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Alfredo Marvão Pereira | Rui Manuel Pereira

Gabinete de Estratégia e Estudos do Ministério da Economia
Office for Strategy and Studies of the Ministry of Economy
Rua da Prata, n.º 8 – 1149-057 Lisboa – Portugal
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Regulated Early Closures of Coal-Fired Power Plants and Tougher Energy Taxation on Electricity Production: Synergy or Rivalry? [1]

Alfredo Marvão Pereira [2], Rui Manuel Pereira [3]

Abstract

This article examines the economic, budgetary, distributional and environmental impacts of the interaction between regulated early closure of coal-fired power plants and new energy taxation rules on fossil fuel-operated power plants using a multi-sector and multi-household dynamic general equilibrium model of the Portuguese economy. Simulation results show first that regulated early closures will lead to meaningful reductions in emissions. They will also induce significant detrimental macroeconomic and distributional effects. Second, when the new energy taxation rules are applied to the coal-operated power plants no significant environmental gains or macroeconomic or distributional losses are observed in addition to what already induced by the forced closures. Only the public sector seems to benefit in the form of additional tax revenues. A different situation occurs, however, if the operators of the coal-fired power plants react to the new energy taxes levied on them by unilaterally deciding to decommission their installations. In this case, although the environmental effects will improve, the adverse macroeconomic and distributional effects will substantially deteriorate. Noticeably, the adverse budgetary effects will also be substantially larger. Overall, we find no synergies between the two policies and, actually, the potential for the opposite to be true.

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

Keywords: Dynamic General Equilibrium, Coal-operated Power Plants, Energy Taxes, Macroeconomic Effects, Distributional Effects, Environmental Effects, Portugal

Note: This article is sole responsibility of the authors and do not necessarily reflect the positions of GEE or the Portuguese Ministry of Economy.

[1] The authors want to thank Ana Quelhas, Maria Pedroso Ferreira, and Ana Cristina Nunes for very useful discussions and suggestions. This is the second of two twin papers dealing with the regulated early closures of the two Portuguese coal-fired power plants. The other paper "On the Macroeconomic and Distributional Effects of the Regulated Closure of Coal-Operated Power Plants," [see Pereira and Pereira (2019)], focuses on the detailed effects of the regulated early closure and how they compare with alternative ways of achieving the same environmental effects.

[2] Department of Economics, The College of William and Mary, Williamsburg VA 23187

[3] Department of Economics, The College of William and Mary, Williamsburg VA 23187

1. Introduction

In November 2017, the Portuguese Government announced its commitment to retire all coal-fired power plants by 2030. In addition, in the context of the 2018 State Budget, the tax on energy products (*Impostos sobre Produtos Petroliferos e Energéticos*, ISP hereafter) was extended to include the taxation of coal used in electricity generation. This extension has a fixed component of 4.26 Euros per ton of coal used and a variable component, which depends on the carbon content of the coal and is indexed to the carbon price in the European Union Emissions Trading System (EU-ETS hereafter).

Portugal has two large coal-fired power plants, one in Sines and the other in Pego. The Sines plant was commissioned in 1985, has a capacity of 1192 MW, and is operated by Energias de Portugal (EDP). The Pego plant was commissioned in 1993, it has a capacity of 628 MW and is operated by Tejo Energia, a joint venture between TrustEnergy and Endesa Generation. These two plants play a major role in the Portuguese energy system. Thermal production of electricity from coal accounted for 26% of the electricity generated in Portugal in 2017: 18% from Sines, and 8% from Pego [DGEG (2018)]. These power plants account for more than half of thermal production of electricity in Portugal with natural gas accounting for the remainder. In addition, coal-fired units are a substantial component of electric power operators generating portfolios. In 2017, the production of electricity from coal in Sines accounted for about 12.5% of the electricity produced by EDP and the production of electricity from coal in Pego accounted for about 42.7% of the electricity produced by Endesa [EDP (2018)].

The environmental impact of these coal-fired power plants is very substantial. In 2017, Sines and Pego accounted for 19.1% of carbon dioxide emissions in Portugal. In fact, they were the two largest individual contributors to greenhouse gases emissions in the country [APA (2018)]. Therefore, it is not surprising that increasing efforts of environmental groups and increasing awareness by the policy makers ultimately translated into the regulated early closure of the two power plants by 2030.

In this paper, we consider three research questions. First, want to identify the effects of closing coal-fired power plants in 2030 in the absence of any changes in the ISP taxation. Second, we want to determine the effects of the changes in ISP tax rules if the coal-fired power plants close by 2030 as scheduled. Third, we want to establish the effects of the changes in ISP tax rules in an environment in which operators decide to close the plants ahead of the scheduled closure dates as a response to the increases in operation costs implied by the new ISP rules.

We address these questions in the context of a multi-sector, multi-household dynamic computable general equilibrium model of the Portuguese economy that builds upon the aggregate dynamic general equilibrium model, known as DGEP. Previous versions of this model are documented in Pereira and Pereira (2014c), and 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)]. The current version of the model has a detailed description of the tax system. On the production side, it features a fine differentiation of consumer and producer goods, particularly those with a focus on energy products. On the household side, 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. For general surveys see Bhattacharyya (1996), Bergman (2005), and Ballard et al. (2009). For a discussion of the merits and concerns with this approach see Sbordone et al. (2010) and Blanchard (2016). In general

terms, our model follows in the tradition of the early models developed by Borges and Goulder (1984) and Ballard, Fullerton, Shoven and Whalley (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).

The remainder of this article proceeds as follows. Section 2 provides a brief description of the disaggregated dynamic general equilibrium model. Section 3 presents the effect of closing the coal fired power plants by 2030. Section 4 discusses the impact of the extension of the tax on energy products to coal used in electricity generation and the effects of accelerated plant closures. Finally, section 5 provides a summary, policy implications, and concluding thoughts.

2. The Dynamic General Equilibrium Model and Simulation Design

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 of the Portuguese economy. See Pereira and Pereira (2017d) 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 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 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 through demand and supply mechanisms 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. 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 link between subsequent time periods. Accordingly, 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 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 prices 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.

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 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.

3. Reference Case, Counterfactual Scenarios and Simulation Design

3.1 Reference Case

The numerical implementation and calibration of the model is consistent with the economy being in a long-term steady state trajectory. The reference case for our simulations is obtained from this steady state trajectory by incorporating into it international fossil fuel price as projected by the International Energy Agency and carbon dioxide prices as forecasted by the Bloomberg News Energy Finance Group. Our reference case assumes that coal-fired power plants are operational indefinitely, and that the ISP tax rules on such activities in effect in 2017 apply for the time horizon of the model.

3.2 Counterfactual Scenarios and Simulation Design

The counterfactual scenarios are designed around two issues: first, the scheduled closure of Sines and Pego in 2030, as announced by the Government on November 2017; and, second, the changes to the ISP tax after 2018 to include coal used in the generation of electricity, which will impact the competitiveness of these power plants in the short term. In CF1, we consider the effects of the regulated early closure of the two coal-operated power plants in the presence of the old ISP tax rules.

There are two sets of additional ISP rules. The first is an energy component, a unit tax which consists of a fixed amount depending directly on the volume of coal used. The second is an additional component, a tax that reflects the carbon content of coal and which is indexed to the price of carbon in the EU-ETS. Specifically, the unit tax rate applying to the purchases of a ton of coal is given by:

$$\tau_{isp,fuel,t} = \tau_{unit,fuel,t} + \tau_{carbon,c,t} \times \varepsilon_{carbon,c}$$

where, $\varepsilon_{carbon,c}$ is the conversion factor between physical units of coal and its carbon content.

The effect of the additional tax burden will depend on how long the coal-operated power plants will remain active. At the same time, the increase in fuel costs for electric power facilities associated with the expanded ISP tax is expected to move up the effective closure dates for the two power plants as a result of operational considerations. The policy, as designed, will make the plants unprofitable and lead to their closure years earlier than the date determined by the functional life expectancy of the plant. In this case,

operators in the electric power industry will react to the additional tax burden with an accelerated closure schedule.

Accordingly, we consider four counterfactual scenarios. We consider first a set of scenarios, CF2 and CF3, in which the extension to the ISP includes only the fixed unit tax on energy, and then a second set of scenarios, CF4 and CF5, in which both the energy and carbon tax components are in place. In CF2 and CF4 there is no reaction by operators in the electric power industry and the plant closure will be as scheduled in 2030. In turn, in CF3 and CF5 the industry responds to the additional tax burden by closing the plants ahead of schedule. Specifically, we consider that the increase in fuel costs associated with the energy component of the tax moves up the plant closure by 5 years (from 2030 to 2025). In addition, the increase in fuel costs driven by both the base fixed energy tax and the carbon content of the fuel are large enough to justify the closure of these plants 10 years earlier than expected based on operational considerations. We present the list of simulation results in Table 1.

3.3 On the Presentation of the Simulation Results

We present the simulation results as percent deviations from the reference scenario, thereby allowing for a direct comparison across counterfactual scenarios. In Tables 2 - 5, we focus on the effects of the different policy scenarios as simulated for 2040, which we refer to as long-term effects.

While the coal-operated power plants remain active, the higher costs associated with the production of electricity from coal due to the increase in the ISP tax burden will increase the cost of generating electricity relative to the status quo. Naturally, such price effects disappear in the long term as both power plants eventually close. Accordingly, the main differences among the five scenarios are going to be short-term transitional effects. We would not expect significant differences in the long-run trajectories for the flow variables. The same is not true, naturally, for the stock variables, such as public and foreign deficits or accumulated reduction in emissions.

Accordingly, in most of our discussion of the results we focus in the differences in the transitional effects of the different policies as well as their cumulative effects by 2040. See Tables 6 – 12. Finally, Table 13 presents a snapshot of the main effects of the policies relative to the simple case of the regulated early closure in 2030, CF1.

3.4 A Note on Electricity Prices in General Equilibrium

Lastly, as the price of electricity plays such a critical role in our analysis, and given the different notions prevalent in the literature as to what they represent, it is important to clarify the exact meaning of electricity prices in general equilibrium. In our model, electricity prices are market-clearing prices under general competitive market assumptions.

Electricity prices reflect equilibrium conditions and therefore a balance between supply and demand conditions. Ultimately, they can be conceptualized as average production prices for the amounts of electricity produced under the prevailing market demand conditions.

On the supply side, prices reflect all costs of production: capital, labor, energy, and materials. Because of the dynamic nature of the model, all stocks have fixed costs in the short term but are variable in the long term. On the demand side, prices reflect additional considerations induced by fuel substitution effects by households and businesses as well as higher production costs by businesses across all sectors of

economic activity. They reflect income effects and losses in purchasing power by households due to higher prices across sectors of economic activity and feedbacks that affect consumers' budget constraints.

4. Simulation Results

4.1 Effects of Regulated Early Closures: CF1

Overall, closures and limits to the coal generating capacity in Portugal result in an increase in electricity prices. The electric power system adjusts to the plant closures by partially replacing coal-operated generation with natural gas. Where possible, further expanding investment in renewable energy, including hydroelectric facilities, wind turbines and solar energy systems will provide for a cost-effective way to address the capacity shortfall associated with discontinuing coal-operated electricity generating units. Finally, an increase in electricity imports partially compensates the decline in domestic electric production.

The closure of the coal-operated power plants has a significant and positive effect on the environmental performance. At the same time, this effect is very narrow in scope, as it comes exclusively, and by design, from the electric power system. These reductions do not reflect an overall change in the patterns of energy use in the economy. This leads to a residual concern on the pedagogical value of this measure of early closure vis-à-vis system wide measures aiming at reducing emissions across the board in the country.

The increase in electricity prices due to the early closure of the coal-operated power plants reverberates throughout the economy, leading to detrimental macroeconomic effects, as well as adverse distributional effects. The negative macroeconomic effects are widespread and notable across sectors of economic activity. The distributional effects are pronounced and highly regressive. These effects also raise concerns with respect to international competitiveness and to social justice.

4.2 Effects of the ISP Extension - Fixed Energy Component: CF2 and CF3

It is informative to compare the transitional effects associated with the extension to the ISP tax on energy products under the scheduled 2030 closure date, CF2, and with an accelerated plant closure date, CF3, to our previous counterfactual scenario, CF1, with the same intended 2030 closure date and the old ISP rules.

Under CF2, when closure of the power plants remain as scheduled for 2030, we see a short-run and temporary increase in the price of electricity that ripples throughout the economy. Ultimately, cumulative economic effects by 2040 are only marginally more adverse than in CF1, in terms of GDP, employment, and welfare losses and marginally less adverse in terms of public debt and foreign debt positions. Should the coal-operated power plants remain operational through 2030 we would observe a marginal improvement in the public sector account, reflected in lower levels of public indebtedness, due to the additional tax revenues.

The accelerated plant closure by 2025 induced by the additional operating costs, as in CF3, yields more substantial differences relative to the central counterfactual scenario, CF1. With the earlier closure, we observe an additional cumulative reduction in CO_2 emissions of 42.1%. These additional reductions in emissions reflect the additional five years during which the coal-operated power plants will be inactive and not contributing towards atmospheric emissions.

The accelerated closures also move forward the reduction in economic activity and weaker economic conditions associated with higher electricity costs. The cumulative effect of these additional years of weaker economic conditions is that the cumulative indicators of economic performance deteriorate, accumulated GDP losses increase by 45.4% and accumulated employment-years increase by 47.5% vis-à-vis CF1. Noticeably, the intertemporal welfare indicator are 32.0% lower than in the central case CF1.

Importantly, in CF3, public debt now deteriorates by 124.5% relative to the central CF1 case. The larger increase in public debt is due to the combined effect of first, the fact that addition tax revenues from the extension to the tax on energy products applies for a shorter period of time due to the accelerated plant closures and second, that the negative contractionary effects last longer with an accelerated closure schedule.

Overall, if the plant operators do not respond to the new ISP rules, the effects of the new rules will be in general marginal for emissions, macroeconomic performance and welfare and only significant as a new source of public revenues. If, however, the plant operators respond to the new ISP rules by deciding to close down the coal-operated power plants earlier than scheduled, the environmental impact will be much greater but so will be the adverse macroeconomic, budgetary and welfare effects.

4.3 Effects of the ISP Extension - Energy and Carbon Components: CF4 and CF5

Finally, we consider the effects of the additional costs associated with both the energy and the carbon tax component of the extension to the ISP tax. In both CF4 and CF5, electric power producers face the additional tax on the energy content as well as the indexed tax on carbon in the cost of coal used in the production of electricity. In the first case, CF4, the scheduled closure of 2030 applies while in the second case, CF5, operators react by anticipating the closure by ten years. In these cases, the patterns of the results are similar to the cases in the previous subsection that considers only the new rules on the energy component of the ISP. The differences in the cumulative environmental, macroeconomic, and distributional effects, however, are substantially more pronounced.

Under the scheduled closures, CF4, the new ISP rules applying to both energy and carbon content have relatively small effects. There is a marginal reduction in emissions, which goes hand in hand with small deteriorations in economic performance and household welfare relative to central counterfactual scenario, CF1. The effects on the public sector account are more favorable with the extension to the tax on energy products only under the assumption that the plants remain operational through 2030. In this case, we would observe a 9.3% gain in the public debt position in CF4 with respect to CF1.

The situation is fundamentally different if plant operators accelerate the closure schedule due to operational considerations and the plants cease operation in 2020. It is important to note that these changes are due exclusively to the early closure itself as the extensions to the ISP tax barely becoming effective before seeing the closure of these two facilities. The accumulated gain in CO_2 emissions reductions relative to CF1 increase by 82.2%, which reflects the additional decade without coal-operated power plants.

In turn, the negative effects on economic performance also occur concomitantly for an additional decade. The accumulated detrimental effects on GDP increase by 89.4% and the accumulated loss in employment-years increases by 95.1% relative to the central counterfactual scenario in CF1. The intertemporal effects on household welfare increase by 61.3%. The effects on public debt are quite severe under CF5, showing an 310.3% increase in the public debt in CF5 relative to CF1, as the early closure

substantially decreases the tax bases as it deepens the contractionary effects and eliminates the tax revenues benefits of the changes to the ISP.

5. Summary and Policy Implications

This article examines the environmental, economic, budgetary and distributional effects of the scheduled closure of coal-fired power plants in Portugal as well as the extension of the ISP taxation to coal used in power generation. Specifically, we consider three research questions. First, what are the effects of closing coal-fired power plants in Portugal in 2030 in the absence of any changes in the ISP taxation? Second, what are the effects of the changes in ISP tax rules in an environment in which coal-fired power plants close as scheduled? Third, what are the effects of the changes in ISP tax rules in an environment in which operators decide to close coal-fired power plants ahead of the scheduled closure dates?

The five policy scenarios we consider have similar long-term effects. Over time, once the plants have closed, the extension to the tax on energy products to these facilities has no effect as the new ISP rules disappear when the power plants are effectively closed. The differences in short term transitional effects, however, are very significant, as the new ISP rules are relevant while the plants are operational, and an accelerated closures' schedule extends the duration of the adverse effects on economic performance and household welfare.

More specifically, and in answer to the first research question, we find that the closure of the coal-operated power plants has a significant and positive effect on the environmental performance. The increase in electricity prices due to the early closure of the coal-operated power plants reverberates throughout the economy, leading to detrimental macroeconomic effects, as well as adverse distributional effects. The negative macroeconomic effects are widespread and notable across sectors of economic activity. The distributional effects are pronounced and highly regressive. These effects also raise concerns with respect to international competitiveness and to social justice.

In turn, in response to the second question, the extension of the tax on energy products to coal used in the generation of electricity provides little to no additional environmental gains, as long as private sector agents do not react to the changing profitability of these facilities and maintain the scheduled closure dates at 2030. The economic and distributional effects, however, are marginally worse than the old energy tax rules due to a small increase in production costs, and its effect on electricity prices. Naturally, there is a small gain in the public debt position.

Finally, in terms of the third research question, an important result emerges from the analysis of the effect of the expansion of the tax on energy products to coal used in electricity generation and the potential for their accelerated closure by the operators. Indeed, if operators in the electric power industry react to the new ISP rules by accelerating the closure of the coal operated power plants, the situation changes substantially. The environmental gains are much more pronounced but so too are the negative economic and distributional effects. More importantly from the perspective of the public sector, the public debt position clear deteriorates due to contracting tax bases in the face of weaker economic conditions.

These results lead to several important policy recommendations. First, the regulated early closure of the coal-fired power plants may be very effective in reducing emissions but it is not innocuous from a macroeconomic or a distributional perspective. The domestic authorities, therefore, should undertake the proper efforts to mitigate such adverse effects.

Second, the new ISP rules are at best irrelevant in the presence of the forced closures. Regardless of whether or not the scheduled closures are enforced, there are no environmental advantages from the new ISP rules although they will certainly produce economic and distributional costs. Emissions reductions would only result from the accelerated closures of the coal generating units, in which case the adverse macroeconomic, distributional, and budgetary effects would be substantially larger. Indeed, the least detrimental of the five policy scenarios we consider, from both macroeconomic and social justice perspectives is the basic central scenario of scheduled closures in 2030 without changes in the ISP.

A final note. In 2016, Portugal introduced a tax on carbon dioxide emissions from fossil fuel combustion activities. This tax was implemented as an additional component to the ISP, based on the carbon content of each type of fossil fuel with a level indexed to the EU-ETS. The tax expanded the scope of policy efforts to reduce emissions beyond the large energy-intensive industrial emitters participating in the EU-ETS – which were exempted from this add-on to the ISP - to include the many households and businesses that together can make a substantial contribution towards domestic emissions reductions efforts. The additional component to the ISP for coal based on the carbon content of the fuel effectively doubles the price on carbon in electricity generation from coal and it raises both legal and equity concerns. This is because the coal-fired power plants already participated in the EU-ETS and were therefore already subject to carbon pricing mechanisms.

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Table 1 List of Simulation Scenarios

Reference:	• No closure for Sines and Pego • No changes to the ISP rules.
CF1:	• Current closure schedule of 2030 for Sines and Pego • No changes to the ISP rules.
CF2:	• Current closure schedule of 2030 for Sines and Pego • New ISP tax rules - fixed amount for energy component alone
CF3:	• Modified closure schedule of 2025 for Sines and Pego • New ISP tax rules - fixed amount for energy component alone
CF4	• Current closure schedule of 2030 for Sines and Pego • New ISP tax rules - fixed amount as well as on carbon content.
CF5:	• Modified closure schedule of 2020 for Sines and 2021 for Pego • New ISP tax rules - fixed amount as well as on carbon content.

Table 2 Long Run Energy and Environmental Effects (2040)

Percent Change from Baseline

		Energy Tax		Energy and Carbon Taxes	
	Current CF1	**Current CF2**	**Early CF3**	**Current CF4**	**Early CF5**
Electricity Price	7.21	7.20	7.15	7.19	7.13
Electricity Production	-5.60	-5.60	-5.56	-5.59	-5.55
Natural gas	2.12	2.12	2.10	2.11	2.09
Renewable energy	1.50	1.51	1.61	1.53	1.65
Net Electricity Imports	34.55	34.53	34.28	34.49	34.16
Energy Demand	-2.08	-2.08	-2.07	-2.08	-2.07
Electricity Share	-3.58	-3.58	-3.57	-3.58	-3.56
CO2 Emissions	-22.01	-22.02	-22.02	-22.02	-22.02

Table 3 Long Run Macroeconomic Effects (2040)

Percent Change from Baseline

		Energy Tax		Energy and Carbon Taxes	
	Current CF1	Current CF2	Early CF3	Current CF4	Early CF5
GDP	-0.57	-0.57	-0.58	-0.57	-0.59
Consumption	-0.14	-0.14	-0.14	-0.14	-0.15
Investment	-0.12	-0.12	-0.12	-0.13	-0.12
Employment	-0.19	-0.19	-0.20	-0.19	-0.20
Public Debt	1.89	1.86	2.98	1.82	4.22
Foreign Debt	0.74	0.73	1.16	0.75	1.66

Table 4 Long Run Effects on Industry Output (2040)

Percent Change from Baseline

		Energy Tax		Energy and Carbon Taxes	
	Current CF1	Current CF2	Early CF3	Current CF4	Early CF5
Total	-0.572	-0.571	-0.582	-0.569	-0.591
Petroleum Refining	-0.026	-0.030	-0.028	-0.036	-0.028
Electricity Production	-5.599	-5.595	-5.562	-5.589	-5.546
Biomass	1.281	1.286	1.349	1.297	1.380
Agriculture	-0.374	-0.372	-0.388	-0.369	-0.400
Equipment Manufacturing	-1.435	-1.432	-1.527	-1.427	-1.594
Construction	-0.132	-0.133	-0.132	-0.134	-0.130
Transportation	-0.326	-0.325	-0.339	-0.324	-0.351
Textiles	-0.699	-0.697	-0.707	-0.692	-0.718
Wood, pulp and paper	-1.499	-1.493	-1.541	-1.482	-1.575
Chemicals and pharmaceuticals	-0.944	-0.943	-0.957	-0.939	-0.970
Rubber, plastic and ceramics	-1.226	-1.224	-1.256	-1.221	-1.279
Primary metals	-1.473	-1.470	-1.520	-1.465	-1.558
Other	-0.167	-0.166	-0.176	-0.165	-0.183

Table 5 Long Run Welfare Effects (2040)

Percent Change from Baseline

		Energy Tax		Energy and Carbon Taxes	
	Current CF1	Current CF2	Early CF3	Current CF4	Early CF5
All Households	-0.143	-0.142	-0.145	-0.141	-0.147
First Quintile (Lowest Income)	-0.317	-0.316	-0.319	-0.315	-0.321
Second Quintile	-0.198	-0.198	-0.199	-0.197	-0.200
Third Quintile	-0.146	-0.146	-0.147	-0.145	-0.148
Fourth Quintile	-0.130	-0.130	-0.133	-0.129	-0.135
Fifth Quintile (Highest Income)	-0.081	-0.081	-0.084	-0.080	-0.086

Table 6 Effects on Electricity Prices (Intertemporal)

Percent Change from Baseline

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
CF1	-0.11	-0.13	-0.15	-0.18	-0.21	-0.24	-0.27	-0.31	-0.35	-0.39	7.12	7.21
CF2	0.17	0.13	0.10	0.06	0.03	-0.01	-0.05	-0.09	-0.13	-0.17	7.11	7.20
CF3	0.11	0.06	0.01	-0.04	-0.09	6.99	6.97	6.97	6.98	6.98	6.99	7.15
CF4	0.77	0.71	0.65	0.60	0.55	0.50	0.45	0.40	0.36	0.32	7.10	7.19
CF5	6.97	6.94	6.91	6.90	6.89	6.89	6.88	6.89	6.90	6.91	6.93	7.13

Table 7 Cumulative Effects on CO2 Emissions

2015=100

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
CF1	-0.01	-0.02	-0.02	-0.03	-0.03	-0.04	-0.05	-0.06	-0.08	-0.09	-20.32	-233.55
CF2	0.07	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	-20.13	-233.38
CF3	0.07	0.07	0.08	0.08	0.08	-19.20	-38.67	-58.33	-78.18	-98.22	-118.45	-331.73
CF4	0.26	0.30	0.33	0.37	0.40	0.43	0.45	0.48	0.50	0.53	-19.71	-232.98
CF5	-18.12	-36.64	-55.36	-74.26	-93.36	-112.64	-132.11	-151.78	-171.63	-191.68	-211.92	-425.22

Table 8 Cumulative Effects on GDP

2015=100

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
CF1	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.10	0.12	0.14	-0.41	-6.41
CF2	0.00	0.00	0.01	0.02	0.02	0.03	0.04	0.06	0.07	0.09	-0.45	-6.44
CF3	0.01	0.01	0.02	0.04	0.05	-0.46	-0.99	-1.52	-2.06	-2.62	-3.18	-9.32
CF4	-0.02	-0.03	-0.04	-0.05	-0.06	-0.06	-0.06	-0.06	-0.06	-0.05	-0.60	-6.56
CF5	-0.50	-1.01	-1.52	-2.04	-2.56	-3.10	-3.64	-4.18	-4.74	-5.31	-5.88	-12.14

Table 9 Cumulative Effects on Employment

2015=100

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
CF1	0.04	0.05	0.05	0.06	0.07	0.08	0.10	0.11	0.12	0.14	-0.05	-2.11
CF2	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.13	-0.05	-2.11
CF3	0.05	0.07	0.08	0.09	0.11	-0.07	-0.24	-0.42	-0.61	-0.79	-0.99	-3.12
CF4	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.10	-0.08	-2.14
CF5	-0.11	-0.28	-0.45	-0.62	-0.80	-0.98	-1.17	-1.35	-1.54	-1.74	-1.94	-4.12

Table 10 Cumulative Effects on Public Debt

2015=100

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
CF1	0.00	0.00	-0.01	-0.01	-0.02	-0.02	-0.03	-0.04	-0.06	-0.07	-0.09	6.99
CF2	-0.01	-0.01	-0.02	-0.03	-0.05	-0.06	-0.08	-0.11	-0.13	-0.16	-0.20	6.68
CF3	-0.01	-0.01	-0.03	-0.04	-0.06	-0.08	0.02	0.22	0.55	1.01	1.59	15.69
CF4	-0.01	-0.02	-0.04	-0.06	-0.08	-0.10	-0.14	-0.17	-0.21	-0.26	-0.31	6.34
CF5	-0.01	0.09	0.30	0.63	1.08	1.65	2.36	3.20	4.17	5.29	6.56	28.68

Table 11 Cumulative Effects on Foreign Debt

2015=100

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
CF1	0.01	0.02	0.03	0.05	0.07	0.09	0.12	0.15	0.18	0.22	0.26	6.44
CF2	0.01	0.02	0.03	0.05	0.07	0.09	0.12	0.15	0.19	0.23	0.27	6.40
CF3	0.01	0.03	0.05	0.07	0.10	0.13	0.25	0.45	0.75	1.14	1.63	13.44
CF4	0.02	0.04	0.06	0.10	0.13	0.17	0.22	0.27	0.33	0.40	0.47	6.84
CF5	0.03	0.14	0.33	0.61	0.99	1.46	2.04	2.72	3.52	4.43	5.47	24.04

Table 12 Cumulative Effects on Welfare

2015=100

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2040**
CF1	-0.03	-0.03	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.18	-1.75
CF2	-0.04	-0.05	-0.05	-0.06	-0.06	-0.06	-0.07	-0.07	-0.07	-0.07	-0.21	-1.77
CF3	-0.06	-0.07	-0.07	-0.08	-0.08	-0.22	-0.36	-0.50	-0.64	-0.79	-0.93	-2.52
CF4	-0.07	-0.08	-0.09	-0.10	-0.11	-0.12	-0.12	-0.13	-0.14	-0.14	-0.28	-1.83
CF5	-0.22	-0.35	-0.49	-0.63	-0.76	-0.91	-1.05	-1.19	-1.34	-1.49	-1.64	-3.26

Table 13 Comparative Results: Cumulative Effects by 2040

Effects of CF1 = 100.0

		Energy Tax		**Energy and Carbon Taxes**	
	Current CF1	**Current CF2**	**Early CF3**	**Current CF4**	**Early CF5**
CO2	100.0	100.0	142.0	99.8	182.0
GDP	100.0	100.5	145.4	103.9	189.4
Employment	100.0	100.0	147.9	101.4	195.3
Public Debt	100.0	95.6	224.5	90.7	410.3
Foreign Debt	100.0	99.4	208.7	106.2	373.3
Welfare Loss	100.0	101.1	144.0	104.5	186.5

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126: Reference Forecasts for CO2 Emissions from Fossil-Fuel Combustion and Cement Production in Portugal
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127: Regulated Early Closures of Coal-Fired Power Plants and Tougher Energy Taxation on Electricity Production: Synergy or Rivalry?
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