The road to Paris with energy-efficiency strategies and GHG emissions-reduction targets: The case of Spain

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Abstract:

Recent warnings about the impacts of climate change have led international climate negotiations to focus on the necessary global long-term goal (LTG) presented in the Paris agreement (COP21). Over 120 countries, numerous non-governmental organizations, and many corporate leaders support LTG propositions on the basis of voluntary cooperation and widely disseminated information on national contributions, to achieve sustainable development with zero emissions by 2100, compatible with the achievement of poverty eradication and equity (see IPCC (2014) and FCCC (2015)). However, the starting point for each country and agency differ considerably, and specifically- defined national objectives are demanded necessary. Based on a Computable General Equilibrium (CGE) model, calibrated with Spanish data for 2010 and including GHG emissions and energy demands, this article considers the Paris Accords by defining and comparing a range of dynamic 2010-2050 scenarios in which the Spanish economy advances to zero emissions. We also evaluate the long-term economic and environmental impacts to 2020, 2030, and 2050.

Keywords: Emissions abatement, Energy efficiency, CGE model, 2015 Paris agreement, renewable energy.

1. Introduction

In December 2015, over 120 countries, various non-governmental organizations, and many corporate leaders reached the so-called "Paris Accords" (PA or COP21) within the United Nations Framework Convention on Climate Change (FCCC). The PA seeks to strengthen the global response to the threat of climate change, in order to achieve sustainable development with zero emissions by 2100, and simultaneously to advance poverty eradication and equity, globally. The PA has recently been accepted and ratified by more than 55 parties to the Convention, including the European Union (EU).

The EU also signed on to the Kyoto first commitment period (2008-2011s), pledging to reduce its emissions by 6% compared to 1990 levels. The second commitment period of Kyoto (2013-2020) covered the period between 2013 and the start of a new global agreement, and is therefore valid until the new PA. The EU countries (together with Iceland) agreed to jointly meet a 20% reduction target compared to 1990, in line with the EU's own targets.

The EU climate strategy aims to achieve an economy-wide GHG reduction target of at least 20% by 2020 compared to 1990, 40% by 2030, and 80% by 2050 (see EU, 2016a). As the EU's emissions for 2005 are slightly lower than those of 1990, we use emissions in 2005 as the reference point.

Moreover, in 2020, the Emissions trading system (ETS) will cover around 45% of EU GHG emissions, mainly emissions from the power, industry, and aviation sectors. The EU wants these types of emissions to be 21% lower than in 2005 in all countries. For the remaining sectors, not covered by ETS and accounting for around 55% of the total EU emissions, the targets differ according to national wealth. Both measures globally represent an approximate 20% cut below 1990 levels by 2020. For Spain, the overall requirement is 10% above 2005 levels (see Figure A3 in Annex). Additionally, by 2020, the EU aims to obtain 20% of its energy from renewable sources and to improve energy efficiency by 20%. More specifically, the EU as a whole aims for a share of renewables of around 10% in the transport sector.

Regarding the situation in 2030, the target of a 40% reduction in emissions is planned to be achieved with reductions of 43% of the emissions of sectors with ETSs, and with reductions of 30% in the remaining sectors, for which it will be necessary to establish individual binding targets. Regarding the share of renewables, the target for 2030 is to achieve from this source at least 27% of the energy consumed in the EU. And, in relation to improving efficiency, the European Council has planned an energy saving target of 27%, with a potential revision up to 30%. The additional annual investment required to implement these targets is estimated at € 38 billion for the EU as a whole over the period 2011-2030, representing approximately 0.26% of the EU's overall added value in 2015 (see Eurostat, 2016). The objective is to achieve a reduction of 80% by 2050, after a 60% decline by 2040. This 80% reduction aims to be achieved as a reduction in domestic (own) emissions, thus avoiding any recourse to international credits.

In this context, what can be said specifically about Spain, a country with important external energy dependence of about 80% compared to 55% in the EU. In Spain, in line with the EU strategies, two governmental plans for energy diversification and savings have been defined, one for the period 2004-2010 and the other for 2011-2020 (see IDEA 2016 a and b), which we can call PER 2005-2010 and PER 2011-2020.

The current PER, covering the period 2011-2020 was approved by the Government on 11 November 2011, in accordance with Directive 2009/28 / EC of the European Parliament and of the European Council, dated 23 April 2009. The European standards set for Spain the objective that renewable sources will account for at least 20% of final energy consumption in 2020 - the same target as for the EU average - together with a minimum contribution of 10% of renewable energy sources in transport, objectives which were incorporated in the PER 2011-2020. According to forecasts, production of renewable electricity by 2020 should exceed 38% of total national production. PER 2011-2020 analyses the technical aspects of the study of the evolution of energy transport facilities in general, and the study of the management of the electrical system, and makes a set of proposals for action for the integration of renewable energies and improved distribution. In terms of generation. The objective is to prioritize the use of electrical energy from renewable energy sources and suggests the need for a stable and predictable economic framework that encourages generation from such resources, while ensuring that associated investments will obtain reasonable rates of return.

The PER 2011-2020 divides the necessary investments into three main areas: electric, thermal, and biofuels. The planned investments and the corresponding support (additional costs of administration and the private sector) are included in the following table:

Table 2: PER 2011-2010, investment and support forecast

(Thousand euros) Investment	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total 2011-2020
Electrical area	6,993	7,117	4,734	4,043	4,320	4,663	4,938	5,559	6,377	6,998	**55,743**
Thermal area	353	362	420	451	676	746	724	794	843	911	**6,279**
Biofuels	0	0	0	0	45	300	0	30	300	100	**775**
Total investment	**7,346**	**7,479**	**5,153**	**4,494**	**5,041**	**5,709**	**5,662**	**6,383**	**7,520**	**8,009**	**62,797**
Cost for the Public Administration											
Public investment aids	24	64	81	95	107	123	131	139	136	137	**1,037**
Financing	4	7	10	12	14	17	19	21	24	26	**155**
Other policies (information, etc…)	2	14	7	7	6	6	6	6	6	6	**67**
Subtotal Public Adm		**85**	**98**	**114**	**128**	**146**	**156**	**166**	**166**	**169**	**1,259**
Cost for the private sector											
Renewable electricity premiums (base scenario)	489	1,325	1,954	2,283	2,502	2,671	2,790	2,923	3,078	3,218	**23,235**
Incentives to renewable heat	-	2	8	13	18	23	27	31	34	36	**191**
Subtotal private sector	**489**	**1,327**	**1,962**	**2,296**	**2,520**	**2,694**	**2,817**	**2,954**	**3,112**	**3,254**	**23,426**
Total costs (base scenario)	**520**	**1,413**	**2,060**	**2,410**	**2,648**	**2,841**	**2,973**	**3,120**	**3,278**	**3,423**	**24,686**

Source: IDEA (2016b), page 570.

As shown in the table, an additional investment is predicted during the decade of more than 62 billion euros, of which 55 billion correspond to electricity generation facilities and more than 6 billion to thermal installations. The additional support from the Administration is 1.259 billion and from the private sector around 23 billion. This means that the investments and costs attributable to the Plan exceed 87 billion euros and that we can assume an annual cost of less than 9 billion euros, or approximately 0.7% of the expected average Spanish GDP (about 1300 billion euros). We will assume, therefore, that non-investment spending will be about 25 billion, approximately 0.2% of GDP, leaving an additional 0.5% for investment.

2. Methodology

This work presents the development of a multi-sector, dynamic Computable General Equilibrium (CGE) model to represent the Spanish economy in 2010. The work is based on previous energy-related CGE models. Specifically, the production and consumption structure follows Duarte et al., (2014a); the dynamic path is included as in Duarte et al., (2014b), and different specifications on the use of private cars by consumers follows the work of Figus et al. (2016).

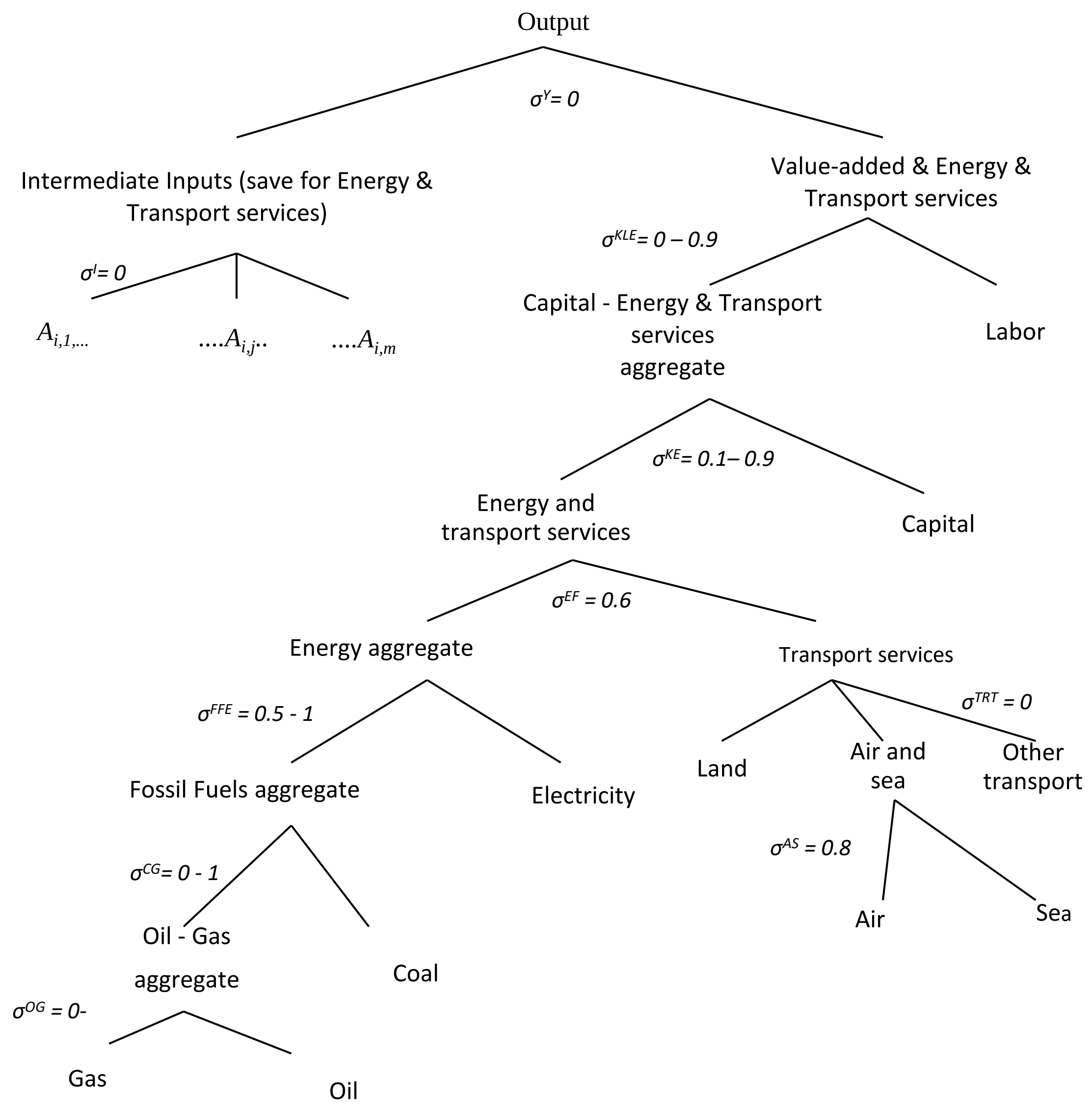
Our work uses a recursive dynamic CGE model to evaluate the long-term economic and environmental impacts up to 2020, 2030, 2040 and 2050.

The input-output table consists of 34 economic activities, two production factors (labour and capital), and other accounts, such as Households, Companies, Savings/Investment, Government, and a Foreign Sector. The latter consists of two other accounts: transactions carried out with the rest of the European Union (EU), and with the Rest of the World (ROW). The special interest in our study is focused on the energy sector, which is disaggregated into four energy accounts: coal, petroleum, gas, and electricity.

We explain here the nesting and relationships among energy sectors, with the rest of sectors in production and consumption.

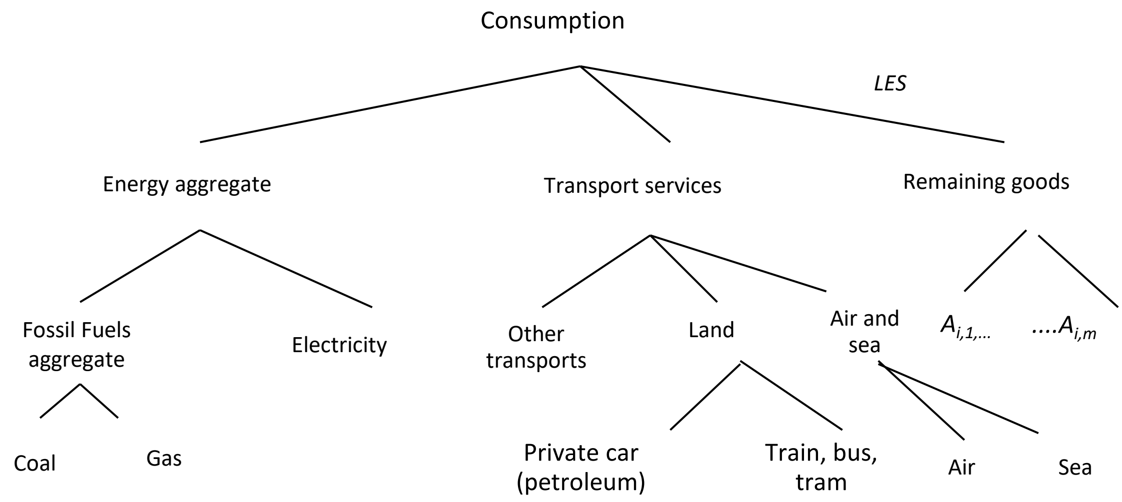
Figure 1 represents the structure of the production sectors. Total output is obtained through a combination of a value-added-energy aggregate-transport composite and all other intermediate inputs according to a Leontief function (fixed technical coefficients). The value-added-energy aggregate-transport composite is a multi-level constant elasticity of substitution (CES) production function, combining an aggregate of energy and transport services, capital, and labor. On the right side, travel by air and sea includes an additional nest as it is more difficult to substitute between them because they are not used for short-distance transport. On the left side, the structure of the energy aggregate follows the GTAP-E model (Burniaux and Truong, 2002). Demand for energy is a CES composite of electricity and a fossil fuels aggregate, which is itself a CES composite of coal and oil-gas that represents an additional bundle to substitute between oil and biofuel.

Figure 1. Nested structure of production



Concerning consumption, Figure 2 presents consumer preferences defined by a three-stage nested CES utility function. In the case of the transport services aggregate, consumers choose the mean of transport following a Leontief function between land, air, and sea, and other transports, on the assumption that this decision depends on distance travelled rather than relative prices.

Figure 2. Household consumption nesting structure



Concerning factor markets, the labour and capital factors are considered to be mobile across sectors. The model also includes a wage curve to consider unemployment. The elasticity parameters are selected on the basis of a review of the literature on this topic.

The model above is calibrated for the Spanish economy of 2010, and dynamically extended for the period 2010-2050. The values of the main parameters of the dynamic model are obtained from actual average data for Spain for a period of 10 years 2005-2015 (INE, 2005-2015). Specifically, the annual interest rate is 4.22% and the growth rate is 0.77%. The relationship between capital and investment in the steady-state is obtained from the calibration of the model using the information of the Spanish input-output table. A detailed description of this dynamic can be found in Duarte et al. (2016).

The attribution of emissions to final demand is obtained using input-output models (see also Turner et al., 2012, and Duarte et al., 2014). In this regard, the emissions estimated in the CGE model take into account both household direct emissions, E^{DH}, and emissions from production activities, E^{PA}.

$$E = E^{DH} + E^{PA}$$

E^{DH} emissions are obtained as the product of a vector **i** of emissions per unit of each type (“Coal”, “Refined oil”, and “Gas”) of energy by household consumption vector **c**. E^{PA} emissions are calculated using the input-output model (see Sanchez-Chóliz et al. (2007)).

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

where **d** is a vector of productive emissions intensities (Kt of CO_{2eq} per monetary unit of output); $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ is the Leontief inverse matrix, and **s** is the vector of final demand.

We consider greenhouse gas (GHG) emissions expressed in kilotons of equivalent carbon dioxide (Kt of CO_{2eq}), with information obtained from the Emissions satellite accounts provided by the Spanish National Statistics Institute (INE, 2010).

3. Future scenario for the Spanish economy

3.1. Baseline scenario: balance path and description for 2010

The baseline scenario, used to evaluate the impacts of our scenarios described in the following section, is calibrated by assuming an annual interest rate of 4.22% and a growth rate of 0.77% (INE, 2005-2015). The balance path from 2020 to 2050 represents the expected evolution if no environmental policies are implemented.

Direct and indirect emissions for the baseline scenario, both the base year and the evolution of emissions of the balance path, are presented in Table 1. We assume that the unit vector of emissions (Kt of CO_{2eq} per monetary unit of output) does not vary.

Table 1. Spanish GHG emissions in the baseline scenario (2010, 2020, 2030, 2040, and 2050)

	2010		**2020**	**2030**	**2040**	**2050**
	GHG (Kt)	%	GHG (Kt)	GHG (Kt)	GHG (Kt)	GHG (Kt)
Household direct emissions (1)	73,351	*20.89*	79,198	85,512	92,330	99,690
Emissions from production activities (2)	277,720	*79.11*	300,028	323,947	349,773	378,942
Households	126,893	*36.14*	133,328	143,957	155,434	167,826
Export	87,089	*24.81*	92,865	100,268	108,262	116,893
Government	27,971	*7.97*	29,576	31,934	34,480	37,229
NPISH	797	*0.23*	834	901	973	1,050
Investment	34,971	*9.96*	43,424	46,886	50,624	55,944
Total emissions (1+2)	**351,070**	***100.00***	**379,226**	**409,459**	**442,103**	**478,632**
% change to 2005 emissions	*-19.05*		*-13.47*	*-6.57*	*0.88*	*9.21*

Source: Own elaboration.

As we can observe, economic activities in 2010 account for 79.11% of GHG emissions, and emissions from production activities associated with households are the most significant; 126,893 Kt of CO_{2eq}, followed by emissions associated with exports that represent 24.81% of GHG emissions. Additionally, household direct emissions represent 20.89% of GHG emissions, which is lower than indirect emissions but still significant. In sum, in a first analysis, we can see that emissions associated with household activities are significant.

Specifically, the sectoral structure of direct emissions is presented in Table 2 for the base year 2010. Emissions from “Electricity” represent the most significant account, followed by the “Agriculture and Livestock” sector and “Land transport services”. Their shares are, respectively, 13.28%, 11.57%, and 10.10% of total GHG emissions. Note that emissions associated with transport services are larger if we include sea, air, and other transport services. Then, “Refined petroleum products” represent around 4.47% of GHG emissions.

Table 3 presents the structure of indirect emissions associated with production activities in 2010, showing that GHG emissions associated with household consumption are mainly due to the ”Services”, ”Industry”, and “Energy” sectors, while “Industry” represents a significantly larger share of emissions attributable to exports. Then, emissions associated with Government and NPISH are explained by the “Services” sector (mainly education and health), and those associated with investment arise primarily from the “Construction” sector.

Regarding the emissions in 2005, based on data from EU (2016b), and assuming the growth and interest rates previously established, there are reductions in total emissions in 2020 and 2030. However, without changes in the current path, increases in emissions could be observed from 2040 that goes against the “Paris Accords".

Table 2. Structure of direct atmospheric emissions in Spain in 2010

Sectors	**GHG (Kt)**	**%**	**Sectors**	**GHG (Kt)**	**%**	**Sectors**	**GHG (Kt)**	**%**
Agriculture and livestock	40,604	11.57	Construction materials	34,035	9.69	Hotels and restaurants	1,848	0.53
Forestry	67	0.02	Metal products and machinery	13,256	3.78	Communication services	678	0.19
Aquaculture	2,772	0.79	Other metal products	2,168	0.62	Credit and Insurance	445	0.13
Coal	5,099	1.45	Machinery	720	0.20	Real estate	93	0.03
Refined petroleum products	15,696	4.47	Manufacture of motor vehicles	1,585	0.45	Public administration	4,258	1.21
Electricity	46,639	13.28	Transport equipment	364	0.10	Education	1,265	0.36
Gas	13,230	3.77	Furniture	477	0.14	Health care	1,424	0.41
Water	13,915	3.96	Construction	1,608	0.46	Other services	888	0.25
Agri-food industry, beverages and tobacco	6,289	1.79	Commercial services	6,515	1.86	Households	73,351	20.89
Textile products	726	0.21	Land transport services	35,469	10.10			
Wood and cork	805	0.23	Sea transport services	3,387	0.96			
Paper, publishing and printing	3,270	0.93	Air transport services	4,875	1.39			
Chemical products	12,222	3.48	Other transport services	1,029	0.29	**TOTAL**	**351,070**	**100.00**

Source: Own elaboration.

Table 3. Structure of indirect atmospheric emissions in Spain in 2010

	Households		Exports		Government		NPISH		Investment	
	GHG (Kt)	%	GHG (Kt)	%	GHG (Kt)	%	GHG (Kt)	%	GHG (Kt)	%
Agriculture	10,124	7.98	9,315	10.70	102	0.36	0	0.00	1,084	2.80
Energy	27,808	21.91	6,777	7.78	1	0.00	0	0.00	223	0.58
Industry	35,218	27.75	53,879	61.87	5,608	20.05	0	0.00	8,654	22.38
Construction	1,267	1.00	251	0.29	313	1.12	0	0.00	23,324	60.31
Services	41,106	32.39	5,992	6.88	19,332	69.12	797	100.00	4,978	12.87
Transport and communications	11,369	8.96	10,874	12.49	2,614	9.35	0	0.00	411	1.06
TOTAL	126,893	100	87,089	100	27,971	100	797	100	38,673	100

Source: Own elaboration.

3.2. Simulated scenarios

Our simulated scenarios are based on criteria from the Paris agreement and the EU climate strategies and targets, considering Spain specifically. We focus on energy production, energy use, and direct and indirect emissions in all scenarios, showing the results as percentage changes compared to the baseline path, and to 2005 emissions in all scenarios. We simulate the improvement in all cases as a logistic evolution to capture the gradual adaptation of the populace to policy targets. This allows us to consider a period of acceleration in the transformation towards a low-carbon society that goes from approximately 1920 to 1945 (the prior years of adaptation) and the later years of assimilation toward the 2100 goal of zero emissions.

We design the following three scenarios:

- **Scenario 1** includes the improvements in the use of energy produced by the current technologies, in other words, the reduction of the unit direct coefficient of emissions from productive activities and from households. This improvement does not involve a change in technology, but does require a reduction in energy wastage and emissios. It addresses measures such as the use of better insulation in production processes and in homes, improvements in electrical distribution networks, and the fixing of temperature caps in heating and cooling. Recycling processes are also involved. The reduction of transportation of goods, via the substitution more local goods is also assumed. Specifically, we model a logistic evolution that attains the 20% improvement by 2050.
- **Scenario 2** simulates technological improvements in the use of energy, both in production and households, implying a better use of technology. For instance, the replacement of obsolete or low-efficiency devices by appliances labeled Class A or higher, the use of electric cars, and improvements in electrical distribution networks. Following the Paris agreement and the proposals from the EU, we consider that the agricultural sectors improve by 10% by 2050, the industry and transport sectors improve by 30% by 2050, and the remaining sectors improve by 40% y 2050. The improvement in energy sectors by households is also 30% by 2050. We again consider that the coefficients of emissions per unit of output are not fixed, as the coefficients of energy use change and the sectoral ratios of “emissions/energy used” are fixed. This involves something new, compared with prior work in the literature.
- **Scenario 3** includes both Scenarios 1 and 2, simultaneously.

The cost of improvement follows the PER for the period 2011-2020, involving an annual spending of 0.2% of total production[1]. Additionally, annual investment by sectors in technology is 0.5% of total production. For simplicity, these payments are considered as fixed coefficients. The 0.2% of expenditure is obtained as an indirect tax on production, depending on the emissions by sector and is included in Scenario 1. Then, the improvement in Scenario 2 is funded by an indirect tax to collect 0.5% of total production and depends on the energy use by sectors. Scenario 3 includes both taxes.

Finally, we consider that the total reduction towards zero emissions should be achieved by renewable energies, which will be addressed in future works.

4. Results

The following tables present the impacts of previous scenarios, defined based on reductions in energy wastage and on gradual technological improvements in the use of energy. We present the results as percentage changes in the values of the baseline path, covering the period 2010-2050.

Reductions in energy wastage are addressed through a logistic reduction on coefficients of emissions in Scenario 1. Table 4 shows that total emissions could fall by more than 40% by 2050, compared to a scenario without changes, that means a reduction of 35.20% relative to emissions in 2005. This allows us to achieve (or at least to advance significantly towards) the objectives proposed in the Paris agreement and in EU climate strategies. As expected, the use of energy is not reduced significantly because the cuts in emissions do not arise from changes in energy efficiencies, but from reductions in coefficients of emissions associated with waste. In any case, Table 5 shows that reductions in industrial energy use are greater than reductions in household energy use due to the limiting effect of taxes.

[1] We calculate these percentages on total production rather than GDP, based on a first cautious approach.

Table 4. % change in direct and indirect emissions

	Scenario 1				Scenario 2				Scenario 3			
	2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Household direct emissions (1)	-7.46	-27.29	-36.23	-41.13	6.55	-15.82	-18.18	-18.07	-14.40	-39.64	-48.59	-52.50
Emissions from production activities (2)	-7.57	-25.65	-33.30	-41.33	0.36	-7.48	-8.49	-8.60	-11.41	-33.31	-41.19	-47.13
Households	-7.49	-25.87	-33.74	-41.06	1.11	-8.55	-9.96	-9.79	-11.22	-34.12	-42.22	-47.77
Export	-7.81	-25.41	-32.71	-41.31	-0.99	-7.05	-7.78	-7.54	-12.07	-33.07	-40.64	-46.68
Government	-7.37	-26.02	-34.08	-40.88	1.14	-6.22	-7.31	-7.41	-10.29	-32.25	-40.42	-46.07
NPISH	-7.70	-26.04	-33.89	-41.19	0.82	-5.85	-6.17	-5.80	-11.72	-32.31	-40.07	-45.51
Investment	-7.43	-25.25	-32.68	-42.46	0.45	-6.03	-6.37	-8.12	-11.33	-32.10	-39.73	-46.86
Total emissions (1+2)	**-7.54**	**-25.99**	**-33.91**	**-41.29**	**1.66**	**-9.22**	**-10.51**	**-10.58**	**-12.04**	**-34.64**	**-42.73**	**-48.25**
% change to 2005 emissions	**-19.15**	**-30.13**	**-32.63**	**-35.20**	**-11.11**	**-14.29**	**-8.78**	**-1.31**	**-23.08**	**-38.29**	**-41.62**	**-42.88**

Source: Own elaboration.

Table 5. % change in the use of energy

		Scenario 1				Scenario 2				Scenario 3			
		2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Household energy use	Coal	-0.33	-0.42	-0.52	-0.62	-1.05	-18.27	-21.92	-21.75	-1.41	-18.59	-22.29	-22.18
	Oil	-0.30	-0.39	-0.49	-0.59	-1.31	-17.79	-21.28	-21.09	-1.63	-18.09	-21.63	-21.50
	Electricity	-0.31	-0.40	-0.50	-0.60	-1.07	-18.35	-22.02	-21.84	-1.40	-18.66	-22.37	-22.26
	Gas	-0.31	-0.40	-0.50	-0.60	-1.07	-18.35	-22.02	-21.84	-1.40	-18.66	-22.37	-22.26
Industry energy use	Coal	-1.17	-1.26	-1.34	-1.43	-4.59	-12.33	-14.21	-14.06	-5.69	-13.32	-15.23	-15.14
	Oil	-1.20	-1.27	-1.35	-1.43	-4.37	-11.78	-13.78	-13.68	-5.51	-12.66	-14.69	-14.64
	Electricity	-2.02	-2.11	-2.19	-2.27	-5.02	-9.42	-10.75	-10.67	-7.00	-11.39	-12.74	-12.72
	Gas	-0.63	-0.71	-0.80	-0.89	-1.15	-6.78	-8.59	-8.57	-1.76	-7.40	-9.26	-9.31
Total energy use	**Coal**	**-1.17**	**-1.25**	**-1.34**	**-1.43**	**-4.58**	**-12.34**	**-14.22**	**-14.07**	**-5.69**	**-13.33**	**-15.24**	**-15.14**
	Oil	**-0.85**	**-0.94**	**-1.02**	**-1.11**	**-3.21**	**-14.07**	**-16.63**	**-16.50**	**-4.04**	**-14.73**	**-17.33**	**-17.25**
	Electricity	**-1.67**	**-1.75**	**-1.84**	**-1.93**	**-4.20**	**-11.27**	**-13.08**	**-12.98**	**-5.84**	**-12.89**	**-14.73**	**-14.69**
	Gas	**-0.57**	**-0.66**	**-0.75**	**-0.84**	**-1.13**	**-8.73**	**-10.85**	**-10.81**	**-1.70**	**-9.30**	**-11.48**	**-11.50**

Source: Own elaboration.

Scenario 2 simulates improvements in energy efficiency in production and in households, in line with the guidelines proposed in the Paris Agreement, which leads to a reduction in the use of energy of more than 20% in households, and more than 10% in industry, by 2050. Thus, total energy use could be reduced by around 15% by 2050, with significant reductions in the consumption of oil, coal, and electricity. These reductions in the use of energy imply cuts in the coefficients of emissions that finally suppose a reduction in total emissions of more than 10% by 2050 compared to a baseline without technological improvements and a reduction of 1.31% compared to emissions in 2005. Indeed, falls in direct household emissions are around 20%, but emissions from production activities are lower. We should note that the reduction in this scenarios are lower than the improvements in energy efficiency due to the rebound effect produced by lower energy costs that increase real income associated with higher efficiencies, leading to an increase in the use of other goods and services.

Finally, both strategies, simultaneously applied in Scenario 3, imply a larger reduction in total emissions by 2050 that could reach almost 50% in total emissions compared to the baseline without improvements, and a reduction of 42.88% in total emissions compared to emissions in 2005. This finding entails a large reduction in emissions in line with the EU proposals. This reduction could be even larger in household direct emissions.

Additionally, the total use of energy is reduced by 15.14% in coal, 17.25% in oil, 14.69% in electricity, and 11.50% in gas.

These results achieve the objective of reducing emissions considerably, although larger efforts to facilitate efficiency improvements, to promote the reduction of waste, and to study and supervise the rebound effect in other goods, are required.

Table 6 shows the results in energy production by sectors, for all scenarios. As expected, the largest reduction in the use of energy obtained in Scenario 2 leads to more significant falls in the energy production of electricity, coal, oil, and gas, due to improved technology. The reduction of energy waste leads to smaller cuts in energy production.

Table 6. % change in sectoral energy production

	Scenario 1			
	2020	**2030**	**2040**	**2050**
Electricity production	-1.68	-1.77	-1.85	-1.94
Coal production	-0.75	-0.84	-0.93	-1.02
Oil production	-1.58	-1.67	-1.75	-1.84
Gas production	-0.57	-0.66	-0.75	-0.84
	Scenario 2			
	2020	**2030**	**2040**	**2050**
Electricity production	-4.24	-11.31	-13.12	-13.02
Coal production	-3.66	-11.78	-13.66	-13.49
Oil production	-7.40	-17.86	-20.33	-20.20
Gas production	-1.13	-8.73	-10.85	-10.81
	Scenario 3			
	2020	**2030**	**2040**	**2050**
Electricity production	-5.89	-12.94	-14.79	-14.75
Coal production	-4.33	-12.54	-14.44	-14.33
Oil production	-8.88	-19.13	-21.61	-21.54
Gas production	-1.70	-9.30	-11.48	-11.50

Source: Own elaboration.

When we observe the impacts of these measures on the economy, Table 7 presents a summary of the main issues, percentage changes in relation to the baseline scenario. The payment of the cost of prior strategies involves slight reductions in total private consumption induced by price hikes, and a decline in disposable income after increasing taxes. However, the reduction in income through lower energy costs in Scenario 2 leads to an increase in the expense of other goods and services (rebound effect) that could drive increases in total consumption by 2050, in line with increases in total production driven by improvements in the use of one of the main inputs (energy), broadly in line with total exports rising, while total imports are reduced. Indeed, unemployment is reduced from 2040.

Table 7. Macroeconomic results (% change)

	Scenario 1			
	2020	**2030**	**2040**	**2050**
Total production	-0.34	-0.42	-0.50	-0.58
Total exports	-0.36	-0.44	-0.52	-0.61
Total imports	-0.46	-0.54	-0.63	-0.71
Total private consumption	-0.31	-0.40	-0.50	-0.60
Unemployment	1.24	1.48	1.74	1.99
	Scenario 2			
	2020	**2030**	**2040**	**2050**
Total production	-0.98	-0.65	-0.18	0.24
Total exports	-1.28	-0.87	-0.38	0.03
Total imports	-1.54	-2.35	-2.31	-1.95
Total private consumption	-0.94	0.30	1.06	1.59
Unemployment	3.79	0.68	-1.34	-2.72
	Scenario 3			
	2020	**2030**	**2040**	**2050**
Total production	-1.33	-1.07	-0.66	-0.31
Total exports	-1.64	-1.35	-0.93	-0.59
Total imports	-2.01	-2.82	-2.85	-2.56
Total private consumption	-1.28	-0.08	0.61	1.05
Unemployment	5.09	2.15	0.32	-0.84

Source: Own elaboration.

5. Conclusions

This paper presents a first attempt to evaluate alternative proposals of the Paris Agreement by 2050. We design a dynamic CGE model with a high level of detail on energy and transport services structures, for the period 2010-2050, in which the Spanish economy advances to zero emissions by 2100. Our simulations assess alternative policy options in two lines: improvements in the use of energy through reductions in energy waste and emissions, that are simulated via coefficients of emissions abatement, and efficiency improvements in the use of energy through the replacement of obsolete or low-efficiency devices, both in production and consumption functions. In both scenarios, improvements are modeled using technological progress as a logistic evolution to capture the gradual adaptation of citizens and firms to policy targets by 2050. We include an approximation of the payment of estimated costs of the PA via taxes on emissions-intensive and/or energy-intensive products. Certain conclusions can be derived from this study.

First, the reduction of emission coefficients for fixed technologies (associated with a lower energy vintage in households and production activities) is an efficient way to achieve a large emissions abatement, in line with the proposals of the Paris Agreement and the goal of zero emissions by 2100. Specifically, more than 40% of total emissions could be reduced, compared with a baseline scenario without policies and more than 35% compared to emissions in 2005.

Second, efficiency improvements in the use of energy allow for a considerable reduction in the total use of energy (coal, oil, electricity, and gas) with more substantial cuts in household energy use than in industrial energy use, and then we can considerably reduce the necessary emissions associated with production. Moreover, the total energy production is also reduced, showing an improved use of energy inputs in production, as total production rises by 2050. This result means that output could be produced by using less energy and attaining similar economic results in income or private consumption. However, this reduction in the energy bill implies increases in income that lead to an increase in the use of other goods and services. This rebound effect could involve important declines in the rate of improvements initially achieved through energy efficiency. This result notes the possible existence of a trade-off between efficiency improvements to reduce the use of energy and consequently positive impacts in disposable income that encourage emissions. In any case, our findings show that impacts on total output are not significant and therefore, alternative technologies for a more efficient use of energy can be implemented and be consistent with economic growth.

Finally, both strategies together allow for the achievement of the double objective of reducing emissions and reducing the use of total energy in the economy, reinforcing both processes with the reductions proposed by the Paris Agreement.

Our simulations suggests that, by 2050, the emissions reductions could be 48.25%, compared to the expected evolution if nothing is done, reductions which are undoubtedly very important to progress in the battle against climate change. Moreover, these figures, when compared to 2005 levels, represent reductions of 42.88%, which are far from zero emissions, but are nevertheless an important first step. Moreover, the use of renewable energies, non-emitting energies, such as nuclear, and other alternatives, such as carbon sequestration (not analyzed in this paper) will undoubtedly produce important reductions in the future.

However, our results also indicate that large efforts are required to achieve the objective of zero emissions by 2100. Our strategies present the road towards these objectives, reflecting the potential benefits along with the possible drawbacks. Advances in this field will lead us to extend this work to include renewable resources in future work that should be promoted to counteract potential increases in emissions.

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Annex 1

Table A1. Targets for the EU-15 countries under "burden-sharing" (2008-2012)

EU-15	-8%	Bulgaria	-8%
Austria	-13%	Croatia	-5%
Belgium	-7.5%	Czech Republic	-8%
Denmark	-21%	Estonia	-8%
Finland	0%	Hungary	-6%
France	0%	Latvia	-8%
Germany	-21%	Lithuania	-8%
Greece	+25%	Poland	-6%
Ireland	+13%	Romania	-8%
Italy	-6.5%	Slovakia	-8%
Luxembourg	-28%	Slovenia	-8%
Netherlands	-6%		
Portugal	+27%	Cyprus	N/A
Spain	+15%	Malta	N/A
Sweden	+4%		
United Kingdom	-12.5%		

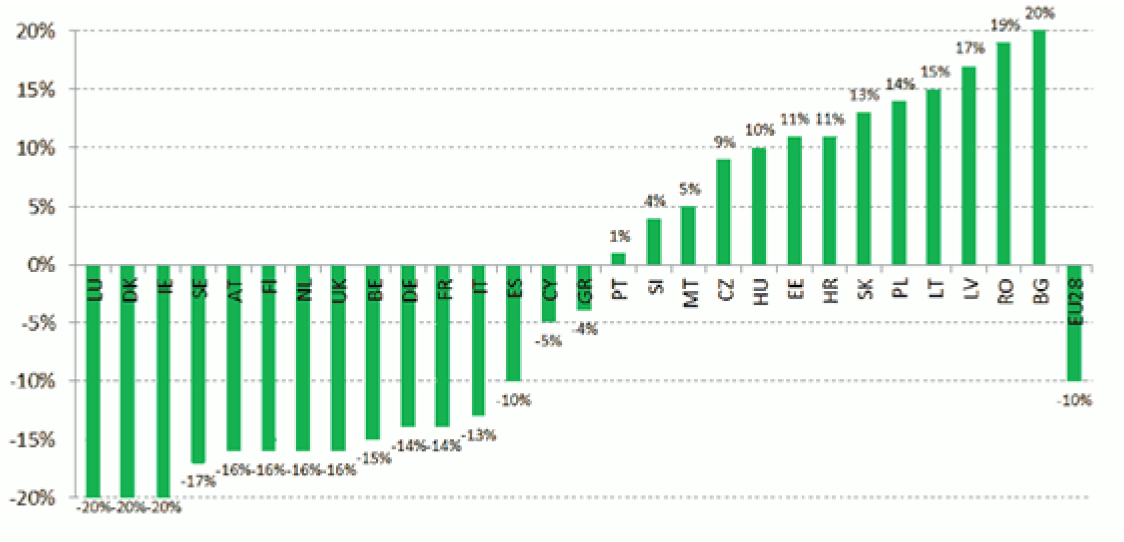
Source: European Commission (2016b)

Table A2: Overview of Member States' contributions to EU GHG emissions excluding LULUCF from 1990 to 2013 in CO_2-equivalent (million tonnes)

Member State	1990	1995	2000	2005	2010	2011	2012	2013
Austria	79	79	80	92	85	83	80	80
Belgium	147	154	149	145	133	123	119	119
Bulgaria	109	75	60	64	61	66	61	56
Croatia	35	25	27	31	28	28	26	24
Cyprus	6	7	8	10	10	10	9	8
Czech Republic	193	153	146	144	136	135	131	127
Denmark	69	77	70	65	62	57	53	55
Estonia	40	20	17	18	20	20	19	22
Finland	71	72	70	69	76	68	62	63
France	549	548	554	555	516	489	490	490
Germany	1,248	1,120	1,044	993	943	923	928	951
Greece	105	111	128	136	119	116	113	105
Hungary	94		74	76	65	64	60	57
Ireland	57	60	69	71	63	59	60	59
Italy	521	533	554	578	506	494	469	437
Latvia	26	13	10	11	12	11	11	11
Lithuania	48	22	20	23	21	21	21	20
Luxembourg	13	10	10	13	12	12	12	11
Malta	2	2	3	3	3	3	3	3
Netherlands	219	231	219	213	214	200	196	196
Poland	474	445	393	398	408	405	399	395
Portugal	60	71	84	88	70	69	67	65
Romania	253	184	141	147	118	123	121	111
Slovakia	76	55	50	52	47	46	44	44
Slovenia	19	19	19	20	19	19	19	18
Spain	291	331	390	441	357	355	349	322
Sweden	72	74	69	67	65	61	57	56
United Kingdom	804	755	720	698	616	570	586	572
EU-28	5,680	5,322	5,177	5,224	4,786	4,630	4,563	4,477

Source: European Commission (2016b)

Figure A3. Member State GHG emissions limits in 2020 compared to 2005 levels



Source: European Commission (2016a)