Tools for a Circular Economy: Assessing Waste Taxation in a CGE Multi-Pollutant Framework

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Abstract

Economic theory states that incineration and landfill taxation can effectively diminish the environmental impacts of pollution and resource use by reducing their associated pollutants while stimulating the reuse and recycling of materials, and therefore, fostering a circular economy. The aim of this research is to assess the economic and environmental effects of these taxes in Spain under different scenarios with a detailed dynamic computable general equilibrium (CGE) model, as there are no studies analyzing this in detail. We focus on the economic impact on GDP and sectorial production and the environmental impact on different categories: global warming potential, marine eutrophication potential, photochemical ozone formation potential, particulate matter, human toxicity (cancer and noncancer), ecotoxicity, and depletion of fossil resources. We find in all scenarios that these taxes have a limited economic impact while reducing all of the environmental impact categories analyzed. The study reinforces the theory that policy makers need to impose taxes on landfill and incineration to reinforce the circularity of the economy and reduce environmental burdens, but also demonstrates that they can improve their design without additional costs.

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Keywords

Environmental taxes, computable general equilibrium, environmental impacts, waste

1. Introduction

Environmental taxation is a powerful tool to reduce environmental pressures (Pigou, 1920; Baumol, 1972; Baumol & Oates, 1971; European Environment Agency, 2013). There are many theoretical and empirical studies that show the environmental benefits of taxes. However, the net effect of these taxes is not clear. The balance between reducing environmental loads (welfare increase) and increasing fiscal pressure put onto economic agents (possible welfare reduction) needs to be analyzed. There is some literature that states that depending on the design of the environmental taxation, a double dividend can be obtained (i.e., a benefit to both the environment and the economy) (Freire-González, 2018; Pearce, 1991; Pereira et al., 2016; Sajeewani et al., 2015). Particularly, by using government revenues to reduce other pre-existing taxes, the costs of imposing an environmental tax are reduced, and in some cases, this leads to the aforementioned double dividend.

Waste management is already the focus of several concurrent, classical environmental policies, such as command and control measures and public investment or awareness-raising campaigns. However, the use of environmental taxation also seems adequate to compensate for the presence of externalities, particularly in the case of landfill and incineration activities, which are at the bottom of the waste hierarchy due to higher environmental impacts. Thus, the use of environmental taxation for waste policy has spread widely, particularly in Europe

(Watkins et al., 2012; Fischer et al., 2012). The most common forms are municipal waste charges for collection and treatment of waste, taxes on certain products (e.g., plastic bags), and taxes on landfill and incineration. The former is usually set to cover the costs of collecting waste in municipalities or other administrative regions but in many places has undergone changes in design to stimulate waste reduction and source separation with the adoption of pay-as-you-throw schemes (Puig Ventosa et al., 2013; Palatnik, 2014; ACR+, 2016). Conversely, taxes on certain products and taxes on landfill and incineration are purely conceived to create incentives toward reducing and recycling waste, improving the circularity of the economies. There are few studies that assess the economic and environmental impacts of incineration and landfill taxes using general equilibrium methodologies. This is due to the high detail needed in the description of the economic sectors. However, some studies have tried to assess the effectiveness and/or the economic impacts of these taxes using other methods. A review of the empirical evidence from different countries can be found in Bartelings et al. (Bartelings et al., 2005). These authors evaluate the effectiveness of the landfill tax in the Netherlands using a CGE model.

This study is focused on assessing the current taxation on landfill and incineration in Spain and proposing improvements based on economic and environmental indicators from the analysis. So, the objective is to obtain evidence on the effects of landfill and incineration taxes and how it could be improved, using Spain as a case study. We use a dynamic CGE model with energy and environmental extensions calibrated for the Spanish economy to assess the economic and the environmental impacts of these taxes. From the macroeconomic impacts perspective, we observe the effects on GDP, prices, and the production of different waste treatment technologies, as well as on the rest of the economic sectors. From the environmental perspective, we observe the effects of these taxes on 31 different pollutant emissions and eight environmental impact categories. We set five different scenarios. The first one assesses the impacts of the current situation in Spain, and the others are four fiscal proposals that could easily be implemented in Spain and could improve the incentives toward waste reduction. Two of them also include subsidies to recycling industries.

Section 2 describes the particularities of landfill and incineration taxes in Spain. Section 3 shows the data used, and section 4 describes the methodology, with a description of the energy-environment-economy model and the different scenarios. Section 5 shows the main results and a discussion of the simulations, and section 6 includes the main conclusions of the research.

2. Taxes on landfill and incineration in Spain

Although the Spanish national government could have promoted the congressional adoption of a law setting a tax on landfill and incineration, this never occurred; therefore, these taxes are not implemented nationwide in Spain. Regions have the legal power to create environmental taxes in the absence of similar previous national levies. In these circumstances, several regions have created landfill and incineration taxes.

As we have calibrated our model with 2007 data (see methodology section for more detail), here we analyze the state of these taxes in that year, and then set the scenarios for the analysis.

In 2007, only four regions had implemented taxes on landfill. None of them had applied taxes on incineration:

Catalonia: Law 16/2003, of June 13, on the financing of waste treatment infrastructures and on the tax on waste disposal (*Ley 16/2003, de 13 de junio, de financiación de las infraestructuras de tratamiento de residuos y del canon sobre la disposición de residuos*). This law set a fixed tax rate of €10/ton of municipal waste disposed of in landfills. Industrial and construction and demolition (C&D) waste were not subject to the tax. This remained unchanged until 2008. Puig et al. (2012) have already described this tax and discussed its effectiveness.

Madrid: Law 6/2003, of March 20, on the tax on waste (*Ley 6/2003, de 20 de marzo, del impuesto sobre residuos*). This law set the following tax rates, which remained unchanged in 2007: a) €10 per ton of hazardous waste; b) €7 per ton of nonhazardous waste, excluding C&D waste; and c) €3 per cubic meter of waste from construction and demolition. Municipal solid waste was also excluded.

Andalusia: Law 18/2003, of December 29, which approves fiscal and administrative measures (*Ley 18/2003, de 29 de diciembre, por la que se aprueban medidas fiscales y administrativas*). This law approved the following tax rates, which remained unchanged in 2007: a) €35/ton of hazardous waste that is susceptible to valorization and b) €15/ton of hazardous waste that is not susceptible to valorization.

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Murcia: Law 9/2005, of December 29, on tax measures regarding assigned taxes and regional taxes for 2006 (*Ley 9/2005, de 29 de diciembre, de medidas tributarias en materia de tributos cedidos y tributos propios año 2006*). In 2007, this law included the following tax rates: a) €15/ton for hazardous waste, b) €7/ton for nonhazardous waste, and c) €3/ton for inert waste.

3. Data

Data used to feed the model and create scenarios come from different sources. The model developed is calibrated with a SAM of the Spanish economy for 2007. A SAM is a square matrix with information on the flow of payments between the various agents in the economic system we want to represent. The SAM we have developed has information on commodities, industries, labor, capital, households, firms, and government and great detail on taxes, investments/savings, and the foreign sector. The supply and use table for purchasers' prices is the core information of the SAM. To homogenize the information with the rest of the sources needed to develop the SAM, we first based our supply and use tables on those from the National Statistics Institute of Spain (INE). We then used the shares of waste treatment industries from Exiobase (Tukker et al., 2013; Wood et al., 2015) to disaggregate these industries in the INE's tables. This is an important step, as we were interested in detailed information on different waste treatment technologies. We performed a similar process to disaggregate different energy and electricity technologies.

After these adjustments, we finally obtained an SAM with 101 industries/101 commodities, with great detail on different waste treatment technologies: (1) incineration: food waste, paper waste, plastic waste, inert/metal waste, textiles waste, wood waste, oil/hazardous waste; (2) biogasification and land application: food waste, paper waste, sewage sludge, composting and land application, food waste; (3) waste water treatment: food waste, other waste; (4) landfill: food waste, paper, plastic waste, inert/metal/hazardous waste, textile waste, wood waste.

Other information used to develop the SAM came from government accounts, Social Security accounts, and tax information obtained from the General Intervention Board of the State Administration (IGAE). Foreign sector accounts came from the INE. Firms' accounts came from the Bank of Spain. Data on stock of capital and depreciation rates by industry came from the EU KLEMS project on growth and productivity (Jäger, 2016).

Regarding the environmental information, consumption of coal, oil, and natural gas and CO_2 emissions of combustion of these sources were obtained from the IEA (2016). Moreover, we obtained information from Exiobase on the emissions of 31 different pollutants at the industry level, including 1) greenhouse gas emissions: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFC), and perfluorocarbon (PFC); 2) general air pollutants: particulate matter < 10 microns (PM_{10}), sulphur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter < 2.5 microns ($PM_{2.5}$), ammonia (NH_3), carbon monoxide (CO), and total suspended particles (TSP); 3) other organic compounds: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyl (PCBs), dioxins and furans (PCDD_F), hexachlorobenzene (HCB), and nonmethane volatile organic compounds (NMVOC); and 4) heavy metals: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), and zinc (Zn).

4. Methodology

4.1. The energy-environment-economy model

We have developed a dynamic computable general equilibrium (CGE) energy-environment-economy model for the Spanish economy. All the equations of the model are detailed in Freire-González & Ho (2018) (see Appendix A), and in Freire-González & Ho (2019) (see supplemental material). Although it has experienced many changes and adaptations, it is an evolved version of Jorgenson & Wilcoxen (1993); Ho & Jorgenson (2007) and Cao et al. (2013); for the analysis of environmental policies.

The model tries to represent all the agents of the economic system into four big categories: households, firms, government and foreign sector. Behavioral equations specified show how income flows across all of them in aggregate terms, so their main economic function in the model are spending money and receiving incomes. However, there are other roles assigned to them. Households also supply labor (which is mobile across sectors and its supply depends on the level of unemployment) and pay taxes to the government. Firms produce goods and services using capital, labor, land, energy and intermediate goods. Cobb-Douglas production functions with constant returns to scale are specified in this version of the model. Firms also pay dividends to households and taxes to the government. Government basically redistributes incomes between agents through taxes, subsidies and transfers, but they also buy goods and services and invests. The foreign sector provides goods and services through imports and buy part of the domestic goods and services produced by firms through exports. This agent also generates transfers of money (inwards and outwards) and investments from other countries. Imports are combined with the domestic output using Constant Elasticity Supply (CES) functions with an Armington assumption (Armington, 1969), thus producing a composite supply for the economy and exports are price sensitive. The current account deficit and world commodity prices are set exogenously.

They all generate savings, as the non-spent part of their incomes. These savings are important in the dynamic behavior of the model because as it is a Solow growth model, economic growth is driven by total savings. Savings from year 1 generates investments, that increase capital stock in period 2 (also decreased by depreciation rate), affecting growth possibilities. However, economic growth also depends on the rate of population growth and technical change.

There are two additional sub-models, an energy and an environmental model. The former describes the energy use through the economic system and the latter the emissions of 31 different pollutants, also detailed in Freire-González & Ho (2018).

4.2. Scenario development

The study evaluates three main scenarios; however, two of them have two different configurations, so there are five scenarios in total tested into the model.

Scenario "current": This scenario consists of testing the economic and environmental effects of current taxes on landfill. We obtain total revenues from these taxes in 2007 and test them into the model with the implicit effective tax rate Spain obtained from the total revenues from the regions that were implementing the tax in 2007: Catalonia, Madrid, Andalusia, and Murcia. Because these revenues are small compared to the total government revenues in Spain, the impacts, both economic and environmental, are expected to be small.

Scenario 1: This scenario assumes the extension of the average tax rates to the rest of the Spanish regions. The average tax rates for the different types of waste in the regions that had this tax in 2007 were approximately as follows: municipal waste (€10/ton), industrial waste (€7/ton for nonhazardous and €17/ton for hazardous) and construction and demolition waste (€3/m^3 for nondangerous and €17/m^3 for hazardous). We multiply these by the amount of each type of waste in Spain in 2007 with data obtained from the National Statistics Institute of Spain. This results in an estimation of the total government revenues if the taxes in the current scenario were extended to all regions of Spain.

We have two subscenarios inside this scenario: 1a) we test only the extension of the tax, and 1b) we use the revenues of this tax to subsidize the waste recycling industries. The latter includes recovered secondary raw materials; food waste for treatment: biogasification and land application; paper waste for treatment: biogasification and land application; sewage sludge for treatment: biogasification and land application; and food waste for treatment: composting and land application. We subsidize these industries in relation to the share they have in value-added generation.

Scenario 2: This scenario supposes a more ambitious taxation that increases the landfill tax rates and extends the taxation to waste incineration: a) landfill: €40/ton for municipal waste, €30/ton for nonhazardous industrial waste, €60/ton for hazardous industrial waste, and €5/m^3 for C&D waste (when C&D waste cannot be considered as inert waste due its hazardous characteristics, a similar tax rate to that for industrial hazardous waste is applied); and b) incineration: €30/ton for municipal waste, €20/ton for nonhazardous industrial waste, €40/ton for hazardous industrial waste, and €10/ton for C&D waste. We have set these tax rates to simulate a scenario with more stringent policies compared to scenario 1, related to waste. These types of policies could be expected, considering how far from the European targets Spain is actually performing (SWD(2017)42 final) and considering that the European Commission has explicitly recommended Spain adopt a landfill tax (European Commission 2017). The proposed tax rates are consistent with some of the most advanced tax rates of landfill and incineration taxes in Europe.

Similar to scenario 1, here we have two subscenarios: 2a) we test only the increase of the tax rates, and 2b) we use revenues of this tax to subsidize the same waste recycling industries as in scenario 1b.

4.3. Environmental assessment

The environmental effects of each scenario (in the form of emissions or resources) have been converted into characterized environmental impacts for two main reasons: first, to facilitate the interpretation of the results by grouping the emission and resource consumption contributing to the same environmental impact category (e.g., global warming potential) and, second, to quantitatively compare the different elementary flows in terms of their ability to contribute to a specific environmental impact category.

The conversion has been done by multiplying each environmental effect (amount of emission induced by each scenario) with its substance-specific characterization factor for each environmental impact category, as done in the characterization step of the common Life Cycle Assessment studies. The characterization factors represent the potential impact of each single elementary flow (emission or resource) in terms of the common unit of the environmental impact category, such as kilogram CO_2-equivalents for greenhouse gases contributing to the impact category global warming potential.

The present study uses the 2013 ILCD-recommended method (Hauschild et al., 2013) and includes the following environmental impact categories: global warming potential (GWP), marine eutrophication potential (MEP), photochemical ozone formation potential (POFP), particulate matter (PM), human toxicity (cancer, HTc, and noncancer, HTnc), ecotoxicity (ET), and depletion of fossil resources (Df). Freshwater eutrophication and ozone depletion were excluded because the emissions reported in the Exiobase data set do not contribute to these two impact categories. Table 1 shows the characterization factors used in the study.

Table 1. Characterization factors of the different emissions and resources for the different impact categories included in the environmental assessment.

Name	Global warming potential	Marine eutrophication potential	Photochemical ozone formation potential	Particulate matter	Human toxicity (cancer HTc)	Human toxicity (noncancer HTnc)	Ecotoxicity	Depletion of fossil resources
	kg CO_2 eq	kg N eq.	kg NMVOC eq.	kg $PM_{2.5}$ eq.	CTUh	CTUh	CTUe	MJ
CO_2	1							
PM_{10}				0.227				
SO_2			0.08	0.061				
Nox		0.389	1	0.007				
$PM_{2.5}$				1				
CH_4	25		0.01					
N_2O	298							
NH_3		0.092		0.067				
CO			0.046	0.0003				
Benzo(a)pyrene					$3.6*10^{-5}$		110	
PAH						$2.4*10^{-7}$		
PCBs					$9.1*10^{-5}$		1,800	
PCDD_F					14.5	$3.6*10^{-6}$	62,000	
HCB							620	
NMVOC			1					
As					$3.3*10^{-4}$	0.017	17,000	
Cd					$2.2*10^{-4}$	0.045	3,900	
Cr					$2.2*10^{-3}$	$2.1*10^{-4}$	21,000	
Cu						$1.3*10^{-5}$	23,000	
Hg					$7.0*10^{-3}$	8.3E-01	12,000	
Ni					$5.2*10^{-5}$	$2.9*10^{-6}$	6,100	
Pb					$2.7*10^{-5}$	$9.4*10^{-3}$	180	
Se							3,000	

Zn		0.016	17,000	
SF6	22,800			
HFC	7,850			
PFC	9,160			
Coal				19.1
Oil				42.3
Natural Gas				44.1

Source: own elaboration.

5. Results

5.1. Economic impacts

From the economic perspective, we have obtained some results from simulations. Figure 1 shows the GDP variation of each scenario in relation to the base case. We observe in all cases that the economic impacts of these taxes on the overall economic system are very low. Even in the case in which we simulate higher tax rates without using tax revenues to subsidize recycling (scenario 2a), GDP drops only by 0.045%. In general, we can say that when revenues from taxation are used as a subsidy for recycling sectors (scenarios 1b and 2b), GDP variation stays quite flat along the time. Scenario 1b actually approaches zero GDP variation after some years. So, it is interesting to point out that taxing landfill and incineration and at the same time subsidizing recycling industries in a revenue-neutral framework could have very little impact on global macroeconomic indicators, such as GDP.

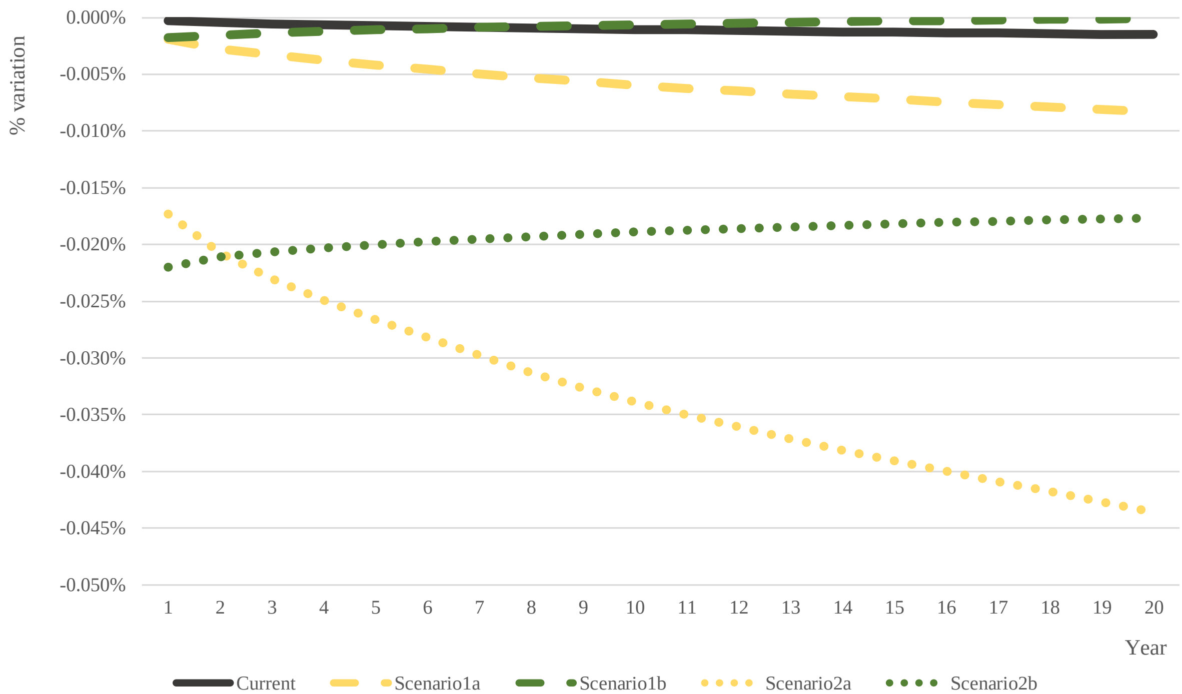


Figure 1. GDP variation in relation to the base case in each scenario.

If we focus on economic results at the industry level (in terms of production and price for years 1 and 20), we can analyze the results described in Figure 2. We observe how economic impacts are small in the current situation and mostly in landfill industries. In scenario 1a, only production of waste landfill industries goes down by 2.87%, and prices go up by 2.82%. There are very low effects on other industries. In scenario 1b, we can see how recycling industries' production increases by 1.98% whereas prices drop by 1.84% (for year 1). As expected, impacts are higher in scenarios 2a and 2b due to the general increase of tax rates. The impacts on landfill industries in scenario 2a suppose a reduction of production of around 12.34% and an increase of prices around 13.36% (for year 1). Conversely, impacts on incineration are much lower: there is a reduction of around 2.07% in production, and an increase of 2.11% in prices. If we move to 2b, we observe similar values and also an increase of around 7% in production and a reduction of 6.16% in prices of recycling industries (for year 1).

In every scenario, even in those with higher tax rates, there are not many impacts on other sectors beyond waste treatment industries, suggesting that waste industries may not be very important in dragging other industries in the economic system.

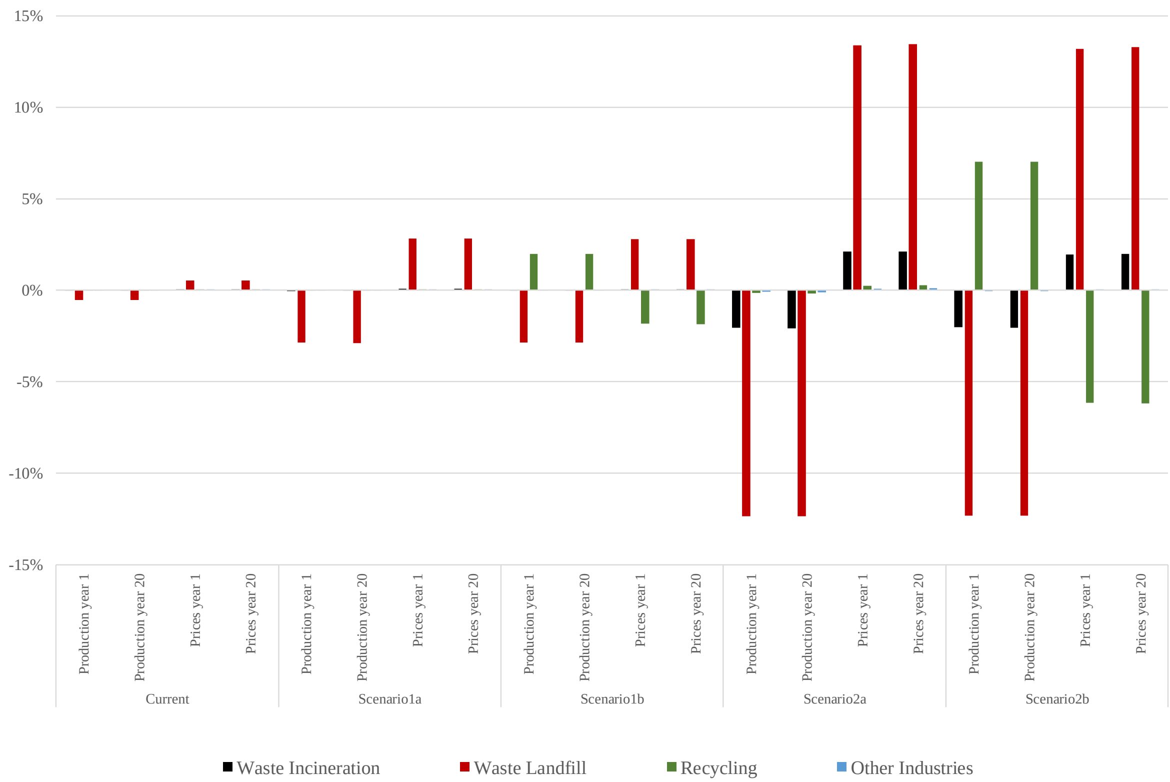


Figure 2. Economic impacts at the industry level of different waste taxation scenarios. Variations in relation to the base case.

5.2. Energy and environmental impacts

In this section, we describe and discuss some environmental indicators from the current and proposed tax reforms. As shown in the methodology section, our model can track different forms of energy use through the economic system and track the emission of 31 different pollutants from the Exiobase project.

Figure 3 shows the four energy indicators of the five scenarios. We observe a reduction in all indicators in all scenarios, so waste taxation induces energy savings, and these savings are larger for higher tax rates (i.e., savings of scenario 2 are larger than those of scenario 1). The largest variation can be observed in the indicator electricity use, and especially in scenario 2a, with a reduction of 0.36%. The most important reductions in electricity use are in scenarios 1a and 2a, where there are no subsidies for recycling industries. This could be explained by the fact that at this level of taxation, the energy used for recycling activities is larger than the lower energy use related to the decrease of production from virgin resources and the decrease of landfill and incineration of waste. Energy intensity and CO_2 intensities also go down in all scenarios, but especially in 1a and 2a, with no subsidies.

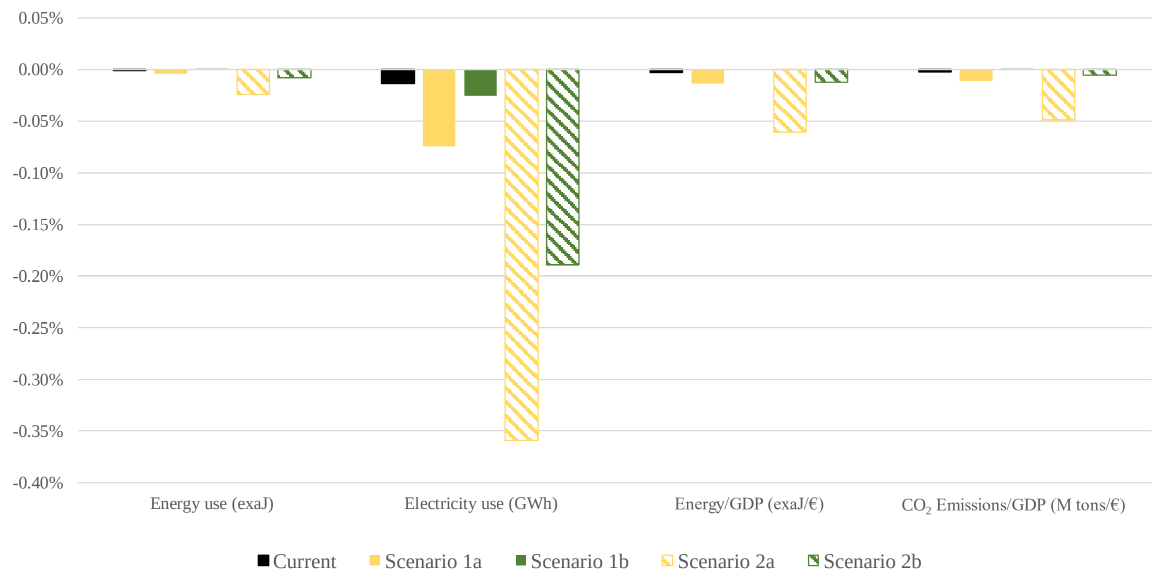


Figure 3. Variation in different energy indicators in relation to the base case.

Figure 4 shows the environmental results of the five scenarios included in the study as a percentage of variation with respect to the characterized impact of the base case. Each graph shows the net variation as black dots, and the emission or resource contribution to such net variation as stacked bars.

Overall, all the scenarios induce little variation in relation to the base case. The largest change was obtained by Scenario 2a in the GWP category. This can be explained by the low magnitude of the tax revenue (in all the scenarios) compared to the global magnitude of the overall economic system. In addition, similar trends between the scenarios were observed for all the environmental impact categories, although the substances driving the changes were different for each impact category.

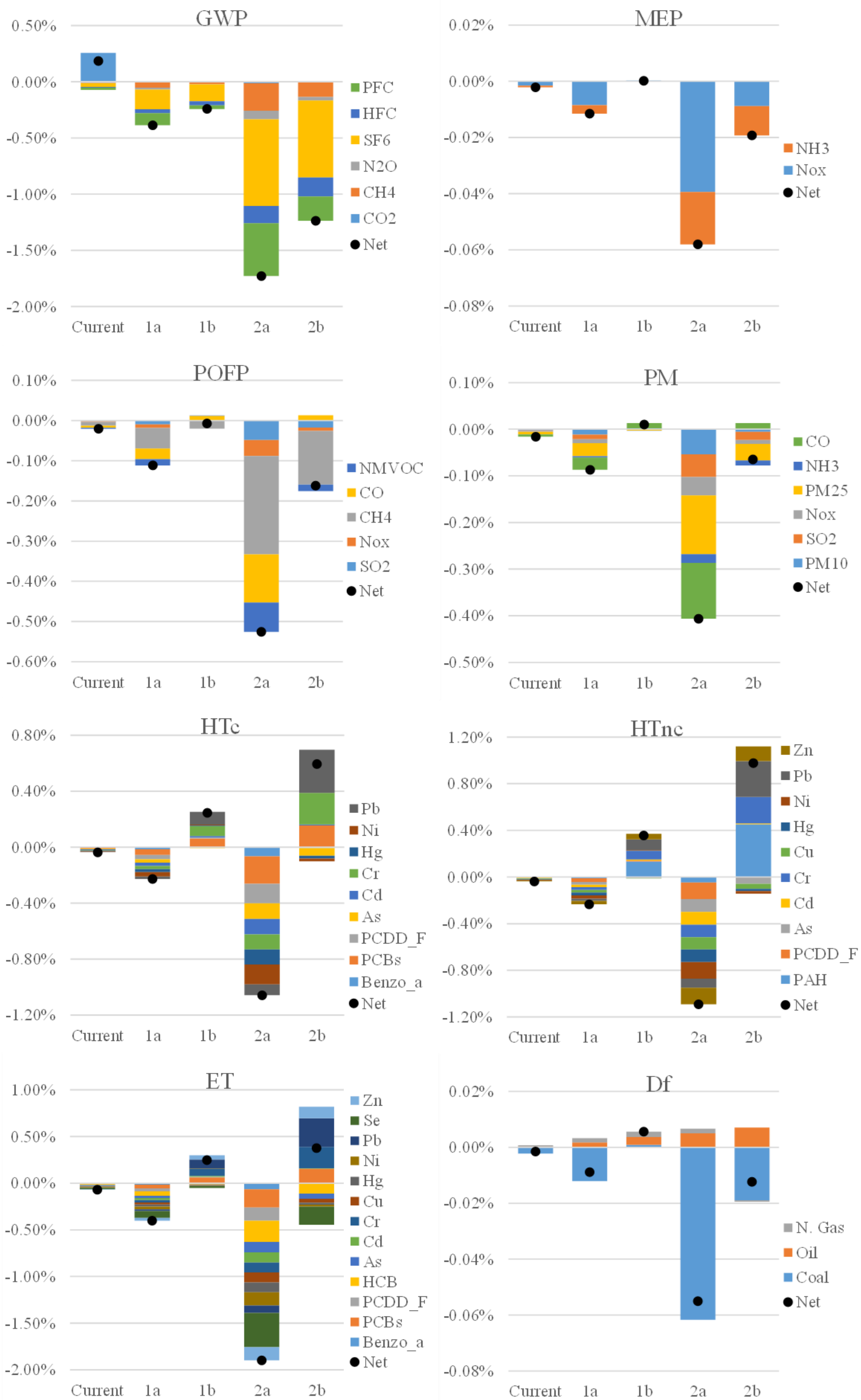
First, the scenario representing the current level of landfill tax in Spain (scenario current) shows a small variation in all the impact categories. The characterized impacts are slightly lower (less than 0.07%) than in the base case for all the impact categories, except GWP. The scenario current shows a GWP of 0.2% higher than the base case, mainly due to the increase of CO_2 emissions. The latter could be explained by a diversion from landfill to incineration of some waste fractions causing fossil CO_2 (e.g., plastic waste).

Second, the introduction of the landfill tax in all the Spanish regions (scenario 1a) shows benefits to the environment due to the decrease of key emissions. The characterized impacts are lower than for the base case for all the impact categories, but the variations are small: 0.4% for GWP, 0.01% for MEP, 0.11% for POFP, 0.14% for PM, 0.23% for HTc and HTnc, 0.40% for ET, and 0.01 for Df.

The substances driving such environmental benefit are different for each impact category. In the case of GWP, the benefit is mainly due to the decrease of SF6 and PFC emissions. This decrease is also observed in the current scenario, but the benefit is hidden by the impact related to the increase of CO_2 emissions. It has to be noted, however, that this large contribution of SF6 and PFC in the GWP results is not only related to the decrease of emissions (i.e., kg of SF6) but also to the high characterization factors for GWP (i.e., 22.800 kg CO_2 eq./kg SF6 and 9.160 kg CO_2 eq./kg PFC; see Table 1). Appendix 1 shows the direct emissions variations without the conversion to characterized impacts.

Third, the inclusion of the incineration tax in all the Spanish regions, together with an increase of the landfill tax rate (scenario 2a), also shows environmental benefits in all the impact categories; the characterized impacts are lower than the baseline scenarios for all the impact categories (0.06% for MEP, 0.53% for POFP, 0.65% for PM, 1.06% for HTc, 1.09% for HTnc, 1.90% for ET, and 0.06% for Df). The emissions involved in the GHG savings are the same as for scenario 1a, but in this case the decrease of emissions is larger than for scenario 1a. This applies to all the impact categories, not only to GWP.

Finally, the utilization of the revenue to incentivize waste recycling activities (scenario b) appear detrimental to the environment for all the impact categories. Their characterized impacts are larger than the impacts of scenario a (comparing 1a with 1b and 2a with 2b, respectively). For example, the characterized impacts on GWP of scenarios 1b and 2b are 0.2% and 1.2% larger than the baseline, respectively. This is mainly due to the increase of SF6, CH_4, and PFC in both scenarios. These results highlight that, at the level of taxation simulated in scenarios 1b and 2b, the emissions induced by increased recycling (direct emissions of remanufacture) are larger than the avoided emissions related to the decrease of production from virgin resources and the decrease of landfill and incineration of waste.


GWP
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
Current
1a
1b
2a
2b
PFC
HFC
SF6
N2O
CH4
CO2
Net
MEP
0.02%
0.00%
-0.02%
-0.04%
-0.06%
-0.08%
NH3
Nox
Net
POFP
0.10%
0.00%
-0.10%
-0.20%
-0.30%
-0.40%
-0.50%
-0.60%
NMVOC
CO
CH4
Nox
SO2
Net
PM
0.10%
0.00%
-0.10%
-0.20%
-0.30%
-0.40%
-0.50%
CO
NH3
PM25
Nox
SO2
PM10
Net
HTc
0.80%
0.40%
0.00%
-0.40%
-0.80%
-1.20%
Pb
Ni
Hg
Cr
Cd
As
PCDD_F
PCBs
Benzo_a
Net
HTnc
1.20%
0.80%
0.40%
0.00%
-0.40%
-0.80%
-1.20%
Zn
Pb
Ni
Hg
Cu
Cr
Cd
As
PCDD_F
PAH
Net
ET
1.00%
0.50%
0.00%
-0.50%
-1.00%
-1.50%
-2.00%
Zn
Se
Pb
Ni
Hg
Cu
Cr
Cd
As
HCB
PCDD_F
PCBs
Benzo_a
Net
Df
0.02%
0.00%
-0.02%
-0.04%
-0.06%
-0.08%
N. Gas
Oil
Coal
Net

391

Figure 4. Variation of environmental impacts of the five scenarios in relation to the base case.

6. Conclusions

Environmental taxes are intended to reduce the importance of targeted activities that generate environmental impacts. Most of these taxes imposed on damaging activities, however, were not originally designed with this aim but to raise revenue. There is also the belief that taxes, in general, generate costs for the economy, without considering or fully understanding the (economic) benefits of improving environmental conditions.

We have assessed the economic and environmental effects of incineration and landfill taxes in Spain in different scenarios. The current scenario considers the current situation (i.e., this tax is only in force in a few regions). Scenario 1 considers a realistic improvement in our view, as it extends this tax to the entire country. Scenario 2 is a desirable and more ambitious scenario that increases current tax rates on landfill and incineration to converge with European objectives regarding waste policies. In addition, scenarios 1 and 2 also include two additional subscenarios in which we simulate a subsidy to recycling industries that amounts to the total revenues from these taxes. These scenarios allow us to depict a complete picture of the environmental and economic effects of these kinds of taxes.

In all cases, the results of simulations with the dynamic CGE model show limited economic impact, which is reduced when revenues are used for subsidies in recycling industries. This is mainly due to the low weight of this industry within the whole economic system.

Incineration and landfill industries are always the most affected activities with low effects on other industries.

The results do show some relevant environmental benefits of the taxation. Although the benefit caused by the current level of taxation was small related to the overall magnitude of the economy, we can see that increases in taxation bring significant benefits for all the impact categories assessed. In contrast, and unexpectedly, the use of such taxes to subsidize recycling activities decreases some of these environmental benefits to a degree that they worsen in relation to the base case. This is the case for the toxicity impact categories (HTc, HTnc, and ET).

In addition to the environmental impacts included here, aspects that could favor the adoption of these policies could also be considered. On the one hand, the impacts of landfill (e.g., methane or groundwater emissions) remain for many years after the economic activity is finalized and make the land unusable for other purposes for many years, which could be considered a scarce resource close to urban areas. On the other hand, these policies stimulate recycling, whose main rationale is minimizing the extraction of raw materials. Recycling can be considered in practice as a sort of domestic production of raw materials, which is particularly relevant for those that are not available in the country (e.g., most metals and rare earths in the case of Spain). Recycling, therefore, can also help minimize the economic vulnerability derived from excessive exposure to certain raw materials and foster a circular economy.

If we consider the nonmarket economic benefits (fewer externalities) of reducing these pollutants on aspects such as human health and global warming due to landfill and incineration taxation, the negative economic impacts could be partly or totally compensated. Further research is necessary to analyze this in depth.

From an academic perspective, this paper improves the existing literature of waste policies and circular economy by adding significantly more detail to the economic and environmental analyses of waste taxation policies. First, from an economic perspective, given that both our simulation model and the SAM contain specific detail on different waste treatment industries, we can observe the specific effects of taxation on landfill and incineration, rather than on the waste sector as a whole. Second, as the model provides detail on many different pollutants, unlike other studies, we can assess the impact of these taxes on the pollutants and develop environmental indicators that are useful for environmental, economic, and health policies. This can help policy makers more deeply understand the nature of different fiscal configurations from a global perspective and how they can improve current waste taxation. These results, however, have to be considered just as a guidance in policy-making, and be combined with other kind of assessments, given the uncertainty and assumptions behind this type of models.

This research shows that incineration and landfill taxes are effective in reducing environmental impacts at a low economic cost. We have considered the option of using revenues in creating subsidies for recycling industries, but empirical studies have found that other uses for these revenues, such as reducing other pre-existing taxes, could lead to even better results in economic terms, leading to a double dividend (Freire-González, 2018).

Environmental impacts can be managed by the use of taxation. An adequate design of these policies is key for circular economy strategies to obtaining effective environmental results while minimizing economic impacts.

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Appendix 1. Average annual variations of individual pollutants

Figure S1 shows the average annual variations of different pollutants modeled under the different scenarios. Although there is a reduction of most pollutants, there are some pollutants, such as SF6, PFC, PCBs, HBC, Zn, Cr, Pb, and PAH that increase in the scenarios that include subsidies to recycling industries. However, we observe a general decrease in all other pollutants in relation to the base case. The current situation shows a very slight reduction in all pollutants, meaning that current taxes might be too low to reduce pollution. Scenario 1a and, especially, scenario 2a lead to a higher reduction in most pollutants.

Similar to the economic impacts, the annual average variations are small (between +0.4% and –0.8%). This is due to the relative importance of industries affected by the scenarios in relation to the rest of the emissions of the economic system.

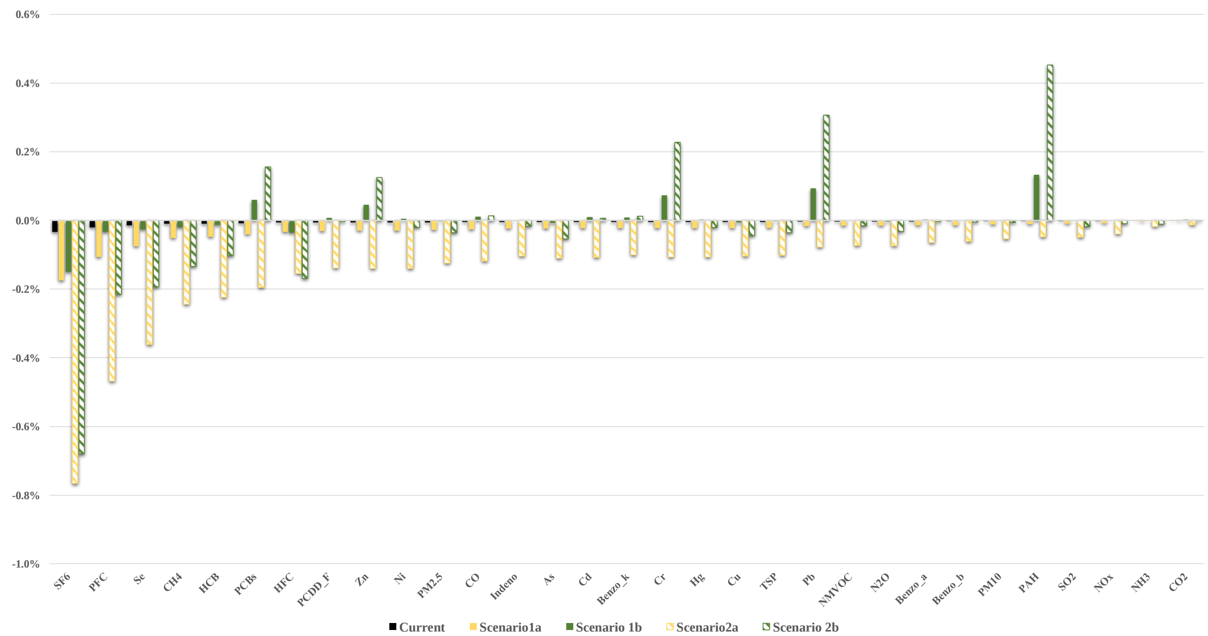

Figure S1 Average annual variations of pollutant emission variations in relation to the base case under different scenarios.