of different air pollutants at their external costs, CO2, N2O, NOx, SO2, CO, and PM emissions decline much more than proportionally vis-à-vis the relative magnitude of the two policies. Still, such policy is not enough to generate the desired reductions in CO2 emissions. More importantly, however, in absolute terms better environmental results in terms of GHG emissions and the air pollutants are achieved through CO2 taxation than through direct taxation of such emissions at their external costs.

The results pertaining the introduction of other GHG gases and the different air pollutants raise the question of the environmental relevance of independent taxation of the different air polllutants in addition to CO2 taxation. That is, it questions the relevance of using multiple tax instruments to achieve reductions in different emissions that are linked through technological and economic conditions. Ultimately, the benefits of complementing the taxation of carbon dioxide with the taxation of other air pollutants at their external costs does not seem significant from either efficiency, fairness or environmental perspectives to justify the complexity of considering them. Indeed, a greater reduction in the emissions of all GHG and of all air pollutants is achieved simply by using a CO2 tax to achieve the IPCC CO2 emissions targets.

These results and recommendations are fully consistent with recent evidence in the literature. For example, Muller (2012) and Crago and Stranlund (2015) show that co-benefits of GHG policies can be significant in magnitude and argue that it is not socially beneficial that climate policies should be tailored to reflect these local air pollution co-benefits. In turn, Brunel and Johnson (2019) local pollution policies are unlikely to be of the magnitude necessary to address greenhouse gas targets. We add the macroeconomic and distributional dimension to the issue to suggest that the policy focus should be on developing an adequate carbon tax and counting on its spillovers to achieve the desired reductions in the emissions of air pollutants.

This research opens the door to a few critical follow-ups from a practical environmental policy perspective. In this work, we assume that the revenues from carbon taxation are not recycled, i.e., they revert to the general government budget. There is, however, plenty of evidence that careful recycling of such revenues is necessary if the adverse macroeconomic and distributional effects of carbon taxation are to be avoided. [See, for example, Marron and Toder (2014), Jorgenson et al (2015), and Kirchner et al (2019)]. Naturally, different recycling strategies have different macroeconomic and distributional effects and therefore different potential for rebound effects in terms of the use of the different fossil fuels and the corresponding emissions of CO2 and co-pollutants. On the flip side Parry et al (2015) highlight the relevance of recycling mechanisms in the presence of co-pollutants to increase the co-benefits of carbon policies.

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 significant challenges in terms of air pollution widespread. The concerns over the macroeconomic and distributional effects of environmental policies and the quest for parsimony in the choice of instruments unavoidable if there is some hope of meaningful policies ever being adopted.

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Figure 1 - Greenhouse Gas Emissions in 2016: 67.621 Mt CO2e

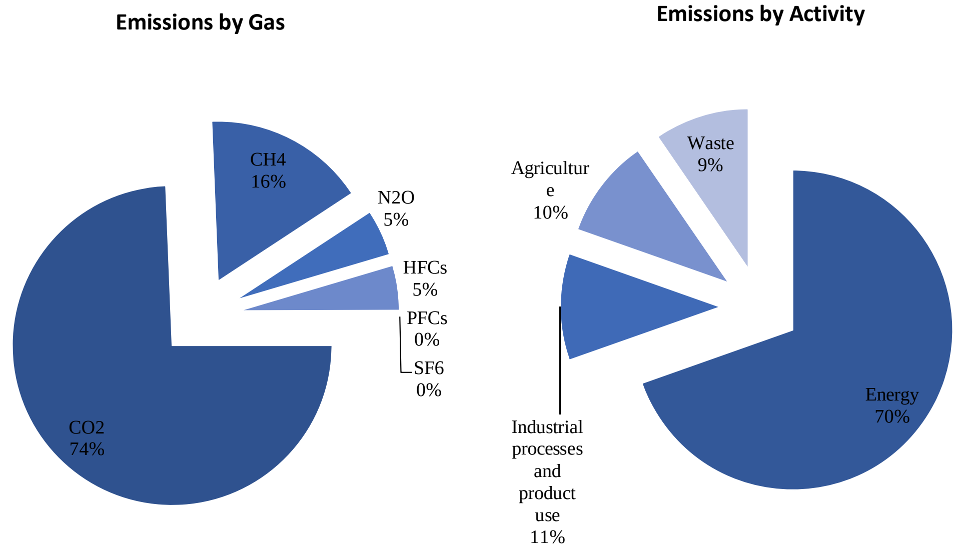

Figure 2 - Air Pollutants in 2015

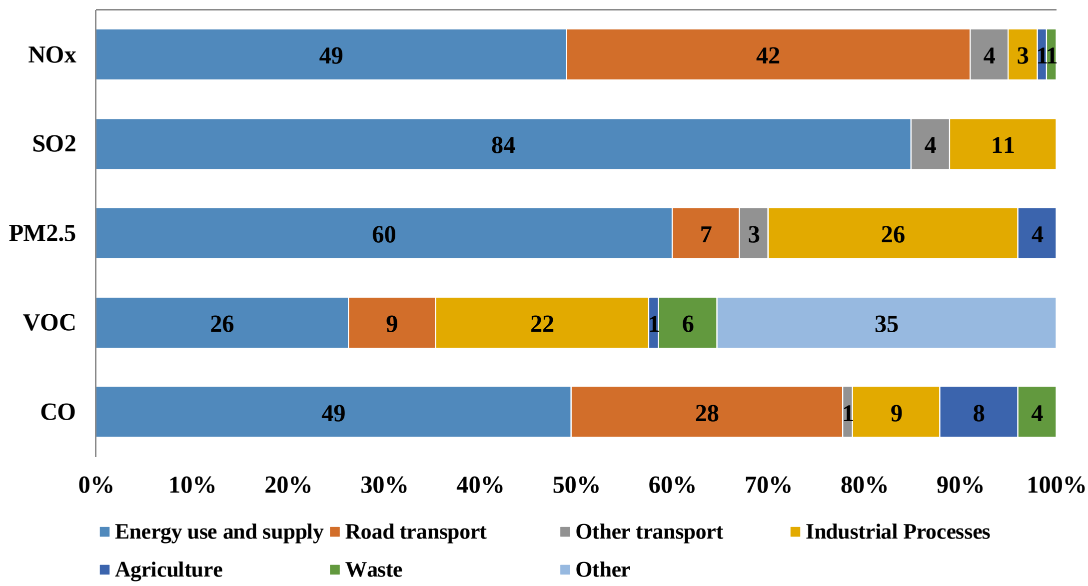

Table 1 - External Costs from Air Pollution

Unit: Euros per ton

	SO2	NOx	PM2.5	VOC
Austria	7,200	6,800	14,000	1,400
Belgium	7,900	4,700	22,000	3,000
Denmark	3,300	3,300	5,400	7,200
Finland	970	1,500	1,400	490
France	7,400	8,200	15,000	2,000
Germany	6,100	4,100	16,000	2,800
Greece	4,100	6,000	7,800	930
Ireland	2,600	2,800	4,100	1,300
Italy	5,000	7,100	12,000	2,800
Netherlands	7,000	4,000	18,000	2,400
Portugal	**3,000**	**4,100**	**5,800**	**1,500**
Spain	3,700	4,700	7,900	880
Sweden	1,700	2,600	1,700	680
UK	4,500	2,600	9,700	1,900
EU-15	5,200	4,200	14,000	2,100

Table 2 - Energy Taxes

% of GDP

	Reference	CF1	CF2
Environmental Taxes	2.28	3.90	2.89
Road Contribution	0.22	0.21	0.22
Tax on Oil Products - ISP	1.90	1.84	1.82
CO2 Tax	0.16	1.85	0.16
Taxes on Other pollutants	0.00	0.00	0.67

Table 1 Long Run [2030] Effects on the Energy Markets

Percent Change from Baseline

	CF1	CF2
Carbon Tax	114	0
Energy Price	13.91	4.83
Electricity Price	12.59	4.66
Electricity Production	-10.17	-4.07
Thermal Generation	-25.61	-10.33
Renewable Energy Systems	-2.18	-0.98
Net Electricity Imports	12.81	5.09
Energy Demand	-12.40	-4.72
Electricity Demand	-9.80	-3.92
% Electricity in Final Energy Demand	2.97	0.84

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