Modeling the carbon consequences of pro-environmental consumer behavior

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Abstract: Households, as consumers of goods and services through their lifestyles and spending choices, drive environmental change. Using a recent (2008) social and environmental survey of Spanish households, we evaluate the effects of improvements in environmental awareness, and of changes induced by regulations and carbon taxes. We consider these drivers of behavioral change for different income levels. A range of scenarios including the adoption of energy efficient appliances, modal shift to public transport, healthier diets, and the associated carbon emissions and job effects, are estimated using a Computable General Equilibrium (CGE) model. Our results suggest that reductions in carbon dioxide, methane, and sulphur dioxide emissions may be compatible with increases in income and reductions in unemployment. Modal shift to public transport is shown as a successful economic and environmental policy.

Keywords: Environmental behavior; Consumption patterns, Emissions abatement; CGE model; Rebound effect
JEL Classifications: Q56; Q57; C67; C68; Q4; Q51

1. INTRODUCTION

The Agenda 21 (UNEP, 2001) identifies unsustainable lifestyles in advanced economies as a major cause of environmental pressures, and calls for a behavioral shift. Lifestyles and living conditions depend on multiple variables: socio-demographic (gender, age, household size, income, education), structural (type and age of living accommodation, use of energy efficient appliances, access to public transport, leisure travel) (Tabi, 2013), institutional (rules and regulations, incentives) and cultural (lifestyles). Households impact the environment directly through heating, cooking, travel, and indirectly through upstream emissions associated with the production of consumption items (see Munksgaard et al., 2005). Thus, the analysis of consumption patterns and their relationship with income levels, lifestyles, and production becomes a key element in the design of environmental policies. Consumer decisions may have significant effects on production and related emissions. In this way, modifying behavior and consumption-decisions towards low energy and carbon intensive alternatives are one of the primary challenges of any environmental policy.

In this context, this paper analyzes environmental (CO_2 emissions, methane, and sulphur dioxide) and socio-economic (jobs, contribution to GDP) implications of household lifestyle and consumption choices and explores the potential of different policies (regulations, changes in environmental awareness, carbon tax) to achieve environmental outcomes, i.e. reduction in emissions, as well as their compatibility with economic goals. Specifically, we propose the first CGE model with detailed pathways for the adoption of household appliances with different energy efficiency levels and for the acceptance of different modes of transport in both production and consumption functions. This is achieved through linking these sectors and consumption choices with specific micro-data on household environmental behavior, which enables the formulation of more realistic scenarios about consumer choices and more realistic responses to policies. As far as we know, this is the first study linking these micro and macro information for the evaluation of a range of policy options to influence household behavior and reduce emissions along global supply chains, i.e. direct and indirect emissions.. Our scenarios take into account modal shifts from private cars to public transport, healthier vegetable-based diets, and adoption of efficient electrical appliances, which are widely regarded as principal household choices in reducing emissions (European Union Sustainable Development Strategy, EU SDS, European Commission, 2009). Additionally, this paper also seeks to evaluate "rebound" effects (Jevons, 1985) for households, in line with a growing literature investigating how 'green' behavior and associated savings in terms of money and associated carbon emissions of individuals in one area is off-set by additional expenditures in other areas and sectors (Sorrell et al., 2009; Hubacek and Guan., 2011; Chitnis et al., 2014; Li and Lin, 2015). In other words, we show that analyzing household income groups, and their sensitivity to environmental policies can shed light on the design of policies.

Taking Spain as a case study, we develop and evaluate alternative scenarios of pro-environmental consumer behavior triggered by a range of policy measures. The bases of scenario sets 1 and 2 are policies promoting pro-environmental behaviors and scenario set 3 aims to achieve the same objectives through the introduction of a carbon tax, which would motivate changes in consumption as a response to changes in prices. As income is acknowledged as one of the main factors affecting consumption in general and electricity consumption in particular, different income groups are considered in both types of scenarios. A noticeable novelty in our scenarios is that our scenarios are constructed following the micro-data of the Survey on Households and the Environment (NSI, 2008a), a national survey which offers detailed information on habits, consumption trends, and attitudes of households in relation to various aspects of the environment (such as energy saving, reduction in water consumption, and recycling). This is the first time that this survey is used for designing scenarios of consumption choices and environmental improvement, analyzing the repercussion of these changes on environmental and economic outcomes. Spain, which is not only representative for a wide range of industrialized, developed countries but we also make use of a set of novel datasets in our modeling that do exist in many other developed countries as well but have yet to be used for the type of analyses we performed in this study.

Our work uses both input–output and Computable General Equilibrium (CGE) tools to quantify the direct and indirect effects of the simulated scenarios. Prior work in the line of input-output research, such as Duchin (2001, 2003), Hubacek and Sun (2001), Duchin and Hubacek (2003), Minx et al. (2009), Duarte et al. (2010), and Tian et al. (2014), among others, establishes a framework for the analysis of consumption scenarios, and their effects on the environment. We incorporate the consumption-based emission accounting of input-output modeling into a Computable General Equilibrium (CGE) model and calibrate the CGE based on the 2008 input-output data of Spain. A high level of disaggregation is taken into account for the agricultural, energy, agro-food industry, and transport services sectors. In recent years, a number of energy-related CGE models have been published with varying degrees of scope and detail (Burniaux and Truong, 2002; Liu and Lu, 2015; Igos et al. 2015). In comparison with this line of literature, our model includes a detailed substitution within the energy aggregate as well as different transport services in both production and consumption function. Our analysis focuses on the emissions of carbon dioxide (CO_2), methane (CH_4), and sulphur dioxide (SO_2), given our research interest in the effects of a healthier vegetable-based diet and modal shifts of transport, respectively.

In summary, we are interested in addressing the following questions: What could be the effects of switch to more environmental behavior in line with official regulations and the norms of the most environmentally-conscious countries? Are pro-environmental objectives compatible with socio-economic goals such as growth in income and employment? How do household characteristics, such as income level, influence choices and associated impacts? What kinds of public policy are more effective in reducing carbon emissions: taxes on emission intensive products, promotion of green alternatives, or regulations? To address these questions in a novel and convincing way, we calibrate consumption scenarios based on detailed economic and emission accounts linked to alternative consumption choices in terms of transport, food and household appliances. Our research sheds light on which measures should be undertaken to more effectively reduce emissions.

2. MATERIAL AND METHODS

2.1. The CGE model

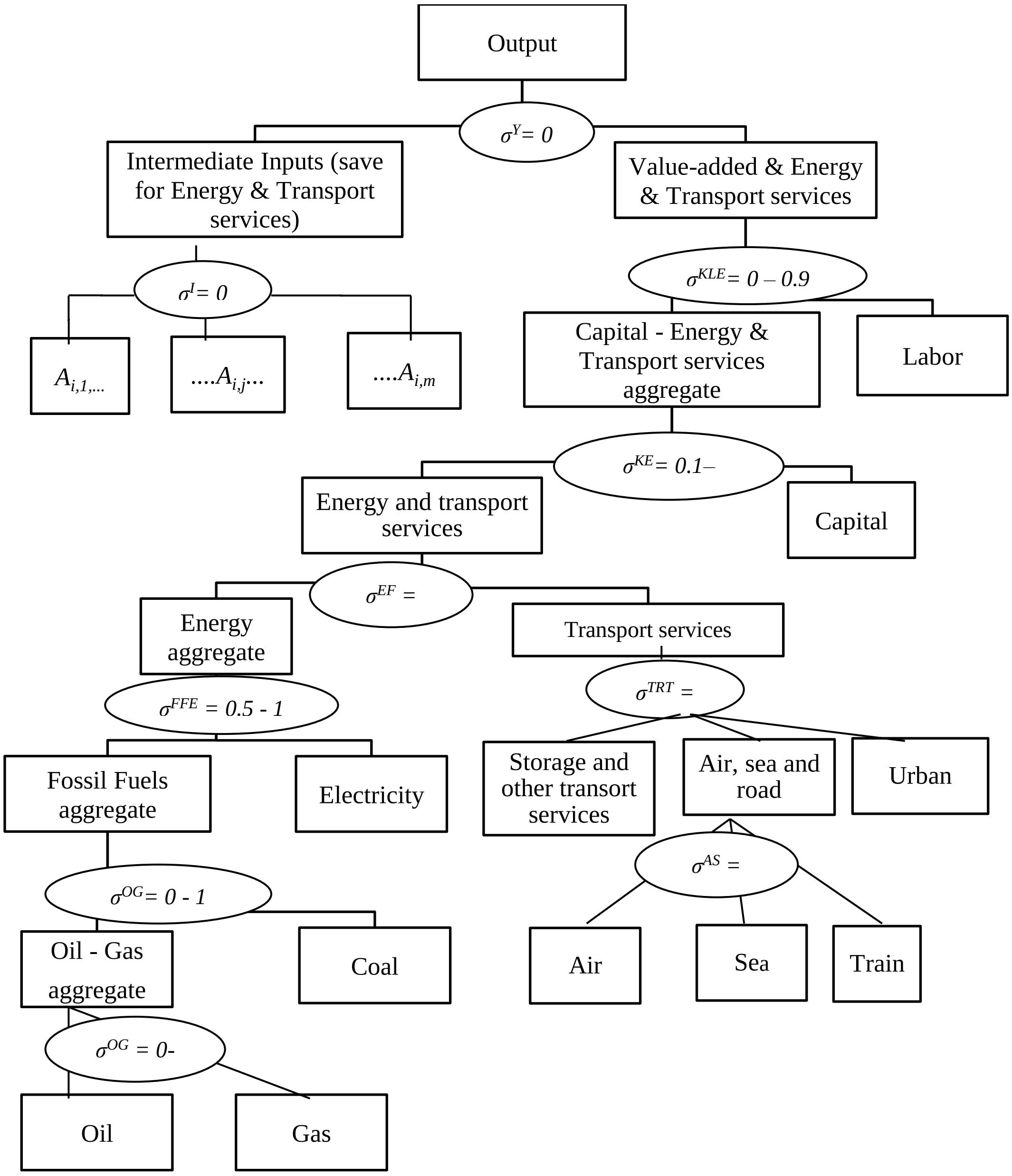
We develop a multi-sector, static Computable General Equilibrium (CGE) model to represent the Spanish economy in 2008. We choose the year 2008 because the Survey on Households and the Environment, used as reference for the formulation of our scenarios, also refers to this period. The CGE model is calibrated using a symmetric input-output table for Spain in 2008, constructed by the authors from available supply and use matrices (NSI, 2008b). We adopt the industry technology assumption of Rueda-Cantuche et al. (2009) to build the symmetric matrix. The information on total, imported, and domestic inputs from the use matrix is employed to build the corresponding symmetric matrix for 2008 (Suárez et al., 2010). The household consumption in the input-output table is disaggregated into 4 income groups of households by level of monthly net income, using data from the Household Budget Survey (NSI, 2008c). The economy is represented by 46 sectors, with very detailed sub-sector level representation of energy, transport, and food industry. This disaggregation of sectors allows us to examine the most polluting sectors (see Table SI1 of the Supplementary Information (SI)).

Figure 1 provides an overview of the production technology. Producer behavior is specified through a seven-stage, nested CES (constant elasticity of substitution) production function, and through a zero-profit condition, following a production structure similar to the GTAP-E model (Burniaux and Truong, 2002) for the energy aggregate, and similar to Liu and Bohlin (2012) for the transport services substitution. At the top level of the production structure, firms minimize their costs by choosing an optimal combination of the intermediate inputs, except for energy and transport services and the composite of value-added, energy input, and transport services (VAET). The VAET, the second level, contains labor and the aggregate of capital, energy, and transport services. At the third level the aggregate of capital and energy and transport services is obtained through a CES combination of the capital factor and the energy-transport services composite. Since this study focuses on assessing energy and transport issues, we pay special attention to the modeling of both sectors. The total demand for energy is a CES composite of electricity and a fossil fuels aggregate, which is a CES composite of coal and oil-gas composite. The total demand for transport services is also a CES composite of urban, storage and other transport services, and air, sea and road aggregate, which is a CES composite of alternative means of transport (air, sea and train).

The elasticity parameters were selected on the basis of a review of the relevant literature and studies in this field (De Schoutheete, 2012; Burniaux and Truong, 2002; Rutherford and Paltsev, 2000; Paltsev et al., 2004; De Melo and Tarr, 1992, for the CET function; Hertel, 1997, for the Armington approach; Liu and Bohlin, 2012, for the transport services substitution).

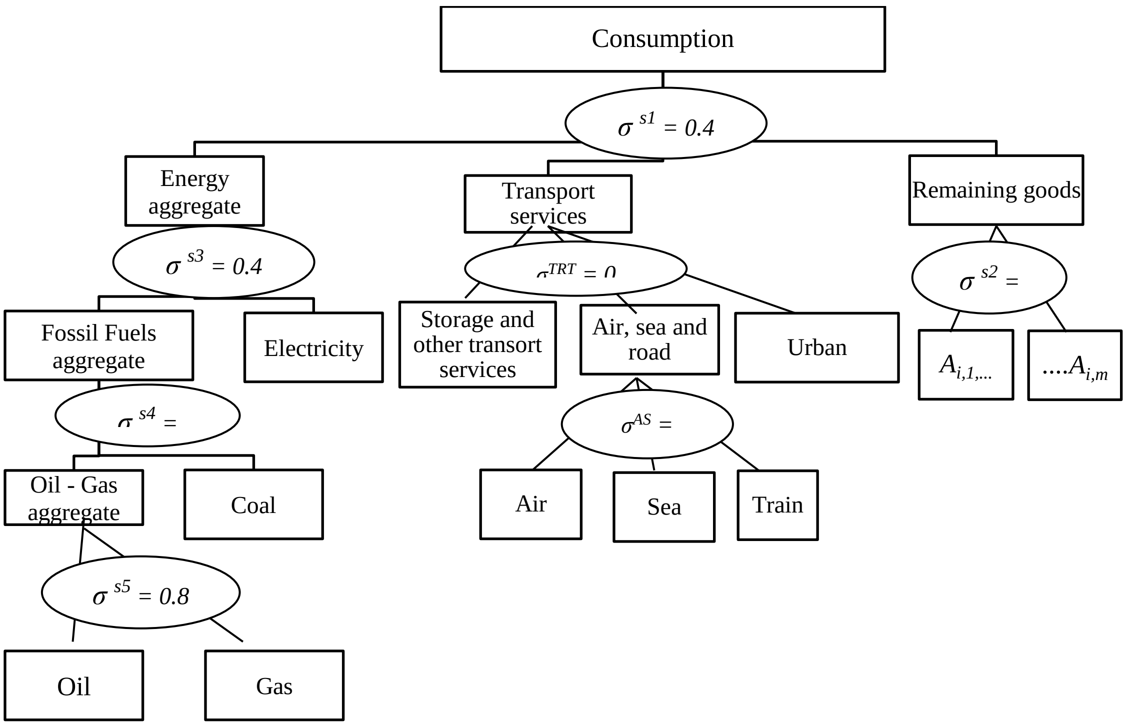
Output in each sector can be earmarked to domestic or foreign demand through a constant elasticity of transformation (CET) function. We adopt an Armington approach, in which domestic and imported goods are imperfect substitutes with different elasticities.

Figure 1. Structure of the model



Consumer preferences are defined by a four-stage nested CES utility function. See Figure 2 for the nested structure for the different goods: energy goods (Oil, Gas, Coal and Electricity), transport services (Urban, Air, Sea, Train, Storage and other transport services) and remaining goods. The consumer maximizes the total utility subject to the budget constraint. Consumer income comes from the sale of factor endowments and direct transfers from the government and other institutions, and is spent on consumption, tax payments, savings, and transfers to other institutions. The government collects taxes from households and industries and receives transfers from other institutions, and at the same time spends them on consumption, savings, and transfers to other agents. Total public expenditure is modeled through a fixed-coefficients structure. Lump-sum transfers between the government and the consumer are endogenously adjusted to ensure the same level of public spending. As we simulate carbon tax policies in some scenarios, these additional tax revenues are adjusted to reduce the fiscal deficit but maintain the level of public spending. As we work with a static model, we approximate to a welfare measure through households and government consumption. The model also includes a wage curve specification, following Blanchflower and Oswald (1990) and Küster et al. (2007), which allows us to consider imperfect competition mechanisms within the labor market and to analyze unemployment.

Figure 2. Consumption nesting structure



2.2. Emissions accounting and attribution to Spanish final demand

In our analysis we include carbon dioxide (CO_2), and nitrogen monoxide (N_2O).[1] As these two greenhouse gases (GHG) have different Global Warming Potential (GWP), we consider total GHG emissions in metric tons of equivalent carbon dioxide (CO_{2eq}), calculated on the basis of the factors published in IPCC (2007). The emissions accounts are obtained from the *Accounts emissions by industry and households as final consumers* (NSI, 2008d) for Spanish emissions, and from the *World Input-Output Database (WIOD)* (WIOD, 2008; Timmer, 2012) for other parts of the world. WIOD offers time series from 1995 to 2011 of inter-sectoral

[1] The emissions of sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are not considered because data are not available for all countries. In any case, they are usually not significant.

transactions of 35 sectors and 59 products; its geographic area covers 41 countries: 27 EU counties, 13 other major countries in the world, and the remaining countries aggregated to a single "rest of the world" region. We use data for the year 2008. Additional information required for disaggregating the GHG emissions account in 46 sectors is taken from MAGRAMA (2008b).

The emissions E_H^{TOT} estimated in the CGE model attributable to Spanish household activity take into account both household direct emissions, and direct and indirect emissions from production activities (see previous literature such as Ferng, 2002; Resosudarmo, 2003; McDonald and Patterson, 2004; Hanley et al., 2006; Liu and Bohlin, 2012; Duarte et al., 2014). In other words,

$$E_H^{TOT} = E_H^D + E_H^I \quad (1)$$

E_H^D refers to household direct energy emissions (emissions generated from heating, cooking, car use, and so on), and are obtained as the product of the row vector $\mathbf{i} = (i_e)$ of emissions per unit of each type of energy and the column vector $\mathbf{c} = (c_e)$ of household energy consumption. The index *e* refers to the type of energy product ("Coal", "Oil" and "Gas"). Note that electricity consumption is not included, because in the Spanish statistics its emissions are attributed to the electricity production sector. E_H^I refers to the emissions embodied in goods and services consumed by Spanish households.

Using the input-output model we can estimate E_H^I, as emissions from production activities aiming to satisfy the consumption activities of final consumers. This relationship can be expressed by Eq. (2) as follows (Sanchez-Chóliz et al., 2007).

$$E = \mathbf{d}' \, (\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{s} \quad (2)$$

Where $\mathbf{d}$ is a vector of emissions (Kt of CO_{2eq}, CH_4 and SO_2) per monetary unit of output; $\mathbf{A}$ is the technical coefficient matrix of production; $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ is the Leontief inverse matrix; $\mathbf{s}$ is the vector of final demand or a component of final demand, and E is the emissions from productive activities necessary to meet demand $\mathbf{s}$ in an economy with the technology described by $\mathbf{A}$.

Moreover, we can estimate the following components of E_H^I, which include Spanish emissions embodied in domestic household final consumption $\mathbf{y}_S^H$, emissions embodied in Spanish household final consumption $\mathbf{y}_{EU}^H$ ($\mathbf{y}_{ROW}^H$) imported from EU (ROW), and emissions embodied in intermediate inputs $\mathbf{M}_{EU}^S$ ($\mathbf{M}_{ROW}^S$) imported from EU (ROW). Thus, E_H^I can be estimated as

$$E_H^I = \mathbf{c}_S'(\mathbf{I}-\mathbf{A}_S)^{-1}\mathbf{y}_S^H + \mathbf{c}_{EU}'(\mathbf{I}-\mathbf{A}_{EU})^{-1}\mathbf{M}_{EU}^S\hat{\mathbf{x}}_S^{-1}(\mathbf{I}-\mathbf{A}_S)^{-1}\mathbf{y}_S^H$$
$$+\mathbf{c}_{ROW}'(\mathbf{I}-\mathbf{A}_{ROW})^{-1}\mathbf{M}_{ROW}^S\hat{\mathbf{x}}_S^{-1}(\mathbf{I}-\mathbf{A}_S)^{-1}\mathbf{y}_S^H$$
$$+\mathbf{c}_{EU}'(\mathbf{I}-\mathbf{A}_{EU})^{-1}\mathbf{y}_{EU}^H + \mathbf{c}_{ROW}'(\mathbf{I}-\mathbf{A}_{ROW})^{-1}\mathbf{y}_{ROW}^H \quad (3)$$

Where $\mathbf{c}_S$ is a vector of Spanish emissions (Kt of $CO_{2eq,}$ CH_4 and SO_2) per monetary unit of output. $(\mathbf{I}\text{-}\mathbf{A}_S)^{-1}$ is the Leontief inverse matrix of the Spanish economy, with $\mathbf{A}_S$ being the Spanish matrix of domestic technical coefficient. $\mathbf{c}_{EU}$ is a vector of EU emissions per unit of EU production, and $\mathbf{c}_{ROW}$ is the vector of ROW emissions per unit of ROW production. $\mathbf{A}_{EU}$ and $\mathbf{A}_{ROW}$ are the EU and ROW technical coefficient matrices, and $\mathbf{M}_{EU}^S$ and $\mathbf{M}_{ROW}^S$ are import matrices of intermediate inputs from the European Union and Rest of the world. Data for constructing $\mathbf{A}_{EU}$, $\mathbf{A}_{ROW}$, $\mathbf{M}_{EU}^S$ and $\mathbf{M}_{ROW}^S$ are collected from the WIOD database .

In summary, we use the input-output model to attribute emissions from production processes throughout global supply chains to the components of final demand (i.e. households, exports, public expenditure, and investment) once emissions generation is modeled in the CGE model in line with Turner et al. (2012b) and Duarte et al. (2014). In this study, we consider all emissions (domestic and foreign) embodied in goods consumed by Spanish households, using information from the multiregional input-output tables of the WIOD (Timmer, 2012). In this way, we obtain estimations of the global footprint associated with Spanish household behaviors. The CGE model provides us with $\mathbf{c}_S$, $\mathbf{A}_S$, $\mathbf{y}_S^H$, $\mathbf{x}_S$, $\mathbf{y}_{EU}^H$ and $\mathbf{y}_{ROW}^H$ that are introduced in (1) and (3) for the emissions estimations, which differ across our scenarios.[2]

Finally, we take into account the 'rebound' effects triggered in each scenario simulation. Given that alternative improvements can imply savings in household spending in certain sectors and lead to both income and substitution effects spilling over to production sectors and export-import possibilities, prices will undergo numerous and complex adjustments throughout the whole economy, leading to an increased supply of other goods. While partial equilibrium analysis focuses on the sector affected by a policy, assuming the rest of the economy is not affected, CGE models consider other sectors and regions and incorporate constraints and feedbacks between different economic sectors, allowing for a more complete assessment.

3. DESCRIPTION OF SCENARIOS

[2] Note that the CGE model is calibrated to the 2008 total symmetric input-output table for Spain and the domestic matrix is obtained from a $\mathbf{A}_\mathbf{S}^\mathbf{T}$ (Spanish matrix of total technical coefficients).

Our simulations are divided into three sets of scenarios. The starting point is the Survey on Households and the Environment (NSI, 2008a), and in particular the micro-data of the survey. See detailed explanation in the Supplementary Information. The first block simulates a general improvement in the behavior of consumers in relation to the environment. These scenarios consider higher shares of efficient electric appliances with a rating of higher than *A+*, healthier vegetable-based diets, and the promotion of sustainable means of urban transport through the switch from traveling by passenger vehicle to collective modes (bus, train, and underground). In this regard, our first group of scenarios simulates a change in the behavior of Spanish households in line with the guidelines, official regulations, social recommendations, best experiences and/or social norms of the most pro-environmentally-conscious countries. We assess the results in 3 areas (electricity saving, transport, and diet) separately (Scenario 1a, 1b and 1c, respectively) and simultaneously (Scenario 1d).

Scenario 1:

Scenario 1a "*Energy*": Electricity saving is achieved through an efficiency improvement in household energy use, via replacement of obsolete or low-efficiency domestic devices with appliances labelled Class A, A+ and A++. For this, we compare the current shares of electrical appliances with A, A+, A++ ratings (refrigerator, washer, and dishwasher) in Spanish households (Baseline scenario) obtained from the Survey on Households and the Environment (NSI, 2008a) in Scenario 1a. This is defined by increasing the Spanish shares in energy efficient appliances to match the share in German households, which stands at 76.06% based on data from the Federal Statistical Office of Germany (2014), REMODECE survey (2012) and GAP (2013 (See also a similar process in ADEME, 2012).

Scenario 1b "*Transport*": The need for a modal shift from private cars to public transport is well known, and we now consider as baseline scenario the current use of public and private transport obtained from the Survey (NSI, 2008a). We simulate a change in modal share of trips following the data from the European Metropolitan Transport Authorities (EMTA, 2012) for the case of Madrid, a large city considered in the group of "sustainable mobility" with a relatively high share of public transport of 40.1%. The current Madrid shares define Scenario 1b "*Transport*". We consider that the share of other means of transport (bicycle, foot,…) remains the same. The new modal share of public transport would involve a different consumption of urban transport services by households, and at the same time, a reduction of fuel consumption by households due to a drop in the modal share of private cars. These demand shocks are included in the CGE model as demand reductions in the fuel cost of private car use, and demand increases in spending on urban public transport.

Scenario 1c "*Diet*": In this case, we simulate more environmentally friendly eating patterns, based on recommendations for a healthier diet (SENC, 2007). These recommendations involve consuming at least 3 portions of fruit and vegetables, each of 120 grams (≥ 360 g. a day) and consuming around 100 grams of meat.

Scenario 1d "*All*": All previous behaviors are considered simultaneously.

Scenario 2:

In the second set of scenarios, we analyze the effects of improvements in the current environmental awareness of Spanish households. We consider the current situation regarding the use of efficient electrical appliances (Scenario 2a) and public transport (Scenario 2b) using the taxonomies of ELI and EMIND mentioned in Section 2.3. These scenarios allow us to evaluate household behavior in terms of environmental awareness and income level, and to assess whether soft public policy (education and advertisement), designed to encourage consumers to be more environmentally friendly, may be more efficient than the policies of scenarios 1a and 1b, which usually require official regulations and controls.

-Scenario 2a "*Energy*": Based on the ELI taxonomy, this scenario assumes that a given household changes its category, increasing its environmental awareness by one level (e.g. rising from low to medium level) across income groups. Table SI3 shows the efficiency improvements achieved, and these levels are considerably lower than in Scenario 1, but less important as the income level rises. This allows us to anticipate that these measures may not be sufficient to reach the guidelines and levels of Scenario 1, but they can be a significant improvement.

-Scenario 2b "*Transport*": Based on the EMIND taxonomy, we simulate a jump to a higher level of environmental awareness in the use of public transport, for any income group. Demand changes involved in this scenario are also presented in Table SI4. Those with a high-income level are more affected by the encouragement, through promotion of environmental awareness, to use public transport, in spite of the fact that the reduction in the use of private transport is modest.

Scenario 3:

In the third set of scenarios, we consider whether fiscal measures can be more effective than those proposed in previous scenarios to motivate changes in consumption of the same polluting goods: electricity expenditure (Scenario 3a), transport use (Scenario 3b) and healthier diets (Scenario 3c) separately, and simultaneously (Scenario 3d). Specifically, we have in mind the new energy taxation rule (European Commission, 2011) as a reference point, whose aim is to favor renewable energy sources and CO_2 emissions reductions. This tax has two parts: a tax based on the energy content of fuels and electricity, at €0.15 per GJ, and another based on CO_2 emissions at €20 per ton of CO_2. These rates are minimal requirements for every Member State; each member is free to set higher rates. In this line, we only consider the embodied energy of the most polluting goods on which this paper focuses (Electricity, Petroleum, Livestock, Meat industry), and evaluate the effects of paying €20/tCO_2. These taxes are included in the consumption function, as taxes on final consumption paid by households. However, the sensitivity analysis in the Supplementary Information compares the results applying this tax to all sectors, in line with prior works such as Bordigoni et al. (2012) and Rochi et al. (2014).

4. RESULTS

4.1. The baseline

Table 1 reports GHG, SO_2 and CH_4 emissions associated for the baseline situation. It shows that GHG emissions associated with the production of consumption items far outweigh a household’s direct emissions from heating and driving (84.7% vs.16.3%). The medium-high income group (H3) accounts for the largest share of total GHG and SO_2 emissions, the medium-low income group (H2) takes the largest share in the case of CH_4 emissions, and further the group H3 accounts for the largest share of direct households emissions for all three types of emissions. In contrast, the consumption of the low income group (H1) generates the lowest embodied and direct household emissions.

Emissions generated by exports are also significant, representing 17.4% of GHG, 20.1% of SO_2 and 10.9% of CH_4 emissions. It is also worth noting that emissions from “Electricity” comprise mainly GHG and SO_2 emissions, accounting for 31.6% and 33.9% of total GHG emissions, respectively; whereas emissions from “Livestock” are mostly CH_4, accounting for 55.5% of total GHG emissions (see Table SI1 of the SI). The following scenarios will focus on policy strategies for the most polluting sectors.

Table 1. GHG, SO_2 and CH_4 emissions associated with final demand

		GHG (Kt)	%	SO_2 (Kt)	%	CH_4 (Kt)	%
Production activities		**358,096**	***83.66***	**844**	***98.60***	**2.725**	***98.73***
H1: Low income		21,120	*4.93*	57	*6.70*	239	*8.66*
H2: Medium-low income		60,518	*14.14*	162	*18.90*	669	*24.23*
H3: Medium-high income		61,311	*14.32*	163	*18.99*	657	*23.81*
H4: High income		55,392	*12.94*	145	*16.96*	579	*20.99*
Exports		74,665	*17.44*	172	*20.06*	301	*10.89*
Government		23,861	*5.57*	41	*4.79*	150	*5.42*
ISFLSH[3]		1,111	*0.26*	2	*0.19*	5	*0.17*
Investment		60,117	*14.05*	103	*12.03*	127	*4.59*
Direct household emissions		**69,932**	***16.34***	**12**	***1.40***	**35**	***1.27***
H1	Coal	26	*0.01*	0	*0.00*	0	*0.00*
	Petroleum	6,853	*1.60*	1	*0.14*	3	*0.12*
	Gas	321	*0.07*	0	*0.01*	0	*0.01*
H2	Coal	57	*0.01*	0	*0.00*	0	*0.00*
	Petroleum	17,147	*4.01*	3	*0.34*	9	*0.31*
	Gas	2,970	*0.69*	1	*0.06*	1	*0.05*
H3	Coal	51	*0.01*	0	*0.00*	0	*0.00*
	Petroleum	18,873	*4.41*	3	*0.38*	9	*0.34*
	Gas	2,877	*0.67*	0	*0.06*	1	*0.05*
H4	Coal	42	*0.01*	0	*0.00*	0	*0.00*
	Petroleum	18,285	*4.27*	3	*0.36*	9	*0.33*
	Gas	2,432	*0.57*	0	*0.05*	1	*0.04*
TOTAL		**428,028**	***100.00***	**856**	***100.00***	**2.760**	***100.00***

4.2. Simulations

4.2.1. Impacts of changes induced by environmental recommendations (Scenario set 1)

The main results for the first set of scenarios are presented in Table 2. As we explained above, this set of scenarios address changes in line with the guidelines of the most pro-environmentally–conscious countries. First, we note that the figures of Scenario 1d are close to the sum figures of the other three scenarios, confirming that Scenario 1d is more or less the combination of scenarios 1a “*Energy*”, 1b “*Transport*” and 1c “*Diet*”. Scenario 1b “*Transport*” is the most environmentally efficient scenario which is characterized by the highest percentage of reductions for total GHG and SO_2 emissions (cf. the last panel of Table 2), the largest decline in unemployment, and the most favorable changes in value added, welfare level, and CPI. Moreover, the combination of all pro-environmental guidelines (which can be identified with

[3] Non-profit institutions that serve homes (ISFLSH in Spanish acronym).

Scenario 1d "*All*"), provide good macro-economic results, i.e., allow reductions in unemployment and CPI, and improvements in total output and welfare level, compatible with the reduction of emissions.

Table 2. General results of Scenario 1 (% change with respect to the baseline)

Macro-economic & Environmental results	**Scenario 1a "*Energy*"**	**Scenario 1b "*Transport*"**	**Scenario 1c "*Diet*"**	**Scenario 1d "*All*"**
Total production	0.458	0.821	-0.087	1.174
Total imports	0.363	1.048	-0.289	1.102
Total exports	0.428	0.556	-0.226	0.730
Total private consumption	0.694	0.830	0.046	1.563
Capital investment	0.689	1.398	0.140	2.203
Unemployment	-3.605	-5.569	0.136	-8.918
Wages	0.026	-0.554	0.222	-0.320
Welfare level	0.566	0.654	0.037	1.250
CPI	-0.231	-0.952	0.232	-0.474
Emissions of production activities (GHG)	-0.188	0.889	0.156	0.842
Emissions of production activities (SO_2)	-0.151	-0.179	0.253	-0.060
Emissions of production activities (CH_4)	0.319	-0.334	-1.523	-1.586
Household direct emission (GHG)	0.532	-16.657	-0.179	-16.371
Household direct emission (SO_2)	0.532	-16.657	-0.179	-16.371
Household direct emission (CH_4)	0.532	-16.657	-0.179	-16.371
Total emissions (GHG)	**-0.061**	**-2.200**	**0.097**	**-2.189**
Total emissions (SO_2)	**-0.141**	**-0.432**	**0.246**	**-0.311**
Total emissions (CH_4)	**0.322**	**-0.571**	**-1.503**	**-1.800**

Improvements in energy efficiency in households, through adopting a higher share of efficient electric appliances (Scenario 1a "*Energy*"), lead to reduced consumption of electricity (see Table SI9 of the SI). Table 2 also shows the positive overall effects of Scenario 1a "*Energy*" on total private consumption induced by the positive change in demand for non-electrical goods and services (rebound effect). Driven by increase in private consumption, total production of all sectors of the economy increases, unemployment declines, real wages rise, and the welfare level of the economy is enhanced. The electricity saving leads to a small reduction of total emissions of GHG (0.06%) and SO_2 (0.14%) but also leads to an increase in CH_4 emissions (0.32%) due to the rebound effects with an increase in food related emissions. The rebound effects induce an increase of 372 Kt of CO_{2eq} in direct household emissions that is offset by a reduction of 616 Kt of CO_{2eq} in embodied emissions (see Table SI6 of the SI). Moreover, we can observe that rebound effects in direct household emissions are lower for low-income households, in spite of their larger improvements, because they have a lower level of baseline consumption. However, this measure is not effective in reducing CH_4 emissions.

Substituting public transport for private cars (Scenario 1b "*Transport*") reduces the total emissions of GHG, SO_2 and CH_4. Direct emissions attributed to household consumption decrease, and it is also the case for SO_2 and CH_4 emissions from production activities. GHG emissions from production activities increase, but the decline in direct emissions from households offsets this increase, resulting in a drop of 8,740 Kt of CO_{2eq} due to the reduction in the use of fuel (See Table SI6 of the SI). The largest increase in embodied emissions of household consumption occurs in the richest income group, as a result of their larger demand for private transport. By contrast, the largest emissions cuts occur in the poorest income group (see Table SI6 of the SI). Table 2 also shows the positive effects of Scenario 1b "*Transport*" on the economy, which can be attributed to the stimulus from public policies to build and to adapt cities for a greater use of public transport.

Changing consumer diets to healthier, vegetable-based regimes (Scenario 1c "*Diet*") is aimed at reducing CH_4 emissions, achieving the objective of reducing the total CH_4 emissions by 1.5% (see Table 2). Unfortunately, total emissions of GHG and SO_2 increase, due to increasing emissions of production activities triggered by additional household consumption. The wealthiest household group consumes already a greater proportion of fruit and vegetables and therefore their additional consumption is lower, resulting a lower addition in the associated GHG and SO_2 emissions. The total reduction of CH_4 emissions is 36.24 Kt of CH_4, caused mainly by a reduction of meat consumption (see Table SI6 of the SI). We can see that the poorest group does not achieve a reduction in CH_4 emissions, because their level of meat consumption is lower in the baseline. In terms of the overall economic effect of this scenario, we find declines in total production, and imports and exports; increases in unemployment and CPI; and slight improvement in the welfare level of the economy. All this raises doubts on the potential economic gains of changes in diet, so other measures may need to be taken into consideration.

Finally, the results of Scenario 1d "*All*" show the effects of a strategy designed to incorporate the previous three recommendations into one policy package. This scenario may be more realistic, since these guidelines on key sectors (electricity, transport, food) are not isolated policies. As can be seen in Table 2, this scenario improves results in production, imports, exports, consumption and welfare, and significantly reduces unemployment. At the same time, total GHG, SO_2 and CH_4 emissions fall by 2.2%, 0.3% and 1.8%, respectively, with a large reduction in direct household emissions (see Table SI3 of the SI). We find that results in Scenario 1d "*All*" are mainly influenced by Scenario 1b "*Transport*" with changes from private to public transport.

4.2.2. Impacts of changes in environmental awareness (Scenario set 2)

Our second set of scenarios studies the effects of improvements in the current environmental awareness of households. The main results for these scenarios are presented in Table 3, and supplemented by Tables SI7 and SI10 in the SI.

Table 3. General results of Scenario 2 (% change with respect to the baseline)

Macro-economic & Environmental results	**Scenario 2a "*Energy*"**	**Scenario 2b "*Transport*"**
Total production	0.135	0.376
Total imports	0.106	0.429
Total exports	0.126	0.305
Total private consumption	0.202	0.419
Capital investment	0.202	0.629
Unemployment	-1.058	-2.581
Wages	0.008	-0.172
Welfare level	0.165	0.333
CPI	-0.067	0.145
Emissions of production activities (GHG)	-0.053	0.323
Emissions of production activities (SO_2)	-0.032	0.062
Emissions of production activities (CH_4)	0.087	0.009
Household direct emission (GHG)	0.155	-5.290
Household direct emission (SO_2)	0.155	-5.290
Household direct emission (CH_4)	0.155	-5.290
Total emissions (GHG)	**-0.016**	**-0.665**
Total emissions (SO_2)	**-0.029**	**-0.020**
Total emissions (CH_4)	**0.088**	**-0.068**

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Improvements in environmental awareness regarding the use of efficient electrical appliances, as specified in Scenario 2a "*Energy*", lead to less change than that following the guidelines of Scenario 1a "*Energy*". The total reductions of GHG and SO_2 emissions are slightly lower, and the increase in total emissions of CH_4 is lower (see Tables SI6 and SI7 of the SI). The results by level of household income show that the lower the income, the greater the reduction of emissions from electricity and gas used in production activities (see Table SI7 of the SI). In relative terms, this indicates that policies aimed at promoting more environmentally friendly consumption patterns are more effective among low income groups in comparison with the baseline scenario.

Again, the reductions in GHG, SO_2 and CH_4 emissions are lower with a greater environmental awareness of the benefits of public transport (with a higher level in Scenario 2b "*Transport*") than that under Scenario 1b "*Transport*" (at the levels of the Madrid's public transportation). For example, greater environmental awareness leads the wealthiest to a greater increase in the use of urban transport services (Table SI7 of the SI). However, the greatest reduction in petroleum consumption is found in the medium-high and medium-low income groups. This means that, despite the increased use of public transport by the high income group, this group still heavily depends on private cars, leading to a less significant reduction in petroleum consumption (see also Table SI7 of the SI). To sum up, measures to increase the environmental awareness by education, advertisement, and/or social change are less effective than changes induced by recommendations of more pro-environmentally conscious countries (Scenario 1).

4.2.3. Impacts of changes with carbon tax (Scenario set 3)

Table 4 reports the effects of a carbon tax on the economy. It shows that encouraging changes in household behavior through fiscal measures on electricity, fuel, and meat prices lead to reductions in the total GHG, SO_2 and CH_4 emissions in all scenarios. Reductions take place in both direct household emissions and embodied emissions for producing consumption goods for households.

Looking at the overall economic effect of a carbon tax Table 4 shows a negative picture, with declines in output, imports, exports, private consumption, and welfare, and increases in unemployment. This is due to the design of the scenario in which tax revenues are simply used to reduce fiscal debt instead of recycling back into the real economy and public spending is assumed remaining the same. As a consequence, the reduction in the consumption of those taxed goods does not encourage an increase in demand for un-taxed goods, meaning that the rebound effects are null.

Table 4. General results of Scenario 3 (% change with respect to the baseline)

Macro-economic & Environmental results	**Scenario 3a "*Energy*"**	**Scenario 3b "*Transport*"**	**Scenario 3c "*Diet*"**	**Scenario 3d "*All*"**
Total production	-0.122	-0.214	-0.051	-0.390
Total imports	-0.089	-0.157	-0.020	-0.267
Total exports	-0.131	-0.211	-0.059	-0.403
Total private consumption	-0.079	-0.146	-0.036	-0.261
Capital investment	-0.184	-0.319	-0.068	-0.574

Unemployment	0.876	1.643	0.400	2.934
Wages	-0.030	-0.032	-0.039	-0.101
Welfare level	-0.079	-0.146	-0.036	-0.261
CPI	0.031	0.082	-0.011	0.102
Fiscal deficit	-0.079	-0.146	-0.036	-0.261
Emissions of production activities (GHG)	-0.227	-0.062	-0.191	-0.481
Emissions of production activities (SO_2)	-0.211	-0.084	-0.186	-0.482
Emissions of production activities (CH_4)	-0.110	-0.079	-0.166	-0.356
Household direct emissions (GHG)	-0.007	-0.678	-0.046	-0.732
Household direct emissions (SO_2)	-0.007	-0.678	-0.046	-0.732
Household direct emissions (CH_4)	-0.007	-0.678	-0.046	-0.732
Total emissions (GHG)	**-0.188**	**-0.170**	**-0.165**	**-0.525**
Total emissions (SO_2)	**-0.207**	**-0.094**	**-0.184**	**-0.486**
Total emissions (CH_4)	**-0.109**	**-0.087**	**-0.164**	**-0.361**

Table SI11 of the SI also adds some insights into these scenarios: poorer households are relatively more affected by increases in electricity prices due to carbon taxes; richer households are more affected by increases in fuel prices in terms of total increase in expenditure due to higher price; and the total reduction is due to small reductions in the majority of sectors, rather than dominant reductions in polluting sectors. This is similar to findings in previous scenarios. To sum up, this scenario triggers positive effects in emission reduction across the board, but with widespread socio-economic costs, as manifested by reductions in total output, consumption, imports, exports, and increases in unemployment. This measure is also less effective in reducing consumption in the most polluting sectors.

5. CONCLUSIONS

In this paper, we evaluate the effects of a range of hypothetical changes in environmental awareness and behavior of Spanish consumers. We employed a number of scenarios within a CGE modeling framework and modeled their effects on the economy and the environment. These changes consider three ways to reduce emissions: changes induced by recommendations of the most pro-environmentally-conscious countries, improvements in environmental awareness, and a carbon tax. These changes consider the most polluting sectors and are modeled as: higher shares of efficient electric appliances with a rating of *A+* or higher, higher use of public transport, switching to a healthier diet and all of them simultaneously. Some general conclusions can be derived from the analysis.

First, in general terms, the results from a strategy designed to accommodating all major guidelines and recommendations on key sectors (electricity, transport, food) as one policy package (Scenario 1d "*All*") suggest that reductions in greenhouse gas, methane, and sulphur dioxide emissions may be compatible with socioeconomic goals of increasing income and welfare and reducing unemployment. In other words, the results provide evidence of economic growth going hand-in-hand with environmental protection.

Second, the results by level of household income show that the lower the income, the greater the reduction of emissions from electricity and gas used in production activities. In relative terms, policies aimed at promoting more environmentally friendly consumption patterns are more effective among low income groups.

Third, a modal shift to public transport (Scenario 1b "*Transport*") is the most environmentally efficient choice, and also the best from an economic point of view. Thus, policy efforts to promote and facilitate public transport are critical for reaching the environmental goals.

Four, changing diets towards healthier vegetable-based regimes, aimed at reducing CH_4 emissions, does, in fact, increase total emissions of GHG and SO_2. This increase is due to rebound effects or additional household consumption induced by the savings generated with the healthier diets.

Finally, influencing environmental behavior through carbon taxes may reduce emissions, but the socio-economic benefits of other alternatives are no longer present. In other words, introduction of carbon taxes leads to falls in production, imports, exports, private consumption, welfare, and employment. But these negative effects are also an artifact of the design of the tax that withdraws purchasing power without cycling the money back into the economy. Alternative designs using tax revenues for example for stimulating renewable energy technologies or public transport would certainly counter balance the negative effects to the economy. Our results indicate that there is a trade-off between socioeconomically friendly public policies which focus on encouraging consumers (via regulations and controls) to behave in a more environmentally-friendly way and the more environmentally effective policy of imposing a carbon tax but the extent of the effect depend strongly on the specific design of the policy tool.

Once data become available for all European Union (EU) countries, this study can be extended to consider the behavior of consumers in all EU countries across those key sectors analyzed in this paper, as well as the strategies carried out in all these countries to reduce emissions through changes in consumption patterns. This natural extension would make it possible to identify behavior patterns via a more detailed tracking of trade flows among countries and thus leading to a more effective assessment of environmental pressures in response to the climate change policies.

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