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Economic assessment of CO_2 emissions savings in Spain associated with the use of biofuels for the transport sector in 2010

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ABSTRACT

This article provides an economic assessment of greenhouse gas emissions savings associated with the use of biofuels for the transportation sector in Spain. The reference year used is 2010 in accordance with the target for the implementation of biofuels and other renewable fuels set down in European legislation (Directive 2003/30). The assessment is based on the premise that an increased use of biofuel will displace a similar amount of fossil fuel on a BTU basis, with the amount of biofuel used in 2010 taken as a reference point to conduct the estimates.

The results show that the most cost-efficient biofuel is the biodiesel obtained from waste oil. Regarding the differences between first- and second-generation biofuels, the results show that the latter had very high associated costs. Reaching the biofuel target for 2010 by primarily using first-generation used-oil biodiesel blends would have led to a saving of 58°M€. In contrast, reaching this target by exclusively using second-generation biofuels would have led to a 1000 M€ increase in total costs.

1. Introduction

The strong commitment made by the EU-27 countries to combat climate change has been one of the main motives underlying political support for Renewable Energy Sources (RES). However, it is not as common to analyse the effectiveness of policies implemented by countries, for complying with the mandatory commitments, and their costs and benefits. The fact that the use of RES is usually promoted with taxpayer-contributed, government funding (Cansino et al., 2010) justifies our interest in knowing the impact of these policies on the reduction of greenhouse gas (GHG) emissions, particularly with regard to CO_2 emissions, and the economic outcomes of this reduction (Vergara, 2009; Gerasimchuk et al., 2012).

Difficulties associated with the mitigation of climate change are evident, and many projects are being developed in this regard despite the economic and social resources they require for implementation. These challenges must be considered by policy makers when designing appropriate public policies oriented to mitigating climate change. However, although anthropogenically provoked climate change can be considered as the main market failure (Stern, 2007), the complexity of the entire climate change scenario makes economic valuations a difficult task for the researcher, and complicates the decision-making process for the policy maker (Bell and Callan, 2011; García Fernández, 2006).

In the case of Spain, the transport sector is the largest user of final energy, accounting for 40% of the total final consumption. The fuel volume used is mainly derived from fossil fuel use, accentuating the high domestic dependence on fuels of this type (MITC, 2010). In 2010, fuels used in the transport sector represented 43.6% of the total demand for petroleum-derived products (MITC, 2011) and 26.4% of GHG emissions.

One of the measures, adopted by Spanish authorities to raise domestic targets for CO_2 emission reduction, has been to promote the use of biofuels by the transport sector. Similar to the situation in France, the Spanish incentive system was particularly conducive to the development and use of biofuels, as these fuels enjoyed total exemption from hydrocarbon taxes until 31 December 2012. This exemption was also applied to the biofuel volume contained in fuel mixtures (Wiesenthal et al., 2009).

Recent papers (Lechón et al., 2009) have estimated that reducing CO_2 emissions enables compliance with the objectives set by the EU-27 concerning the consumption of biofuel. These authors

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concluded that the introduction of first-generation biofuels (made from sugar, starch or vegetable oils) causes a positive effect on CO_2 emissions abatement. This conclusion is further discussed in Lechón et al. (2011), by including indirect land-use change (ILUC) emissions.[1] In that paper, the authors found that the positive effects of biofuel use are reduced and, in some of the scenarios analysed, can even give rise to a negative net outcome (i.e., CO_2 emissions are increased with respect to fossil fuel use).

Given that the future is uncertain for first-generation biofuels (Hernández Sobrino et al., 2010), this paper includes an analysis of second-generation biofuels, specifically concerning biodiesel from lignocellulosic biomass, and bioethanol from straw. In fact, recent papers recommend including second-generation biofuels in the estimates of the costs and benefits of biofuels (Gómez et al., 2011; Linares and Pérez-Arriaga, 2013).

The aim of this paper is to conduct an economic analysis of biofuel use, including first- and second-generation biofuels, by the transport sector in Spain in 2010. Perceived benefits would occur when the economic value of avoided GHG emissions, expressed in CO_2 equivalents, equals or exceeds the cost of production of the biofuel used.

A common assumption in lifecycle assessment (LCA) based estimates of GHG benefits (or costs) of renewable fuels, such as biofuel, is that these fuels simply replace an energy-equivalent amount of fossil fuel, such that the total fuel consumption remains unchanged. Accordingly, this paper assumes that an increased use of biofuels replaces a similar usage of fossil fuel. Calculations have been based on 2010 figures as this was the reference year for the targets, fixed by Directive 2003/30 of the European Parliament, concerning the promotion of biofuel use by EU Member States. The assumption made is that these biofuels simply replace an energy-equivalent amount of fossil fuel, such that the total fuel consumption remains unchanged. This is the aim of Directive 2003/30, although authors (Rajagopal et al., 2011) criticized the one-to-one displacement assumption.

The article is structured as follows: Section 2 summarises the relevant legal framework at national and EU-27 levels. Section 3 details the methodology used, and the database employed, for the valuation. Section 4 presents the results and discussion. Section 5 presents overall conclusions.

2. European community and national legal frameworks

European Directive 2003/30/EC addresses the promotion of the use of biofuels, or other renewable fuels, to replace diesel or petrol for transport purposes in each Member State, and thereby contribute to objectives such as meeting climate change commitments, achieving an environmentally friendly and secure fuel supply, and promoting RES usage.

The European Commission (EC) Biomass Action Plan, adopted at the end of 2005, responds to a threefold objective: further promotion of biofuels in the EU-27 and in developing countries; preparation for the large-scale use of biofuels; and, heightened cooperation with developing countries in the sustainable production of biofuels. Among measures intended for ensuring environmental benefits from the policy, the EC intends to highlight the advantages of biofuels in terms of reducing GHG emissions and, in particular, to link these advantages to promoting the implementation of biofuel use. The European Union Strategy for Biofuels (European Commission, 2006) highlighted these fuels as a RES alternative to fossil energy sources used in the transport sector.

Directive 2009/28/EC forms part of the “package” outlined in the “European Energy and Climate Change” strategy, which establishes ways for the EU to achieve its energy objectives for 2020; these objectives include: a 20% increase in energy efficiency; a 20% reduction in GHG emissions; and, a 20% share of RES in the overall EU energy consumption. This Directive also requires each Member State to ensure that the share of energy from renewable sources, in all types of transport in 2020, should be at least 10% of the final energy consumption by the transport sector. This objective now has a binding clause that has brought about a major shift in European policy in this area, since the earlier objective was not mandatory, and was fixed at 5.75% for 2010 (Directive 2003/30). The European Commission (2012) is therefore proposing to amend the current legislation on biofuels, and in particular:

1. To increase the minimum GHG savings threshold, for new installations, to 60% to improve the efficiency of biofuel production processes, as well as to discourage further investments in installations with low GHG performance;
2. To include ILUC factors in the reporting by fuel suppliers, and Member States, of GHG savings associated with biofuels and bioliquids;
3. To limit the amount of foodcrop-based biofuels and bioliquids which can be counted towards the EU’s 10% target for renewable energy in the transport sector by 2020; this means maintaining the use of such fuels at current levels (5% up to 2020), while maintaining the overall renewable energy and carbon intensity reduction targets;
4. To provide market incentives for biofuel use with no, or low, ILUC emissions. This approach is particularly aimed at second- and third-generation biofuels produced from feedstock which do not create an additional demand for land (including algae, straw, and various types of waste). These fuels will contribute towards the target of 10% renewable energy in the transport sector, as stipulated by the Renewable Energy Directive.

The development of renewable energy is a priority commitment in Spanish energy policy, as it involves various favourable effects, such as sustainable development, a reduction of GHG emissions, the introduction of new technologies, a reduction of external energy dependence, lowering of the trade deficit, and increasing the level of employment and rural development (R.D. 1738/2010). The sixteenth item in Spanish Government Law 12/2007 (Jefatura del Estado, 2007), dated 2 July 2007, concerning hydrocarbon use, sets annual targets for biofuels and other renewable fuels for transport purposes to be achieved by 2010. These targets were obligatory from 2009 and set to reach 5.83% in 2010 (which is above the 5.75% set in Directive 2003/30/EC; in other countries such as Ireland it was revised downwards, setting a 3% for 2010 (Thamsiriroj and Murphy, 2010)), 6.4% in 2011, and 6.5% in 2012 and 2013 (R.D. 459/2011). Nevertheless, in a resolution announced by the Spanish Government’s Energy Secretariat on 7 January 2011, the 5.83% goal was downgraded to 4.78% based on the evolution of the biofuels market. This scenario had been foreshadowed and was written into Article 11.4 of Order ITC/2877/2008. In December 2012, the Spanish government approved a downward revision of the 2013 target, from 6.5% to 4.1%.

The promotion of biofuels in Spain, at the time in which this study is set (2010), was based on measures involving tax incentives (zero tax as part of the Special Tax on Hydrocarbons) that were in place until the end of 2012, and the establishment of compulsory quotas for the marketing of biofuels. The Order ITC/2877/2008 of 9

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[1] The concept of ILUC is that a natural ecosystem becomes cropland and replaces grassland or other crops, in order to produce raw materials for biofuels production, and which could increase GHG emissions (Kim and Dale, 2011). For more information on this topic see Hellmann and Verburg (2010), where the consequences of Directive 2033/30 in this regard are analysed.

October 2008, established a mechanism to promote the use of biofuels and other renewable fuels for transport, and set minimum targets for each product until 2010, reaching 3.9% in that year for both gasoline and diesel, together with the above overall goal of 5.83% in 2010.

3. Methodology and database, assumptions

3.1. Methodology

The main barrier to the expansion of biofuel use is its higher production cost compared with conventional fuels. Nevertheless, biofuel consumption has positive environmental benefits derived mainly from GHG emission savings. Based on these facts, the aim of this work consists of conducting an economic assessment, intended to estimate the total economic cost of biofuels that includes both the private cost of production, and the external benefit of using biofuels. The incremental cost of production will be measured as the difference between biofuel production costs and conventional fuel cost. Similarly, the environmental benefits will be measured in terms of GHG savings, estimated as the difference between GHG (CO_2 –eq.) emissions from conventional fuels and biofuels. These will be defined in economic terms by using the market price of CO_2 permits, to estimate the total economic costs of biofuels.

Specifically, the scope of the analysis includes a comparison of conventional fuels (EN-590 Diesel and Petrol) and biofuels, with a distinction made between first-generation and advanced (or second-generation) biofuels. For this purpose, the difference between CO_2–eq. emissions and savings derived from the use of biofuels to displace fossil fuels was calculated, taking into account the increased costs of production associated with the former, within the Spanish transport sector in 2010.

This paper considers two types of first-generation biofuels:

- Biodiesel, which can be blended at a certain percentage with petrodiesel or can substitute it completely. Raw oil material for biodiesel production can be obtained from vegetable oil (whose acronym in this paper is BDA1) or waste oil (BDA2). The blends analysed in the current paper are: mixtures of 5% of biodiesel with diesel (BD5), mixtures of 10% of biodiesel with diesel (BD10) and 100% pure biodiesel (BD100).
- Bioethanol, which can be blended with gasoline. The blends analysed in the current paper are: mixtures of 5% of bioethanol with gasoline (E5) and mixtures containing 85% bioethanol with gasoline (E85).

With respect to advanced biofuels, lignocellulosic biodiesel and bioethanol from straw, mixed in the same proportions as the first-generation biofuels are considered. The importance of lignocellulosic bioethanol stems from the possibility of using what is assumed to be inexpensive feedstock, to avoid direct and indirect competition with human food and pet feed sources, and to reduce the environmental impact of this fuel source, i.e. soil degradation, and water and air pollution, which are associated with the production and use of first-generation biofuels.

3.2. Biofuel consumption in Spain in 2010

Biofuel use in Spain in 2010 amounted to nearly 1.5 million tonnes of oil equivalent (toe) (Table 1), measured across the different types of biofuels (CNE, 2012).

The biofuels consumed in Spain in 2010 were mainly derived from vegetable oil biodiesel, as biodiesel produced from waste oil can only be produced in limited amounts because it depends on the availability of recycled oil from waste oils and animal fats. The bioethanol used in 2010 represents just over 16% of all biofuel use. Within bioethanol total consumption figures, most bioethanol is consumed in low-percentage mixtures (with the E5 mixture accounting for 98.78% of total bioethanol sold). Categories of biofuel provided by CNE (2012) in its report on biofuel consumption in Spain in 2010 do not coincide with those provided by Lechón et al. (2005, 2006) in their LCA. To make these calculations the following were included: in the category of biodiesel BD5, data referring to biodiesel mixtures sold in mixtures of less than 7%; in the category of BD10, mixtures containing a percentage of biodiesel higher than 7% and lower than 30%; and, in the category of BD100, mixtures which have more than 30% biodiesel. In the case of bioethanol, due to the reduced consumption of E10 (1.10% of total consumed ethanol), this has been included in the category of E5.

Table 1
Biofuel consumption in Spain (2010).

Type of biofuel	Consumption (toe)
BD5A1	1000049
BD10A1	55,055
BD100A1	37,249
BD5A2	112,040
BD10A2	6168
BD100A2	4173
E5	238,633
E85	287

Source: Adapted from CNE (2012).

3.3. Cost of biofuels

Biofuel cost calculations take into account the entire production chain through to distribution at the fuelling station. The production chain for biofuels includes the cultivation and harvesting of biomass feedstock, transportation to the conversion plant, biofuel conversion, and distribution. The costs of producing biofuels in Spain were estimated based on data provided by the Spanish Renewable Energy Plan (data referred to investment and operation and maintenance (O&M) costs of a production plant). The price of raw materials for biofuel production was estimated from data provided by the EUROSTAT database. The cost of imported biofuel was taken from CNE (2006). Finally, the cost of conventional fuels was estimated based on different reports published by CNE (2006, 2007, 2008a, 2008b, 2009, 2010), while the cost of advanced biofuels is from data published in Gnansounou and Dauirat (2010) and IEA (2007).

Table 2 shows information concerning the increased cost, i.e. the cost difference (or overcost) of producing biofuels compared with conventional fuels. As can be appreciated, the cost of producing advanced biodiesel is almost five times higher than that required to produce first-generation biodiesel, while to produce advanced bioethanol costs three times that of first-generation bioethanol.

Table 2
Difference in overcost between biofuels and conventional fuels (2010).

Biofuels	Overcost (€/toe)
Biodiesel	169
Bioethanol	407
Biodiesel 2G	817
Bioethanol 2G	1405

Source: Adapted from Gnansounou and Dauirat (2010), IEA (2007) and CNE (2012).

Table 3
CO_2 emissions savings and their economic value for different biofuels (2010).

Type of biofuel	CO_2 emissions saving (Tonne/Toe)			Economic assessment of CO_2 emissions saving (€2010/Toe)		
	Without ILUC	With ILUC (20 years)	With ILUC (100 years)	Without ILUC	With ILUC (20 years)	With ILUC (100 years)
BD5A1	2.32	−2.93	1.27	29.24	−36.93	16.01
BD10A1	2.10	−3.15	1.05	26.44	−39.73	13.21
BD100A1	2.15	−3.10	1.10	27.13	−39.05	13.89
BD5A2	3.05			38.40		
BD10A2	3.05			38.40		
BD100A2	3.16			39.78		
E5	2.41			30.43		
E85	2.40			30.27		
Biodiesel 2G	3.22			40.58		
Bioethanol 2G	3.19			40.25		

Source: Own elaboration from Lechón et al. (2005, 2006, 2011) and IEA (2011).

3.4. CO_2 emissions savings and economic valuation

To estimate the value of GHG savings, two types of information are required:

- First, information regarding the GHG savings derived from the use of biofuels compared to fossil fuels. Within this study, sources of information vary depending on the type of biofuels analysed; Ryan et al. (2006) estimate the valuation of CO_2 mitigation cost for other types of biofuel, and especially for the transport sector:
  a) GHG savings from first-generation biofuels were taken from the LCA of biofuels conducted by CIEMAT (Research Centre for Energy, Environment and Technology), (Lechón et al., 2005, 2006). The LCA comprises all the stages involved in the production and final use of a product. In this case, the production of raw materials, processing, distribution and use of biofuels and fossil fuels was considered. The LCA was applied by following the UNE-EN ISO 14040-43 international standards. While the origin of the raw materials for biofuels consumed in 2010 in Spain does not exactly match that provided by the CIEMAT analysis, the final result is not greatly affected.
  b) GHG savings from second-generation biofuels were taken from IEA (2011). GHG savings data refer to cellulosic ethanol and biomass to liquid (Btl) diesel. In both cases, the range of GHG savings varies between 60 and 120% compared to fossil fuel. For the purpose of making estimates here, this study has used an average value of 90%.
- Second, the economic value of GHG savings must be calculated. There is much debate in the literature concerning the best way for this value to be estimated: some experts support using the Social Cost of Carbon (SCC), which measures the potential damage caused by an increase in global temperature derived from GHG. This value is estimated through the use of integrated models such as FUND or PAGE. A large variation in values obtained by different studies is seen due to the uncertainty surrounding estimates, and the sensitivity of calculations to the initial hypotheses used (discount rate, etc.). Other experts support the use CO_2 permit prices from the carbon market, which provides an indication of the marginal cost of reducing CO_2 emissions such that, if CO_2 limits were optimal, the marginal cost of reducing GHG should be equal to the marginal damage of GHG. Nevertheless, this form of estimation also has drawbacks such as large price fluctuations, especially during the second trading period from January 2008 to December 2012, in which the price sharply climbed at the beginning of the period (middle of 2008) from a few cents to a level close to 30°€/tonne, after which the prices soon dwindled to a level below 6.5°€/tonne until the end of the period (Haita, 2013). For the economic valuation of CO_2 emissions savings, we have used the average 2010 market price as the price of carbon credits.

The CO_2–eq. emissions savings for each type of biofuel are detailed in Table 3, which also shows the evaluation of the savings in terms of 'toe' of biofuels and 2010°euros. Due to the lack of consensus concerning the consideration of the ILUC in calculations, we have not included it in the CO_2–eq. emissions savings when this effect is not considered, and included it when we have taken Lechón et al. (2011) as our reference, using the difference between two periods of amortization of the land: 20 and 100 years. The time of amortization is an "accounting concept" that allows imputing carbon emissions released from land-use changes in one year, relative to the expected biofuel production during the period of time that the converted land will provide raw materials for biofuel production. It must be kept in mind that advanced biofuels such as biodiesel from waste oil do not have the ILUC effect associated with them. Similarly, Lechón et al. (2011) considers that all raw materials for bioethanol used in Spain are sourced locally (within Spanish borders), on which basis bioethanol consumption in Spain has no ILUC emissions. With the currently available information, this assumption could be considered unrealistic. Nevertheless, due to the complexity of this issue, this study will assume that this is the case and the question will be tackled in more depth in future refinements of this work.

According to the data in Table 3, if the ILUC effect is included in calculations for biodiesel from new oil, amortizing land in 20 years would not be advantageous from an environmental point of view, as this would imply an increase in emissions to more than that generated by an equivalent amount of diesel energy.

3.5. Total cost

In the previous section, the main variables required to determine the total cost of biofuels were estimated: on the one hand, the incremental cost of biofuels, measured as the difference in cost production compared to that of conventional biofuels, and on the other hand, the environmental benefits, measured as the difference in CO_2–eq. emissions between conventional fuels and biofuels, expressed in economic terms. The aim in the present section is to estimate the total economic cost that measures the incremental costs of biofuels minus the environmental benefits in terms of CO_2–eq. reductions.

Fig. 1 shows results of total costs of different types and blends of biofuels. As seen from this comparison, which includes all

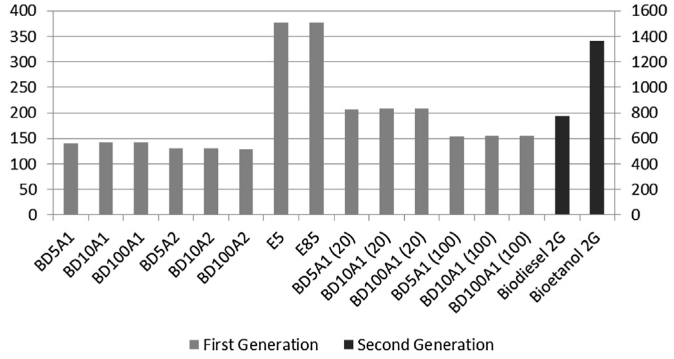

Fig. 1. Total cost of different biofuels and blends (€2010/Toe).
Source: Own elaboration.

considered biofuels, based on current technology the advanced biofuels (right axis) are associated with a much higher increase in cost than the first-generation fuels (left axis). It can be seen that biofuels with a lower total cost are mixtures of biodiesel from waste oil, followed by oil–biodiesel blends, even when the ILUC effect is taken into account.

4. Results and discussion

4.1. Business-as-usual scenario

According to the above methodology, Fig. 2 shows the economic value, based on market prices, of CO_2 emissions savings in Spain in 2010 as a result of the increased consumption of biofuels.

As shown in Fig. 2, inclusion of the effect of changing land use (ILUC) still gives a positive result (although reduced by 33%) when fossil fuels are displaced by biofuels when a longer repayment term is considered (100 years); this outcome may be reduced significantly, or even become negative, in the case of a short payback period (20 years).

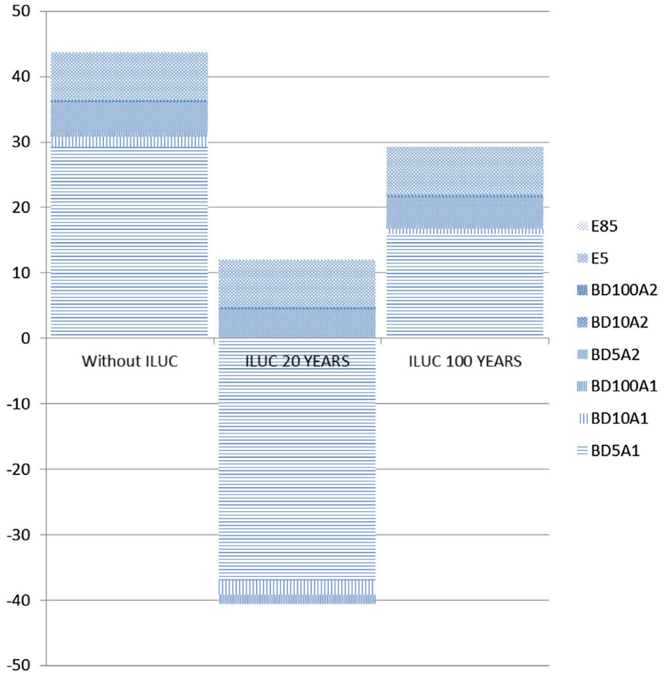

Fig. 2. Economic value of CO2 emissions savings for consumption of biofuels in Spain in 2010 (M€2010).
Source: Own elaboration.

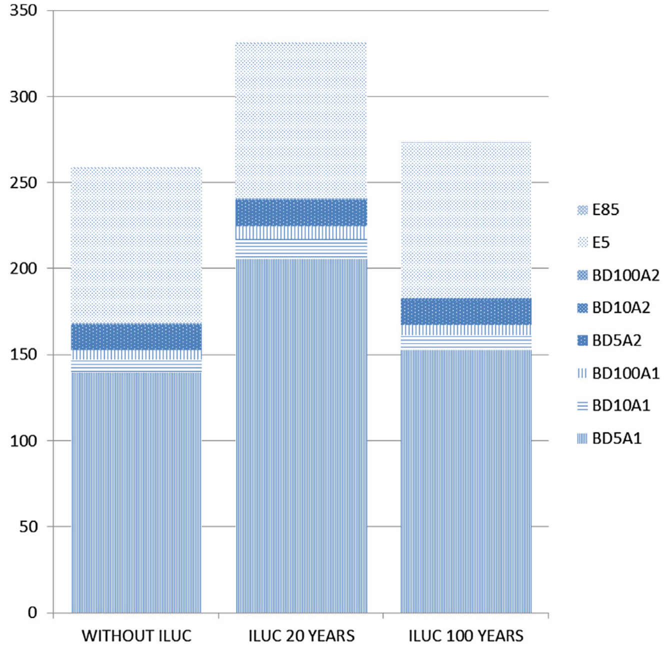

Fig. 3. Total costs of biofuel consumption in Spain in 2010 (M€2010).
Source: Own elaboration.

Fig. 3 shows the total costs (production cost minus environmental benefits) associated with the different biofuels considered in this analysis; the total cost of biofuel consumption in Spain in 2010 is shown with, and without, the ILUC effect. Due to the high cost of biofuel production, and taking the market cost of a tonne of CO_2 for the economic valuation, the analysis indicates that the use of biofuels in Spain in 2010 to displace fossil fuel use involves very high additional costs. The impact of including ILUC emission greatly depends on the land-use change amortization period considered: when the amortization period is taken to be 100 years, the increase in total cost (compared with the situation without ILUC) is 5%, while a 20 year-period entails an increase in total costs of 28%.

4.2. Sensitivity analysis

To complete the analysis, two scenarios were calculated. The first assumes that all biofuels used in Spain in 2010 were the most efficient biofuels available, and the second, in which all biofuels used are considered to be second generation.

The first scenario takes a mixture of BD100A2 (20%) and BD5A1 (80%) as the reference biofuel for calculations, as these biofuels considered individually have a lower cost–benefit profile (129.22 and 139.76°€ 2010/toe, respectively) as shown in Fig. 1. Although BD100A2 provides the best result, to arrive at a scenario in which only this biofuel is consumed is unrealistic, since, as discussed above, this biofuel has a very limited production capacity.

Fig. 4 shows a comparison of the cost-effectiveness of biofuels actually consumed in Spain in 2010, excluding the effect of ILUC. Considering the two scenarios above, scenario 1 gives a better result as it involves an additional cost that is 22.5% less than that for all biofuels combined.

As some studies (Stralen et al., 2013; Ahman and Nilsson, 2008) consider that the second-generation biofuels are absolutely

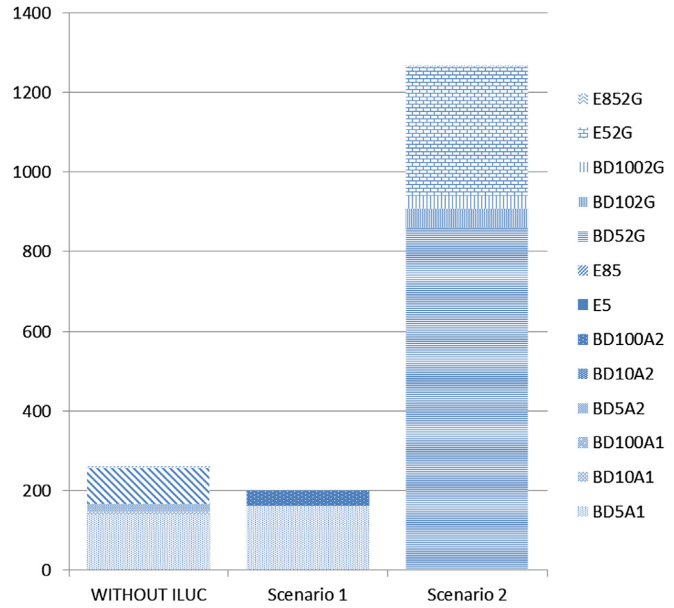

Fig. 4. Sensitivity analysis (M€2010).
Source: Own elaboration.

necessary for 2020 biofuel targets to be reached, the second scenario was also analysed. This scenario is built on the assumption that the use of advanced biofuels was distributed in the same proportion as that of biodiesel and bioethanol actually consumed in 2010 in Spain. Due to the high cost of production of the advanced biofuels, this scenario becomes unviable in the short term, because although such fuels produce less pollution in terms of CO_2–eq. emissions, by including them in the analysis their cost makes them economically inefficient. This scenario is 4.9 times more expensive than the *business-as-usual* scenario.

Finally, to estimate the economic value of the reduction in fossil fuel consumption, the average valuation at market prices of one°tonne of CO_2 in 2010 was used, which amounted to 12.60°euros. However, just how one arrives at a value for a tonne of CO_2 has generated a proliferation of literature around the *social cost of carbon* emissions. This concept is usually estimated as the net present value of expected impacts on climate change over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. Important contributions to this field have been made in different models (Nordhaus, 1991; Fankhauser, 1995; Eyre et al., 1997; Tol et al., 2001; Clarkson and Deyes, 2002; Pearce, 2003; Watkiss et al., 2005; Ackerman, 2010).

The price of one°tonne of CO_2 proposed by these models ranges from 16 to 676°euros, so that the result of our analysis would have varied considerably depending on which model we used (the real scenario without ILUC, as shown in Fig. 3, implies an overcost of more than 258°M€, while taking the value of 16°euros per ton, the overcost would be decreased to below 247°M€, exceeding 2000 M€ profit when the goal in biofuel consumption is fulfilled valuing the ton at 676°€).

Given the lack of consensus on this matter, and uncertainty involved in the handling of multiple variables included in the models, we decided not to include them in our work.

5. Conclusions

Reducing CO_2 emissions is one of the main pillars in the fight against climate change. Among the measures taken within the EU-27, was the commitment to achieve a 5.75% level of biofuel use in 2010 in the transport sector. Specifically, the mandatory targets for biofuel consumption established in the EU Directive 2003/30, together with those established in the Spanish legal framework, resulted in the consumption of 1,453,654 toe of different biofuels in the transport sector in Spain in the cited year. This consumption reduced CO_2–eq. emissions to the atmosphere by about 3.5°Mt, equivalent to an economic value of more than 43 M€ according to the market value of a metric tonne of CO_2 in 2010.

To properly assess outcomes associated with obligations to use biofuels, it is necessary to consider two aspects. First, the effect of changing land use and second, the costs to society of substituting fossil fuels with biofuels. Considering the first point, as shown in this paper, the inclusion of ILUC, which is a controversial topic in the scientific literature (Fritsche et al., 2010 and Böttcher et al., 2013), reduced the positive impact of biofuel use to just over € 29°M in the 100 years land amortization case, or even gave a negative outcome if the amortization period was reduced to 20 years. In this latter case, an extra 2.2°Mt of CO_2–eq. would have been emitted if fossil fuels had been used.

In terms of production costs, the analysis shows that, compared with conventional fuels, biofuels still involve expensive technologies, with negative results obtained for all of the biofuels considered. This extra cost, which Spain had to accept to meet mandatory targets for the EU-27, amounted to nearly € 260°M in 2010 in a best-case scenario; i.e. without considering the effect of ILUC. This additional cost would have been reduced by 22.5% if consumption involved only the more efficient biofuels, specifically BD100A2 and BD5A1. The scenario would have been especially expensive in the case where only second-generation biofuels were used, because the cost of current production is excessive, being 6.3 times higher than the most efficient scenario considered. It is expected that the cost of second-generation biofuels will decrease as production developments take place, with estimated cost reductions for these biofuels for 2010–2030 period ranging between 30% and 60% (Wit et al., 2010).

In view of the overcapacity in the food-based biofuel market, the European Commission considers that investment aid in new and existing capacity for food-based biofuel is not justified. However, investment aid to convert food-based biofuel plants into advanced biofuel plants is allowed to cover the costs of such conversion. Other than in this particular case, investment aid for biofuels can only be granted in favour of advanced biofuels. To remove the political barrier to the kick-start of advanced biofuels, it would be necessary to work on two fronts: a) Ensure a stable supply of sustainable feedstock (waste and residues); b) Support demand by establishing a specific mandate for advanced biofuels by 2020 and beyond (European Commission, 2014a).

More than two thirds of transport-related GHG emissions are from road transport. However, there are also significant emissions from the aviation and maritime sectors, and these sectors are experiencing the fastest growth in emissions, meaning that policies to reduce GHG emissions are required for a range of transport modes (European Commission, 2014b).

The European Commission, in coordination with Airbus, leading European airlines (Lufthansa, Air France/KLM, & British Airways) and key European biofuel producers (Neste Oil, Biomass Technology Group and UOP), launched an initiative to speed up the commercialisation of aviation biofuels in Europe.

The initiative, labelled “European Advanced Biofuels Flight path” is a roadmap with clear milestones to achieve an annual production of two million tonnes of sustainably produced biofuel for aviation by 2020. The “Biofuels Flight path” is a shared and voluntary commitment by its members to support and promote the production, storage and distribution of sustainably produced drop-in biofuels for use in aviation. It also targets the establishment of appropriate financial mechanisms to support the construction of industrial "first of a kind" advanced biofuel production plants (European Commission, 2014c).

Additionally, the Commission's 2011 White Paper on transport suggests that the EU's CO_2 emissions from maritime transport should be cut by at least 40% of 2005 levels by 2050, and if feasible by 50%. However, international shipping is not covered by the EU's current emissions reduction target.

In June 2013 the European Commission set out a strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic GHG emissions. The strategy consists of three consecutive steps: Monitoring, reporting and verification of CO_2 emissions from large ships using EU ports; GHG reduction targets for the maritime transport sector; and further measures, including market-based measures, in the medium to long term (European Commission, 2013).

Therefore, EMSA (European Maritime Safety Agency, 2012) is evaluating if and how biofuels could be used in the shipping sector as an alternative fuel.

The economic analysis carried out shows that it is necessary to consider not only positive environmental externalities and reduced energy dependence that biofuels provide to society, but also the costs associated with compliance with imposed regulatory obligations, which involve additional costs compared with fossil fuels. It should not be forgotten that we are at the beginning of the implementation of a new technology, and that a lot is still to be learned. A decrease in production costs for these fuels is therefore expected. Policies promoting the use of such renewable energies need to take into account the expected future benefits and costs associated with the use of biofuels in the transport sector.

Although robust, the results shown in this paper should be taken with caution. Aspects related to energy security, implications for the development of rural areas or the slope of the learning curve might be considered in future research in a more detailed way. There is a significant lack of consensus in the literature on three important issues. First, a greater consensus is still needed on the best way to assess the impact of biofuels on ILUC. Second, the correct way to measure the social cost of carbon is also subject to much controversy. For this reason, a market price of CO_2 has been used. This price is affected by the problem of volatility, which also suggests taking the results with caution. Third, it would be interesting to contemplate the benefits to some aspects such as that of improving energy self-sufficiency and the improvement in social welfare. Cansino et al. (2013) analyse the effect of the increase of biofuel production in the primary sector, although in a Spanish region. Future research should focus on these issues to improve results.

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