



Economic and social impacts of the biodiesel industry: Assessment and policy implications in Spain

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Abstract

Aim of study: This study evaluates, through the input-output (I-O) methodology, the economic and social impacts (Gross Value Added –GVA– and job creation) of the national biodiesel industry on the Spanish economy in the recent past (between 2005 and 2018). These impacts are also simulated for different scenarios, for an average year following a trend from the past, based on different hypotheses on biodiesel production, trade balance and national production of raw materials. The aim is to guide decision-makers in the planning and design of regulations with implications in the domains of energy, economy and employment.

Area of study: Spain.

Material and methods: I-O methodology.

Main results: The contribution of the biodiesel sector to GVA and job creation in Spain was very high during the construction phase of the biodiesel industry. However, this has been very limited during the operational phase, mainly due to imports of biodiesel and raw material, from Indonesia and Argentina. The economic and social impacts of this industry would be greater if higher amounts of domestic raw materials were used.

Research highlights: The results justify public support for the operation of existing biodiesel plants in Spain in order to increase gross domestic product and employment, including the further implementation of specific measures to encourage domestic production. Policy measures to increase the use of national raw materials could include promoting rapeseed as an ideal cereal rotation in Spain and establishing contracting systems that guarantee farmers' profitability.

Additional key words: input-output analysis; socio-economic effects; policy design; soybean; rapeseed.

Abbreviations used: CIF (cost, insurance and freight); EBB (European Biodiesel Board); ESIOT (expanded symmetric input-output table); EU (European Union); GDP (gross domestic product); GVA (gross value added); HVO (hydrotreated vegetable oil); ILUC (indirect land use change); I-O (input-output); RD (Royal Decree); toe (ton/s of oil equivalent); SIOT (symmetric input-output table).

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Introduction

In the European Union (EU), the consumption of biodiesel has been fostered in recent years mainly because of its environmental benefits over petrodiesel, focusing mainly on reducing CO₂ emissions. The use of biofuels made from biomass provides a renewable alternative to fossil fuels in the EU's transport sector in the framework of the European Green Deal. However, renewable energies must not only be environmentally friendly in order to be sustainable, but also economically and socially beneficial

(Heijungs, 2014). The pandemic caused by SARS-CoV-2, has limited industrial production and business worldwide, affected markets and influenced the drop in oil prices. The exceptional circumstances arising from COVID-19 mean that action by governments must be taken quickly and in the very short term to revive the economy.

The Renewable Energy Directive sets rules for the EU to achieve its 10% of the transport fuel of every EU country from renewable sources such as biofuels through national renewable energy action plans. Along these years, the production, consumption imports and exports of biofuels in

the EU, as well as in Spain, have undergone strong growth in line with the legislative framework. Fig. S1 [suppl.] shows the Spanish biodiesel consumption, production, imports, and exports. In Spain, several policies have been regulating the biofuel targets. The first compulsory target for biofuels in Spain was passed by Law 12/2007 (BOE, 2007) and Order ITC/2877/2008 (BOE, 2008), which established a 3.4% target of final consumption of energy in the transport sector for 2009 and 5.83% for 2010. Royal Decree (RD) 1738/2010 (BOE, 2010) approved targets of 5.9%, 6.0% and 6.1% for years 2011, 2012 and 2013 respectively. These targets were subsequently elevated to 6.2%, 6.5% and 6.5% (6.0%, 7.0% and 7.0% of biofuels in diesel) for the same years by RD 459/2011 (BOE, 2011), measured all these percentages in energy content. Compliance with these targets led to a quick increase of the consumption of biofuels and other renewable fuels commercialized for transport purposes Fig. S1 [suppl.]. Imports incoming from Argentina and Indonesia (APPA, 2013) led to an alarming decline of the biodiesel domestic production in Spain (Espejo Marín *et al.*, 2016) and in Europe in general (EBB, 2012). Therefore, in 2012 the European Biodiesel Board (EBB) complained about dumping. The European Commission started investigations (OJEU, 2012) and imposed anti-dumping duties for five years since 2013 (OJEU, 2013a,b). This policy caused decrease of imports in 2013 and 2014 (Fig. S1 [suppl.]) and a slight recuperation of the biodiesel industry in 2013.

In July 2013, Law 11/2013 (BOE, 2013) set lower targets (4.1% in 2013 and subsequent years) causing a sharp decline of domestic consumption. But Order IET/822/2012 (BOE, 2012) by which biodiesel must be produced in specific plants favoured biodiesel production (Fig. S1 [suppl.]). Resolution of BOE (2014) required hydrocarbon sector operators to purchase 4.8 million tons of biodiesel from 37 plants in the EU, 23 of which were located in Spain (listed in the Resolution). In BOE (2015), RD 1085/2015 adopted new targets of 4.3%, 5%, 6%, 7% and 8.5% (in energy content) for years 2016, 2017, 2018, 2019 and 2020 which led to increased consumption (Fig. S1 [suppl.]). In September 2017, the anti-dumping duties applicable to imports of biodiesel from Argentina were significantly reduced by OJEU (2007) and as a result, imports from Argentina started to increase rapidly. However, the Spanish biodiesel production also increased because of exports (Fig. S1). RED II (OJEU, 2018) established a 14% target for energy from renewable sources in transportation by 2030, with a maximum of 7% of final consumption of energy when they are produced from food and feed crops. In Spain, almost 100% of biodiesel consumed in recent years has been produced from food and feed crops feedstocks, also called first generation biofuels. Although RED II set a share of final consumption of advanced biofuels in the transport sector of at least 0.2 % in 2022, at least 1% in 2025 and at least 3.5% in 2030, a

significant contribution is not anticipated by next decade given the small number of announced projects that are currently moving into construction (IEA, 2018). Therefore, first generation biodiesel will continue being the main European solution to reduce emissions from transport and dependence on imported oil.

By 2020, in Spain, RD 1085/2015 (BOE, 2015) also set a cap of 7% for first generation biofuels, while RD 235/2018 (BOE, 2018) set an indicative target of 0.1% for advanced biofuels. Moreover, the proportion of raw materials used to produce biodiesel is likely to change. Under OJEU (2018), palm oil was qualified as high indirect land use change 'high ILUC-risk', so public support will be more demanding for this feedstock. The Spanish raw material used to produce the biodiesel that is consumed in Spain represented only 0.34% in 2018. The largest proportion of the raw material used to produce biodiesel consumed in Spain came in 2018 from Indonesia (35.69%), Argentina (23.74%), Malaysia (18.53%) and Brazil (8.06%) (CNMC, 2019a). Palm oil is imported mainly from Indonesia and Malaysia, while soybean oil is mainly imported from Argentina and Brazil. Eliminating direct EU demand for palm oil as a biofuel feedstock could lead to substitute it for soy oil or rape oil. Whereas soy is not suitable for cultivation in Spain, the agro-climatic conditions are suitable for rapeseed. However, the area of rapeseed has been very reduced in Spain in comparison with other EU countries, due to the massive poisoning in 1981 when rapeseed oil was mixed with industrial oil for human consumption causing more than 30,000 people to be affected. On 11 February 2019, after a new complaint by EBB, the Commission imposed a definitive countervailing duty on imports of biodiesel originating in Argentina (OJEU, 2019c). In response, Argentine exporters offered a minimum import price (MIP) applicable to all Argentine biodiesel imports to the EU. After accepting the agreement, OJEU (2019b) exempted from the countervailing duty eight Argentinean companies, which could export around 1.2 million tonnes of biodiesel duty-free to the EU every year.

Certainly, the promotion of the use of biofuels in the EU has been highly criticized because of its environmental, social or economic externalities, such as causing deforestation in Indonesia and Malaysia (Malins, 2019; T&E, 2019), putting millions of people at risk of hunger (De Schutter, 2012, 2014) or reducing EU producers' profitability and leading to several bankruptcies because of dumped imports from Argentina and Indonesia (EBB, 2012). However, given the large number of goals which policies in general pursue, interactions are inevitable, so trade-offs and synergies between different goals in the triple dimension (economic, social and environmental) should be taken into consideration by policy makers in any sector (Scherer *et al.*, 2018). The environmental impacts of Spanish biodiesel were assessed previously by

the authors (Fernández-Tirado *et al.*, 2013, 2016, 2017) as part of a PhD thesis that aims to analyse the sustainability of biodiesel in Spain. Apart from these, economic and social impacts must be assessed to analyse sustainability.

In the literature, the I-O methodology has been widely used to analyse the economic impact and job creation in different sectors and at different levels (regional, state, etc.). In the biofuels sector, this methodology has been frequently employed to estimate the economic impact that can result from the use of different types of biofuels in different states or counties in the U.S. (Hodur *et al.*, 2006; Leistriz & Hodur, 2008; Perez-Verdin *et al.*, 2008; Low & Isserman, 2009; Bailey *et al.*, 2011; Dilekli & Duchin, 2016; Zhang *et al.*, 2016; Coon *et al.*, 2017). The biofuel economic impact assessment through the I-O methodology has been less frequent outside the U.S. However, this method has been often used to quantify the economic and job creation effect of the introduction of biofuels at different scales (Thomassin & Baker, 2000; Kulišić *et al.*, 2007; Neuwahl *et al.*, 2008; Mukhopadhyay & Thomassin, 2011; Silalertruksa *et al.*, 2012; Malik *et al.*, 2014; Duscha *et al.*, 2014; Yang *et al.*, 2015; Markandya *et al.*, 2016; Sievers & Schaffer, 2016; Okkonen & Lehtonen, 2017; EurObserv'ER, 2017; Veiga *et al.*, 2018; Brinkman *et al.*, 2018; Loizou *et al.*, 2019; Lechón *et al.*, 2019).

In Spain, de la Rúa (2009) developed an integrated tool 'Life Cycle Assessment I-O' to quantify the economic activity and job creation from the production of bioethanol in Spain; IDAE (2011a) estimated the contribution to the gross domestic product (GDP) of the different technologies for renewable energy supplies, including biofuels, from 2006 to 2020; the Spanish association of renewable energy companies (APPA) publishes annually an inform about the impacts of renewable energies in Spain, covering the contribution of every sector to the GDP and number of jobs. CIEMAT (Centre for Energy, Environment and Technology Research) have also used I-O methodology very often to calculate the creation of direct and indirect employment and the impact on the economy arising from Spanish renewable energy projects other than biodiesel. For example, Sáez *et al.* (1998) discussed, among other consequences, the direct and indirect job creation of a 20 MW power plant fueled by biomass from *Cynara cardunculus*, in southern Spain; Linares *et al.* (1996) analysed, beside the job creation, the effects of this plant in GDP; Varela *et al.* (1999) discussed, among other consequences, the macroeconomic effects and employment generation arising from a biomass plant fuelled by *Cynara cardunculus* and forest residues; Caldés *et al.* (2009) estimated the increase in the demand for goods and services as well as in employment, meeting the stated objectives of thermal power in the PER (Renewable Energy Plan); Santamaría & Azqueta (2015) made a Cost Benefit Analysis (CBA) in order to assess the adequacy of public support

policies of biofuels, covering the impact on the labour market and on the GDP; and finally, de la Rúa & Lechón (2016) presented a socioeconomic study of the production of pellets from *Miscanthus*. Moreover, a literature review of socioeconomic implications of bioenergy can be found at de la Rúa & Lechón (2018).

Although I-O models have been used to assist political decision making for several decades (Okkonen & Lehtonen, 2017), there is an absence of previous work on the macroeconomic impact of policies affecting biodiesel consumption and production in Spain through different scenarios, which justifies the performance of this investigation.

In this context and given the potential impacts that the implementation of energy policies can have in the Spanish biodiesel industry and, consequently, in the Spanish economy and employment, and in its sustainability, analysing various scenarios can help decision makers to optimize development policies of the biodiesel industry. Moreover, evaluating the impacts that this industry had already caused in Spain is also necessary. To this aim, this study assesses the effects of the biodiesel industry in Spain, in the past and the future under different conditions, on economic and social terms, focusing on job creation and gross value added (GVA).

Material and methods

Two metrics were used to estimate the economic and social impacts of the biodiesel industry in Spain: GVA and job creation. GVA is a metric of economic productivity that measures the contribution to GDP and covers all value added (such as income from labour or capital, land rent and taxes minus subsidies). Job creation is a socio-economic metric that measures the increase in employment driven by a specific industry. The 2010 and 2015 symmetric I-O tables of the Spanish economy (SIOT) from INE (2018) were used to quantify macroeconomic impacts with both GVA and jobs indicators, using the I-O model (Leontief, 1984).

An I-O table can be expressed as follows in the Leontief model:

$$X = (I - A^d)^{-1} \cdot D = B \cdot D \quad (1)$$

where X is the vector of total production, I is the identity matrix, A^d is the square matrix of domestic technical coefficients, D is the vector of domestic demand and B is the accounting multiplier matrix (equivalent to the Leontief inverse matrix). Therefore, the increase in domestic production resulting from an increase in domestic demand can be expressed as:

$$\Delta X = (I - A^d)^{-1} \cdot \Delta D = B \cdot \Delta D \quad (2)$$

Types of economic impacts

Direct and indirect impacts

To estimate the impacts on GVA and employment an additional vector that indicates the amount of employment and the added value generated by each activity sector per monetary unit of production has to be included in Eq. (2).

Moreover, the effects on the economy caused by products that were necessary to meet the demands of mandatory targets were considered ‘direct impacts’, while the effects caused by the interactions with other sectors were considered ‘indirect impacts’. Therefore, impacts on employment and GVA are divided into direct and indirect impacts. The symbol $\hat{\cdot}$ indicates that the vector was diagonalized. In this way, the direct impact on GVA is:

$$E_{GVA d} = L_{GVA} \cdot \hat{\Delta D} \quad (3)$$

while the indirect impact on GVA is:

$$E_{GVA i} = L_{GVA} \cdot (\Delta \hat{X} - \Delta D) \quad (4)$$

where the added value multiplier, L_{GVA} , indicates how many euros are generated in the economy for each euro spent initially, as a consequence of the economic activity of the related sectors.

In the same way, job creation was divided into direct and indirect job creation, with direct job creation:

$$E_{jobs d} = L_{jobs} \cdot \hat{\Delta D} \quad (5)$$

and indirect job creation:

$$E_{jobs i} = L_{jobs} \cdot (\Delta \hat{X} - \Delta D) \quad (6)$$

where the employment multiplier, L_{jobs} , is the vector of the employment coefficients, containing the base-year employment in each sector per unit of additional final demand in the different branches of the SIOT. In this analysis, unlike L_{GVA} , for its calculation, physical labour input coefficients are used instead of monetary input coefficients. E_{jobs} represents the number of full-time equivalent jobs (direct and indirect) in Spain resulting from the increase in biodiesel production, and ΔX the increase in production in each branch in Spain, resulting from the increase in biodiesel production.

Impacts during the construction and during the operation phases

1. *Impacts during the construction.* The impacts that occur during the implementation and construction phases of the biofuel industry are temporary economic impacts. The 2010 SIOT was used to quantify these economic impacts from 2005 to 2012 with both indicators, GVA and employment. Most biodiesel plants were built between 2005 and 2012. Given the biodiesel overcapacity (Table 1), new production plants are not foreseeable (IDAE, 2011b). Therefore, higher blending mandates would not cause new temporary impacts.

2. Impacts during the operation phase

a) *Impacts during the operation phase from 2005 to 2018.* These impacts were calculated from 2005, when the biodiesel plants began operating in Spain, to 2018, the last year in which data could be collected. The impacts during the operation phase from 2005 to 2018, were evaluated with two SIOT: 2010 SIOT for impacts from 2005 to 2012, and 2015 SIOT from 2013 to 2018. In order to calculate the increase in production, ΔX , derived from a certain increase in demand for biodiesel, ΔD , during the operation phase, the biodiesel industry must be disaggregated from the activity of the chemical industry (branch ‘11 Chemical industry’) in the SIOT, to a new branch, called branch ‘65 Biodiesel’. Therefore, an ‘expanded’ SIOT of the Spanish economy (ESIOT) of 65×65 , an ‘expanded’ domestic Leontief inverse matrix of 65×65 , and an ‘expanded’ demand vector of 65×1 were used. The disaggregation of the biodiesel sector was carried out using various sources. Most of the data were taken from IDAE (2005) and IDAE (2011b), which break down the intermediate consumption of an average-sized biodiesel plant of 50,000 tonnes. Other costs such as crude oil, electricity or water were taken from more current sources and are detailed later in section ‘Domestic demand from the operation phase’. All prices were deflated to the base years of the tables (2010 or 2015) with data from The World Bank (2019). Then, these costs calculated in euros per ton were multiplied by the annual production of biodiesel, according to CNMC data (2019a) to calculate the ESIOT data.

b) *Impacts during the operation phase for an average year following a trend from the past.*

Table 1. Biodiesel industry capacity (thousand tons/year)

	2005	2006	2007	2008	2009	2010	2011	2012
Accumulated capacity	141.5	248.3	815.2	2,070.0	4,110.4	4,371.4	4,589.4	4,930.9
New construction capacity	141.5	106.8	566.9	1,254.8	2,040.4	261.0	218.0	341.5

Source: APPA (2009b, 2012b, 2013)

Different scenarios were simulated based on different hypotheses on biodiesel production, trade balance (export-imports) and on national raw material production. Since biofuels in general do not become cost competitive with conventional fuels without institutional support, limited growth in the use of biodiesel for transport was foreseen in all scenarios.

Firstly, it was necessary to estimate fuel consumption for an average year following a trend from the past. In all scenarios, the consumption of biofuels in Spain was driven by mandate. We assumed a minimum target for biofuels (OB) 8.5% (energy basis) according to BOE (2015). In all scenarios, a cap of 7% (energy basis) was assumed for first-generation biofuels over total motor fuels. Thus, the demand for biofuels forecast was 3,067,506 tons of oil equivalent (toe).

Since 2016, Spanish blenders prefer to meet the mandates with biodiesel or hydrotreated vegetable oil (HVO), which does not count towards the 7% blending limit for labelling purposes (BOE, 2015), but it is eligible for mandate compliance at the expense of bioethanol use (USDA Foreign Agricultural Service, 2017). Taking this into account, the same percentages of demand for bioethanol (10.3%), biodiesel (73.3%) and HVO (17.7%) over total biofuels was considered as in 2018 for all scenarios. On the other hand, the hypothesis on the trade balance were established taking into account two regulations: i) under OJEU (2019a), palm oil was qualified as 'high ILUC-risk', so public support will be more demanding for this raw material, which could lead to its replacement by soybean or rapeseed oil; ii) duty free imports of biodiesel from Argentina were limited to 1.2 million tons (OJEU, 2019b) and the countervailing duty on imports of biodiesel originating in Argentina increased from 25.0% to 33.4% (OJEU, 2019c), which would help stimulate the national biodiesel industry.

Table 2 summarizes the main hypothesis related to biodiesel production, rapeseed oil production and biodiesel trade balance in each scenario. The reference scenario, scenario 0 (S0), was a baseline for the analysis. S0, assumes a 7% cap (energy basis) on first generation biofuels. A national production which equals the domestic demand for biodiesel, that is, 1,817,945 toe of biodiesel was simulated. The same volume of Spanish rape oil as in 2018

would be used to produce Spanish biodiesel. The cost of feedstock was a major component of overall costs. The forecast rape oil price in all scenarios was 756 €/t according to EC (2018).

Scenario 1 (S1) was an optimistic scenario for biodiesel production plants. In this scenario, 100% of the Spanish plants production capacity was used, that is, 4,357,591 toe (Table 2), and most of the production would be destined for export. Also, the same volume of Spanish rape oil as in 2018 would be used to produce Spanish biodiesel.

Scenario 2 (S2) was an optimistic scenario for biodiesel production plants and for Spanish feedstock producers. In this scenario, also 100% of the production capacity of Spanish plants was used, that is, 4,357,591 toe (Table 2) and also most of the production would be destined for export. Moreover, the amount of Spanish rape oil would increase to replace imports of vegetable oils. In S2, about 225,000 tons of rapeseed would be harvested to produce 89,286 tons of rape oil in Spain as raw material for Spanish biodiesel. This was the maximum amount of rapeseed produced in Spain in the harvests of recent years (MAPAMA, 2017).

Scenario 3 (S3) was a pessimistic scenario for biodiesel production plants. In this scenario, the domestic demand for biodiesel, this is, 1,817,945 toe of biodiesel would be satisfied mainly by imports. Exports, would drop to 2012 levels (Fig. S1 [suppl.]), *i.e.* 178,902 toe. While production to supply domestic demand would reach 757,467 toe, the rest of domestic demand, *i.e.*, 1,060,478 toe would be satisfied by biodiesel imports. Moreover, the same volume of Spanish rape oil as in 2018 would be used to produce Spanish biodiesel.

Domestic biodiesel demand

To calculate the increase in production, ΔX , derived from a certain increase in biodiesel demand, ΔD , it was necessary to define the vector of domestic demand for biodiesel. In this analysis, two types of domestic demand were distinguished: domestic demand from the construction and from the operation phases.

Table 2. Hypothesis assumed in scenarios

Scenario	Spanish biodiesel production (thousand toe)	Domestic rape oil production for biodiesel (t)	Percentage of domestic raw material (%)	Biodiesel commercial balance (thousand toe)
S0 (baseline)	1,818	10,495	0.50	0
S1	4,358	10,495	0.21	2,540
S2	4,358	89,286	1.77	2,540
S3	936	10,495	0.97	-882

Domestic demand from the construction phase. Domestic demand from the implementation and construction phase of the biofuel industry generates temporary economic impacts. The temporary costs of the investment made by the biodiesel industry over the years were calculated using the 2010 SIOT and data from Table 1 and Table 3. Table 1 indicates the new construction biodiesel industry in Spain over the years. Table 3 represents the investment cost (temporary domestic demand) for plants averaging 50,000 t.

Domestic demand from the operation phase. The domestic demand during the operation of the biofuel industry generates permanent economic impacts. The data on the operating costs of biodiesel from Table 4 were used to calculate these impacts. The operating costs of the biodiesel industry were introduced as intermediate inputs in the 65×65 ESIOT. In order to calculate the impacts from the operation phase, a 65×1 vector which includes just the domestic demand for biodiesel (ΔD) 65×1, was used

according to Eq. (2). Some basic adjustments were made, such as the conversion of units or currencies. A plant with a vegetable oil pre-treatment unit was used as a model. This plant allows the use of almost any type of crude oil (soy, rapeseed, palm, etc.). Crude oil represented the main cost, followed by chemical products and salaries.

The percentage of Spanish raw material used to produce biodiesel has increased over the years. Data on the production of industrial crops destined for the Spanish biodiesel industry from 2005 to 2010 were estimated by the area that received the aid for energy crops (FEGA, 2010) established in OJEU (2003), in force until the 2009/2010 campaign, and the average yields of energy crops, obtained from the historical series of the statistic yearbooks of MAPAMA (2017). Likewise, data on the production of industrial crops destined for the Spanish biodiesel industry from 2011 to 2018 were obtained from the statistic yearbooks of MAPAMA (2017). All prices were deflated to the base years of the tables with data from The World Bank (2019).

Table 3. Biodiesel industry investment costs by implementation and construction (M€/50,000 t at current prices of year 2011)

Activity branch	Description	Investment (M€)	
15	Tubes (Process equipment)	1.35	
	Auxiliary equipment (Process equipment)	1.06	
	Tanks (Process equipment)	1.13	
	Pumping equipment (Process equipment)	0.16	
18	Electrical installation	0.75	
19	Compressed air equipment (Installations)	0.11	
	Instrumentation and control (Installations)	0.49	
	Fire protection system (Installations)	0.46	
	Oil pre-treatment technology (Process equipment)	5.05	
	Biodiesel production technology (Process equipment)	3.65	
22	Architecture and interior installations	0.21	
24	Air conditioning and ventilation (Installations)	0.19	
	Natural gas installations	0.08	
25	Water supply and sanitation services (Installations)	0.10	
27	Earthmoving works	0.18	
	Buckets, tubes, loading area (Urbanization)	0.32	
	Buildings (Urbanization)	1.05	
	Auxiliary installations (Urbanization)	0.12	
	Loading area, pipelines (Structure)	0.31	
	Buildings (Structure)	1.58	
	Others (Structure)	0.02	
	46	Civil engineering (Urbanization)	1.48
		Security and health	0.12
	Total		19.95

Source: IDAE (2011b)

Table 4. Biodiesel industry operating costs (€/ton at current prices of 2011)

Activity branch	Description	Cost (€/t RME)	Cost (€/t SME)	Cost (€/t PME)	Cost (€/t SFME)	Source
5	Crude oil	983.54	934.19	809.48	977.52	Indexmundi (2019)
11	Chemical products	56.10	56.10	56.10	56.10	IDAE (2011b)
23	Maintenance	2.94	2.94	2.94	2.94	IDAE (2005, 2011b)
24	Electricity	6.12	6.12	6.12	6.12	Fernández-Tirado <i>et al.</i> (2016); Eurostat (2019)
24	Natural gas	14.36	14.36	14.36	14.36	Fernández-Tirado <i>et al.</i> (2016); Eurostat (2019)
25	Water	0.92	0.92	0.92	0.92	Fernández-Tirado <i>et al.</i> (2016); INE (2020)
31	Land transport and pipeline ^[1]	3.95	3.95	3.95	3.95	CLH (2019); CNMC (2019b)
32	Maritime transport ^[2]		13.5			BCR (2018)
34	Storage	4.22	4.22	4.22	4.22	CNMC (2019c)
41	Financial costs	3.36	3.36	3.36	3.36	IDAE (2005, 2011b)
42	Insurance	3.36	5.26	3.36	3.36	IDAE (2005, 2011b); Ursea (2017)
1-65	Other operating costs ^[3]	15.75	15.75	15.75	15.75	IDAE (2005, 2011b)
	Income by by-products	-12.50	-12.50	-12.50	-12.50	IDAE (2011b)
	Personal operation	20.37	20.37	20.37	20.37	IDAE (2005, 2011b)

^[1] Average prices for Coruña, Barcelona, Cartagena, Castellón, Huelva, Bilbao and Tarragona. ^[2] Euro/dollar change in 2015 = 1/1.110. ^[3] Other operating costs were distributed over the rest of the branches, according to intermediate inputs consumed by the branch '11 Chemical industry. PME: palm methyl ester. RME: rape methyl ester. SFME: sunflower methyl ester. SME: soy methyl ester

According to Fernández-Tirado *et al.* (2016), 2.52 tons of seed are needed to produce 1 ton of crude rapeseed oil, while according to CIEMAT (2006), 2.39 tons of seed are needed to produce 1 ton of crude sunflower oil. During the transesterification process, 1.023 tons of vegetable oil are needed to produce 1 ton of biodiesel. Biodiesel plants tend to be located close to large harbours in Spain, as sea transport is the main mean of transporting oil. The prices of soybean oil, which is usually transported from the harbour of Rosario by handysize tankers, *i.e.* with a capacity of around 25,000 tons, were indicated as free on board (FOB). Spanish tankers were considered for the analysis. Insurance was estimated at 0.1428% of maritime transport cost (Ursea, 2017). Conversely, the price of palm oil was the CIF price. Rapeseed oil does not need maritime transport, as Spanish rapeseed oil was considered. Although Spanish biodiesel factories usually receive the oil and store it in their own storage tanks, the use of facilities of logistics operators is also frequent. In addition, the logistics operators store the finished biodiesel from the plants. A storage time of one month has been assumed, as times longer than two months may cause problems (Burin, 2012).

While in the plants near the refineries the transport of biodiesel is carried out by means of a direct pipe connection, in the more distant plants it is carried out by means

of tanker trucks. In 2015, 2.1% of fuels were transported in tanker trucks and the rest in pipelines (CLH, 2016). Depreciation of equipment and facilities has not been considered in Table 4, as they had previously been included in the implementation and construction phase of the industry.

In addition, data were collected from different Spanish biodiesel companies in order to estimate the number of direct jobs during the operation phase (Fig. S1 [suppl.]), necessary to calculate the job creation. An average ratio of 22 employees per 100,000 t of biodiesel produced was estimated.

Results and discussion

Impacts during the construction phase

Table 5 shows impacts during the construction phase of the biodiesel industry on GVA. The total contribution to GVA derived from the investments made by the biodiesel industry in Spain during the construction phase from 2005 to 2012 was 2,694 million constant euros (2010 prices), the indirect impact (EGVA_i) being much higher than the direct impact (EGVA_d). The greatest economic impact

Table 5. Temporary impacts on GVA during the construction phase (at constant 2010 prices, M€)

Year	E_{GVA_d}	E_{GVA_i}	E_{GVA}
2005	28.87	55.79	84.66
2006	20.96	40.50	61.46
2007	107.64	200.06	307.70
2008	233.29	450.83	684.13
2009	378.38	731.22	1,109.60
2010	48.32	93.97	142.29
2011	40.35	77.98	118.33
2012	63.17	122.83	186.00
Total	920.99	1,773.17	2,694.16

E_{GVA_d} : direct effect on GVA. E_{GVA_i} : indirect effect on GVA. E_{GVA} : direct and indirect effect on GVA

occurred in 2009, the year in which a large number of biodiesel industries were under construction.

Table 6 shows the temporary economic impacts on job creation. The year 2009 stands out in the same way, when more than 23,000 people were employed full time (directly and indirectly) thanks to the implementation of biodiesel industry.

Impacts during the operation phase: from 2005 to 2018

Table 7 shows impacts on GVA that occur during the operational phase of the biodiesel industry. The total contribution to GVA derived from the operation phase of the biodiesel industry in Spain from 2005 to 2018 was 738.49

Table 6. Temporary impacts on jobs creation during the construction phase (number of full-time jobs)

Year	E_{jobs_d}	E_{jobs_i}	E_{jobs}
2005	784	994	1,778
2006	569	722	1,291
2007	2,923	3,540	6,463
2008	6,335	8,034	14,369
2009	10,274	13,031	23,306
2010	1,312	1,674	2,986
2011	1,096	1,390	2,485
2012	1,715	2,188	3,903

E_{jobs_d} : direct effect on job creation. E_{jobs_i} : indirect effect on job creation. E_{jobs} : direct and indirect effect on job creation

Table 7 Permanent impacts on GVA during the operation phase (at constant 2015 prices, M€)

Year	E_{GVA_d}	E_{GVA_i}	E_{GVA}
2005	0.60	0.73	1.34
2006	2.00	2.43	4.42
2007	8.95	10.87	19.82
2008	15.12	18.36	33.49
2009	18.03	21.89	39.92
2010	22.60	27.47	50.07
2011	15.23	18.49	33.72
2012	10.68	12.98	23.66
2013	21.98	22.43	44.41
2014	32.85	33.53	66.38
2015	37.25	38.01	75.26
2016	45.01	45.94	90.96
2017	57.56	58.74	116.30
2018	68.62	70.12	138.74
Total	356.48	382.01	738.49

E_{GVA_d} : direct effect on GVA. E_{GVA_i} : indirect effect on GVA. E_{GVA} : direct and indirect effect on GVA

million constant euros (2015 prices), with the direct impact slightly higher than the indirect one.

Finally, the jobs generated by biodiesel production in Spain were estimated. Table 8 shows the jobs generated in each year from 2005 to 2018 during the operation phase.

Impacts during the operation phase: scenarios simulation

Table 9 shows the impacts on GVA of the operation phase in the simulated scenarios. The contribution to GVA of the biodiesel sector in Spain ranged from 71.87 in S3 to 357.02 million euros in S2. Higher figures were found in scenarios in which biodiesel production increased. However, another influential factor was the amount of domestic raw material used. Thus, the contribution to GVA per toe was higher in S2 (91.7 €/toe), as the amount of national rapeseed oil was higher in that scenario, while the contribution was equal to 83.1 €/toe in S0, 81.9 €/toe in S1 and 86.8 €/toe in S3.

Table 10 shows the impacts on the jobs of the operation phase in the simulated scenarios. New production plants in Spain are not foreseeable (IDAE, 2011b), so only impacts during plant operation and maintenance were considered. The number of jobs ranged from 793 in S3 to 3,942 in S2.

Table 8. Permanent impacts on job creation during the operation phase (number of full-time jobs)

Year	E_{jobsd}	E_{jobsi}	E_{jobs}
2005	5	12	18
2006	18	41	58
2007	79	182	261
2008	134	307	441
2009	160	366	525
2010	200	459	659
2011	135	309	444
2012	95	217	311
2013	133	349	482
2014	199	521	720
2015	225	591	816
2016	272	714	986
2017	348	913	1,261
2018	415	1,091	1,506

E_{jobsd} : direct effect on job creation. E_{jobsi} : indirect effect on job creation. E_{jobs} : direct and indirect effect on job creation

Comparison with other studies

From our results, it has been demonstrated that the impacts of the biodiesel industry during the construction phase, were much greater than the economic impacts of the operation phase in both impact metrics (economic and social) in Spain. The biodiesel sector contributed 2,694 million constant € (at 2010 prices) to GVA during the construction phase, from 2005 to 2012. By contrast, the total contribution to GVA derived from the operation phase from 2005 to 2018 was 695.68 million constant € (at 2015 prices). The economic impacts during the operation phase have been very limited due to the fact that many Spanish biodiesel plants had to close down due to low profitability. The highest cost from the biodiesel produc-

Table 9. Permanent impacts on GVA in the simulated scenarios (at constant 2015 prices, M€)

Scenario	E_{GVAd}	E_{GVAI}	E_{GVA}
S0	80.08	89.30	169.38
S1	150.46	167.79	318.24
S2	168.79	188.23	357.02
S3	33.98	37.89	71.87

E_{GVAd} : direct effect on GVA. E_{GVAI} : indirect effect on GVA. E_{GVA} : direct and indirect effect on GVA. For a description of the scenarios see section 'Impacts during the operation phase for an average year following a trend from the past'.

Table 10. Permanent impacts on jobs in the simulated scenarios (number of full-time jobs)

Scenario	E_{jobsd}	E_{jobsi}	E_{jobs}
S0	484	1,386	1,870
S1	910	2,603	3,514
S2	1,021	2,921	3,942
S3	206	588	793

E_{jobsd} : direct effect on job creation. E_{jobsi} : indirect effect on job creation. E_{jobs} : direct and indirect effect on job creation. For a description of the scenarios see text.

tion is for the crude oil, that comes from oil crops. Oil crops compete for resources (land, fertilizers, water, etc) with other crops (energy, food or feed crops) that could be more profitable. Nevertheless, the impacts associated with the operational phase of the biodiesel industry have grown since 2012, reaching 127.57 M€ in GVA in 2018, representing an increase of 439% over 2012. The scenarios simulation showed that the impact on GVA could reach 357.02 M€, in the most optimistic scenario if plants worked at full capacity with the highest percentage of domestic raw materials used for its production. The same thing happened with the impacts during the construction phase on employment. The year 2009 stood out in the same way, when more than 23,000 people worked full time thanks to the implementation of the biodiesel industry. However, in the operational phase the biodiesel industry generated a maximum of 1,332 jobs per year in 2018. Likewise, the most optimistic scenario for job creation estimates that 3,942 jobs would be created.

The IDAE (2011a) carried out a study on the economic impacts of the biofuels industry during the period 2005-2009. In addition, the APPA (2009a, 2010, 2011, 2012a) carries out an annual study on the macroeconomic impact of renewable energies in Spain. However, none of them distinguished between impacts during the construction phase and impacts during the operation phase. In addition, they calculated the joint contribution to GDP of the biofuels industry (biodiesel and bioethanol together). In contrast, our study analyses the contribution of the biodiesel industry exclusively. In any case, the results of the different studies were included in Tables 11, 12 and 13 for comparison.

The results were quite similar in the three studies in 2005 and 2006, taking into account that our study only shows the impacts on GVA caused by the biodiesel sector, while the other studies show those caused by biodiesel and bioethanol. However, the results were very different for other years. While our figures were proportional to new construction plants (Table 1), the other studies showed results independent of these data. This was especially evident in 2009, when many biodiesel plants were built. In addition, by aggregating the results from 2005 to 2012, our study shows greater impacts on GDP than the

Table 11. Impacts on GVA from 2005 to 2012 (at constant 2010 prices, M€): Comparison of results

Year	IDAE	APPA	This study
2005	131.8	119.6	86.0
2006	144.9	136.8	65.9
2007	150.2	146.5	327.7
2008	151.1	151.1	717.9
2009	273.0	350.1	1149.8
2010		494.0	192.8
2011		426.5	152.0
2012		359.5	209.7
Total		1,975.1	2,901.8

IDAE: Institute for Diversification and Saving of Energy. APPA: Asociación de Empresas de Energías Renovables. *Source:* APPA, 2009a, 2010, 2011, 2012a; IDAE, 2011a; Tables 5 and 7

Table 12. Impacts on GVA from 2013 to 2017 (at constant 2015 prices, M€): Comparison of results

Year	APPA	This study
2013	298.7	44.41
2014	417.7	66.38
2015	487.2	75.26
2016	587.8	90.96
2017	760.0	116.30
Total	2,551.4	393.31

APPA: Asociación de Empresas de Energías Renovables. *Source:* APPA (2018); Table 7

Table 13. Impacts on jobs (number of full-time jobs): Comparison of results

Year	APPA	This study
2005	6,096	1,796
2006	6,583	1,349
2007	7,060	6,724
2008	7,283	14,810
2009	6,347	23,831
2010	5,172	3,645
2011	3,797	2,929
2012	2,909	4,214

APPA: Asociación de Empresas de Energías Renovables. *Source:* APPA (2018), Tables 6 and 8

study of APPA (2012a), even if they are only caused by the biodiesel sector and bioethanol sector is not included.

As for the impacts on GVA from 2013 to 2017 (Table 12), the results from APPA (2018) differed significantly from ours. No biodiesel plant was built during this period, so the economic impacts were caused exclusively by the operation phase of the biodiesel industry. Therefore, the results should be proportional to biodiesel production (Fig. S1 [suppl.]). For this reason, we consider their results to be very optimistic, their figures being six times higher than ours.

In addition, APPA (2010) had very different results on the impacts on employment (Table 13). Although its analysis did not differentiate between jobs during the construction or the operation phase, we also consider its data very optimistic. It recognised that about 75% of the 48 biodiesel plants remained paralyzed due to imports in 2010, and that most of the remaining plants operated well below capacity. However, this argument contrasts with its results, as 5,172 jobs were still created based on its results. These figures can be explained by accepting that the temporary impacts due to the construction of biodiesel plants in 2009 were distributed among other years. However, it contrasts that although in our study there is a ratio between the number of jobs and the GVA, which ranges from 19 to 21, over all years, in its study the ratio varies from 8 to 51.

IDAE-ISTAS (2011) also calculated the number of direct and indirect jobs in Spain in 2009 from renewable energy sources, and its data also vary significantly from APPA (2010). It estimated that 964 direct jobs and 988 indirect jobs were generated by the biofuels sector in 2009. This study considered 439,000 toe of new construction plants and 1,058,000 toe of accumulated power in 2009, unlike our study which considered 1,803,148 toe and 3,632,489 toe, respectively. In addition, IDAE-ISTAS (2011) simply considered percentages of 65% and 35% to divide the employment between temporary (associated with manufacturing and installation) and permanent (associated with plant operation and maintenance). Thus, its results showed that 337 operators worked in 2009 in biofuel plants (biodiesel and bioethanol). According to CNE (2010), 947,275 toe of biofuels were produced in Spain in 2009, creating 36 direct jobs per 100,000 toe of biofuels. On the contrary, our results show that 125 direct jobs (Table 6) were created in the biodiesel sector during the operation phase. The ratio of the number of employees per 100,000 toe, which equals 22, was calculated using data from Fig. S1 [suppl.]. Furthermore, in our study, the percentage of employment during the construction phase (Table 4) is much higher than the employment during the operation phase (Table 6), varying in the 2005-2012 period from 1% in 2005 to 78% in 2010.

Our simulated scenarios were also compared with the results from these studies for the year 2020. IDAE

(2011a) estimated a contribution of the biofuels sector to the Spanish GDP of 149.9 €/toe for the year 2020. Thus, the total contribution of the biofuels sector in Spain to meet the binding targets for 2020 in the transport sector would amount to 524 M€ (at constant 2010 prices). These results vary significantly from ours. However, IDAE (2011a) did not explain some factors, such as the amount of domestic raw material used or the biodiesel trade balance which could modify the results.

In addition, IDAE-ISTAS (2011) foreseen 1,164 jobs in the operation and maintenance of Spanish biofuel plants (biodiesel and bioethanol) in 2020. Their results are more similar to ours in the most pessimistic scenario for Spanish plants (S3). They also estimated 348 jobs for the manufacture and installation of new plants while we do not foresee any job, since new production plants are not foreseeable as previously indicated.

Conclusions

Without any doubt, biodiesel market will go on depending on policies, mainly on mandated demand, which has been hugely changing in recent years in Spain, so considerable uncertainty regarding the projections of production, consumption, imports and exports will exist. In any case, biodiesel production generates positive economic and social impacts on the economic system and, to a greater extent, the more domestic raw materials used for its production. In recent years, the Spanish biodiesel sector has been working well below capacity, so it has had a limited impact. The results obtained justify the adoption of public measures to increase the production of existing biodiesel plants in Spain aimed at increasing gross domestic product and employment. Some measures could be aimed at increasing national market share, such as Order IET/822/2012 (BOE, 2012), which had major impacts in the Spanish economy. In addition, anti-dumping duties have been also important in limiting imports and encouraging domestic production. Other measures could be aimed at increasing domestic raw material. Although rapeseed is an ideal rotation for cereal and rape oil an excellent raw material for biodiesel, the area of rapeseed in Spain has been very small compared to other EU countries. A policy measure to increase the use of domestic raw material (rapeseed oil) could be to conduct outreach campaigns to dispel the myth that oilseed rape is a dangerous crop, an image due to massive intoxication in the country in the past by fraudulent mixing with industrial oil, so that farmers can grow it in rotation with cereals. Another measure could be the establishment of contracting systems that ensure farmer's profitability. In addition, many of the plants that use a higher percentage of domestic raw material are located in economically depressed rural areas, while those that use a higher percentage of imported raw

material tend to be closer to the coast. These measures could therefore also offer new opportunities to diversify incomes and employment in rural areas, as it outlined the EU strategy for the promotion of biofuels. However, the application of the I-O model to regional studies would be required to calculate this impact. Moreover, it is necessary to take into consideration the limitations of the model. Although the proposed model allows the examination of some counterfactuals, *i.e.*, hypothetical scenarios with attributes which vary from a baseline scenario, there might be multiple scenarios that have not been considered in this study. Other limitations include the stability of the technical coefficients, the fact that no economies of scale are contemplated and the opportunity cost of diverting the feedstock used to produce biodiesel to other purposes, or of diverting the land to other crops.

Finally, an analysis of global sustainability of biodiesel which includes not only the economic and social dimensions but also the environmental dimension of sustainable development is needed to guide decision makers to promote sustainable biodiesel in Spain. Hence, it is essential to find out whether different biodiesel alternatives are generating benefits or disadvantages, such as the creation of jobs or increasing CO₂ emissions. Trade-offs between different goals in the triple dimension (economic, social and environmental) should be taken into consideration by policy makers in any sector and will be evaluated in future research.

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