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Environmental behaviour of blueberry production at small-scale in Northern Spain and improvement opportunities

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ABSTRACT

The production of berry, a fruit highly appreciated by consumers, has considerably increased in the last years. Europe Union has 1.55 millions of smallholdings dedicated to blueberry farming. Actually, it is an important sector on Spain agrifood exports, especially in Asturias. In order to increase sustainability in crops, it is necessary to identify the key environmental aspects. Blueberry cultivation methods are well documented in bibliography, but Life Cycle Assessment (LCA) researches are virtually inexistent in Europe. For this reason, this work has studied from an environmental perspective four blueberry orchards sit in Asturias (Northern Spain) and the field agricultural practises used. LCA results showed that the main environmental impacts of blueberry production were originated by the use of fertilisers, followed by the use of fossil fuels, plastic and paper materials and incineration of pruning. Significant differences between conventional and organic crops have not been found. The carbon footprints (CF) obtained in this study were between 0.32 kg and 1.66 kg CO_2-eq/kg blueberry. CF values obtained in two of the systems analysed were within the literature ranges, between 0.20 and 0.80 kg CO_2-eq. per kg of fruit. However, higher values were found in the other two orchards. Environment improvements have been proposed for each particular case. Results here obtained could be used to support policy changes, such as the implementation of sustainable practices in order to lead to a more sustainable blueberry production with lower GHG emissions.

1. Introduction

Nowadays agriculture faces multiple changes mainly because an increase in food production will be necessary in next years to feed a growing population. Addressing the growing need for food worldwide will entail major environmental costs, so the main challenge today is increasing agricultural production and at the same time implementing sustainable production methods (FAO, 2009). In addition, consumer concerns about healthy foods have caused an exponential increase of organic products demand in the last 20 years. Organic production is an agri-food management system that combines animal welfare standards, good environmental practices and preservation of natural resources. European Union has created a logo consumer (EU Ecolabel) which identifies these organic products. This logo promotes "*the circular economy by encouraging producers to generate less waste and CO_2 during the manufacturing process. The criteria also encourages companies to develop products that are durable, easy to repair and recycle*" (European Commission, 2020a).

Life Cycle Assessment (LCA) is a standardized tool to assess the environmental aspects and potential impacts of a product, process, or service. The International Organization for Standardization (ISO) has published a set of standards on LCA and defined the general categories of environmental impacts under the series UNE-EN ISO 14040:2006 (ISO, 2006). LCA has proved to be a relevant and powerful tool to evaluate the environmental performance of different production systems (Abín et al., 2018; Calderón et al., 2010; Canellada et al., 2018; Laca et al., 2021). In addition, this methodology has been successfully employed in different studies to evaluate environmental aspects of primary production (Herrero et al., 2020; Laca et al., 2020), particularly, of agricultural production (Cerutti et al., 2014; Girgenti et al., 2013; Meier et al., 2015; Roy et al., 2009; Strik, 2016). It is difficult to standardize environmental impacts derived from agricultural systems, due to the high variability of agricultural practices and the diversity of cultivated products. These impacts depend directly on geographical area, type of crop and product (conventional or organic), net production (high or low efficiency), productive system (manual or mechanical), distribution and commercialization (exportations or local market), etc. Despite all these variable factors, and with the aim to implement more sustainable practices,

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producers need information about the strengths and weaknesses of their farming systems related to environmental impacts. For these reasons, in recent years, LCA has been increasingly used to analyse the sustainability of food production systems (Roy et al., 2009).

LCA has been employed in many works to evaluate fruit production (Brentrup et al., 2004; Cerutti et al., 2014; Meier et al., 2015). For example, Nikkhah et al. (2016), who applied LCA to kiwi production on Iran, concluded that eutrophication was mainly originated by the use of fertilisers. In a similar study, Mohamad et al. (2014) analysed the optimisation of organic and conventional olive farming in Italy, and reported that the organic olive system had better performance with lower environmental burdens in resource depletion and fossil fuel consumption categories. Keyes et al. (2015) found that fuel use, N- and P-fertilisers, and inputs for pest and disease management on both type of orchards, conventional and organic, were the main responsible of environmental impacts derived from apple production in Nova Scotia (Canada). Related to berry production, Strik (2016) evaluated the organic production of blueberry and blackberry for fresh and processed markets in the north-western United States. These authors concluded that blueberry plants were sensitive to fertiliser source and soil pH and reported that flushing of drip irrigation system and good maintenance was critical for fertiliser and irrigation efficiency. Girgenti et al. (2013), who studied the use of non-renewable energy and greenhouse gas emissions associated with blueberry and raspberry production in Italy, showed that the most significant impacts were related to the use of plastic materials in different phases such as irrigation, mulching and covering.

Berries have gained popularity overt last decade, especially blueberries. Although this fruit of wild origin has always been appreciated by consumers, blueberry crops have recently undergone a notable increase worldwide. This is mainly due to new trends in healthy consumption. Actually, blueberry has been classified as a “superfood”, a food which has high nutritional content on nutrients, vitamins and minerals (Ware, 2017). USA leads world blueberry production and, together with Canada, Chile and Peru, represent 75% of total world area of blueberry orchards. The main blueberry exporting countries are Chile (20%), Canada (19%), Spain (11%), Peru (10%), United States (9%) and Netherlands (6%) percentages are related to the aggregated some of exports of all countries. Europe has 1.55 millions of smallholdings employed to blueberry farming and specifically, in Spain, blueberry production has increased in approximately 300% in recent years (Fepex, 2019). In fact, Spain is the main producer of berries at European level with an approximate production of 50,000 tons of berries in 2018. Although, in this country, most blueberry orchards are located in the Southern region, in recent years, blueberry has become a popular crop also in the Northern Spain (MAPA, 2019a). As mentioned previously, European crops are characterized by small, low-tech plantations with manual tillage tasks, similar to wild blueberry North American’s crops. Conversely, South and North American orchards are frequently harvested using mechanical harvesters, due to the size of the farms, which varies between 0.25 and 30 acres. Moreover, European fruit is sold fresh while 99% of the North America production is commercialized frozen (Greblikaite, 2019; Maine, 2015).

Environmental impacts derived from blueberry production has scarcely been analysed and studies on this topic in Europe are almost inexistent (Strik, 2016). For this reason, in this work, four blueberry production systems located in Asturias (Northern Spain) have been analysed as representative of this crop cultivation at small scale in Europe. The LCA methodology has been employed to evaluate the environmental impacts derived from these systems with the aim to compare orchards and production processes at small scale in Europe. The results obtained would increase the understanding of the environmental impacts associated with blueberry production, which will allow to propose realistic improvement actions to reduce the environmental burdens derived from these production systems.

2. Materials and methods

2.1. System description

The study area was the Principality of Asturias, a region in the Northern Spain, latitude 433401N, longitude 060239W, altitude 127 m. The economy of this region is based on primary and secondary sectors and it is the second largest blueberry producer region in Spain with almost 200 ha occupied by this crop and 800 ton of blueberries produced in 2018 (MAPA, 2019b). Additionally, around 50% berry area is managed organically (CMR, 2018).

The Principality of Asturias is under maritime climate, which is a template climate characterised by abundant precipitation year-round (mean value of 55 mm per year). This region has 25 different type of agricultural soils as siliceous, franc, sandy, etc., with high organic matter content and pH between 3.9 and 4.5. These excellent conditions favour orchards which require high hydric conditions such as berry, kiwi and apple crops.

Asturian blueberry crops are young, are commonly small family-owned systems, usually with a cultivated area between 1 and 2 ha and an average yield of 4000 kg of per ha and year (CMR, 2019; CMR, 2018).

The principal characteristics of the four blueberry systems considered for this study have been summarized in Table 1. The main differences between the four producers are related to productivity type of fertilisers, fertilisers consumption and management of wastes. Three systems are organic and have ecological certification (P1, P2 and P3) and the fourth (P4) employs good environmental practices but it is not certificated. Regulation (EU) 2018/848 on organic production and labelling of organic products (European Commission, 2021a) establishes the certification system that allows the identification of producers who comply with organic production standards.

P1, P2, and P4 have a similar extension of land employed for blueberry production, around 2 ha, whereas P4 cultivates 0.8 ha P1 and P2 consume four times more fertilisers than P3 and P4, around 700 kg/ha compared to 135 kg or 167 kg/ha per year. Related to waste treatment of pruning, P1 and P2 incinerate vegetable mass while P2, P3 and P4 compost the matter *in situ*. P1 and P3 sell around 10–30% of fruit directly to consumer in its installations and online, and the rest of the production through sales association, while P2 and P4 sell its total production through cooperative marketing. P2 and P4 have a store outside the crop and they employ a fuel vehicle for the transport of blueberries to the storage place.

Orchards are located in East (P4), West (P3) and Centre (P1 and P2) of the Principality of Asturias, altitude between 54m and 425 m and slope between 3% and 5%. All crops were planted in 2014, so in all cases plants were six years old during the year of the study (2019), with a density of around 3000 plants per ha. Different varieties of blueberry (*Vaccinium* sp.) are planted, Duke, Central Blue, Bluegold, Aurora, Ozarkblue, Powderblue, Ochlockonee, Chandler and Legacy.

Study period covered from January to December of, 2019. Data were mainly obtained through personal interviews with farmers, visits to the facilities and detailed questionnaires.

2.2. Life Cycle Assessment

2.2.1. Goal and scope definition

The main aim of this work has been to evaluate the environmental impacts derived from blueberry production by means of LCA methodology in order to increase the knowledge about the environmental behaviour of these kind of crops and detect critical spots. The final objective was to find environmental improvements that can be implemented as sustainable practices. The functional unit (FU) was 1 kg of blueberry at the packaging stage-gate.

The system boundaries of this study are considered from the extraction of materials to the orchard gate (“*cradle to gate*” perspective, Fig. 1). This study included: manufacturing processes for inputs,

Table 1
Overview of the main characteristics of the production systems studied.

PRINCIPAL CHARACTERISTICS OF THE SYSTEMS ANALYSED					
INPUTS	P1	P2	P3	P4	Unit
Organic certification	v	v	v	x	–
Location*	Oviedo	Grado	Tapia de Casariego	Nava	–
Altitude	300	425	40	360	m
Occupation crop	2.00	2.00	0.81	1.80	ha
Type of land	meadow	meadow	meadow	meadow	–
Type of soil	clay loam	sandy loam	sandy loam	sandy loam	–
Number of plants	6118	6509	3012	5000	ud
Cultivated varieties	Legacy, Central Blue, Chandler, Liberty, Aurora, Duke, Ochlockonee	Central Blue, Bluegold, Duke, Ozarkblue, Aurora, Powderblue, Ochlockonee	Chandler, Bluecrop, Aurora, Duke, Ochlockonee	Legacy, Chandler, Bluecrop, Brigitta, Aurora	–
Fruit production	5035	5616	4990	6730	kg/year
Land productivity	2517	2808	6160	3739	kg/ha
Sales system	Direct	cooperative	direct	cooperative	–
Type of water	rain and river	well	river	well	–
Type of fertiliser	ecological	ecological	ecological	chemical	–
Fertilisers consumption	691.87	736.08	135.16	167.78	kg/ha
Waste treatment of pruning	incineration	Incineration/composting	composting	composting	–
Pruning waste	6086	500	3750	5500	kg/year
Brushcutting waste	1000	1000	400	585	kg/year
Plant replaced waste	–	–	–	8500	kg/year

• All sited in Asturias (Spain).

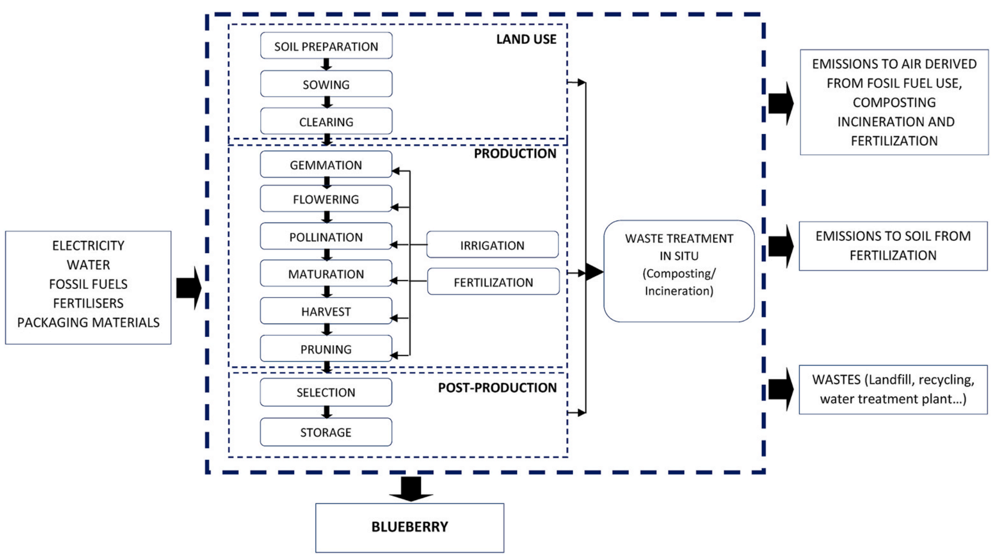

Fig. 1. System boundaries.

transport to the own storage place, packaging, emissions to soil and atmosphere and waste management. Raw material transport and distribution to the points of sale have not been considered in the LCA. Nursery, establishment, low production years and dismantling have been excluded from the analysis, since nursery data were unknown in all cases and no dismantled orchard was carried out as all crops are less than 30 years old. Plants were stablished on 2014 and blueberry production begins in the 2nd or 3rd year of the orchards. Harvesting increases gradually until reaching full production in the 6th-7th year, so 2019 was a full production year (MARM, 2011). Based on PAS 2050 (British Standards Institution, 2007) infrastructures, buildings and facilities existing in the crop were also excluded. Similarly, inputs/outputs that represent less than 1%, such as the emissions from the septic tank and some minor fertiliser ingredients, were also not considered in the analysis.

2.2.2. *Inventory analysis*

Inventory data for the four blueberry production systems are organised in subsystems as it is shown in Table 2. Data were obtained interviewing the producers and/or from reliable literature sources.

The productivity of the systems studied was between 2500 and 6200 kg of blueberries per hectare and year, being the regional average 4000 kg per hectare and year (MAPA, 2020). Water consumption for producing 1 kg blueberry was between 86 and 164 l/FU. The irrigation systems were similar in all orchards, consisting on a network of PVC pipes in underground. Fertiliser was supplied in the irrigation water. P1

Table 2
Inventory data of the systems analysed (FU: 1 kg blueberry).

PRINCIPAL INPUTS OF THE SYSTEMS						
SUBSYSTEM	P1	P2	P3	P4	UNITS	Source
Land use	3.97	3.56	1.62	2.07	m^2	*from producer*
Water consumption						*from producer*
Tap water	5.95	0.18	3.21	1.72	l	
Water natural origin	164.05	115.73	163.00	86.41	l	
Electric Consumption						*from producer*
Electricity company	–	–	0.23	–	kW*h	
Solar energy	0.008	–	–	–	kW*h	
Fossil fuels consumption						*from producer*
Gasoline for machinery	0.11	0.18	0.04	0.04	l	
Diesel for transport	–	0.01	–	0.007	l	
CO_2 uptake	24548.82	23413.74	12194.81	11637.80	g	(Mesa, 2015; Nemeth et al., 2017)
Plastic consumption						*from producer*
Polylactic acid (PAL)	–	27.77	–	–	g	
LDPE plastic	0.02	–	–	–	g	
RPET plastic	25.86	–	1.44	–	g	
PP plastic	7.19	–	–	–	g	
PVC plastic	2.25	–	–	–	g	
Paper consumption						*from producer*
Kraft paper	0.22	–	–	–	g	
Cardboard	62.74	–	–	–	g	
Fertilisers consumption						*from producer*
Total nitrogen (N)	11.61	11.07	0.20	4.02	g	
Water soluble potassium oxide (K_2O)	11.80	11.25	0.68	4.64	g	
Potassium carbonate (K_2CO_3)	–	–	4.10	–	g	
Sulphur trioxide (SO_3) soluble in water	19.84	18.92	–	–	g	
Phosphorous pentoxide (P_2O_5)	2.50	2.39	–	5.99	g	
Total organic matter (TOC)	93.20	101.07	16.03	338.02	g	
Calcium oxide (CaO)	8.94	8.52	0.56	–	g	
Acetic acid	55.89	53.30	–	–	g	
Amino acids	–	–	1.09	–	g	
Humic acids	–	–	2.04	0.52	g	
Fulvic acids	–	–	3.07	0.79	g	
Sulphur (S)	–	–	–	5.22	g	
PRINCIPAL OUTPUTS OF THE SYSTEMS						
SUBSYSTEM	P1	P2	P3	P4	UNITS	Reference
Waste water	5.95	0.18	3.21	1.72	l	*from producer*
Incineration emissions to air						*(SINAMBA, 2009)*
Methane (CH_4)	1.60	0.03	–	–	g	
Carbon monoxide (CO)	33.63	0.62	–	–	g	
Dinitrogen monoxide (N_2O)	0.04	0.001	–	–	g	
Nitrogen oxides (NO_x)	1.54	0.03	–	–	g	
Sulphur oxides (SO_x)	0.38	0.007	–	–	g	
NMVOC	5.04	0.09	–	–	g	
Ethane (C_2H_6)	1.68	0.03	–	–	g	
Butane (C_4H_{10})	1.68	0.03	–	–	g	
Propane (C_3H_8)	1.68	0.03	–	–	g	
Ammonia (NH_3)	0.43	0.008	–	–	g	
Carbon dioxide (CO_2)	857.84	15.79	–	–	g	
Fossil fuel emissions to air						*(MITECO, 2019; Reşitoglu and Altinişik, 2015; Waldron et al., 2006)*
Carbon dioxide (CO_2)	242.70	405.72	91.25	106.59	g	
Methane (CH_4)	0.12	0.18	0.04	0.04	g	
Dinitrogen monoxide (N_2O)	0.01	0.02	0.004	0.005	g	
Carbon monoxide (CO)	7.29	11.40	2.74	2.71	g	
Hydrocarbons (HC)	1.19	1.98	0.45	0.52	g	
Nitrogen oxides (NO_x)	1.13	2.12	0.42	0.65	g	
Sulphur oxides (SO_x)	–	0.10	–	0.06	g	
Nitrogen (N_2)	609.20	1048.05	229.06	286.19	g	
Water (H_2O)	50.75	89.55	19.08	82.04	g	
Oxygen (O_2)	6.86	19.29	2.58	7.92	g	
Fertiliser emissions to soil						*(INIA, 2013)*
Total nitrogen (N)	2.32	2.21	0.04	0.80	g	
Phosphorous pentoxide (P_2O_5)	0.50	0.48	–	1.20	g	
Calcium	1.79	1.70	2.21	–	g	
Potassium	1.28	1.87	0.11	0.77	g	
Sulphur (SO_2)	–	–	–	0.83	g	
Fertiliser emissions to air						*(Aalde et al., 2006; Lasco et al., 2006; MITECO, 2012)*
Ammonia (NH_3)	1.04	0.99	0.02	0.36	g	
Nitrogen dioxide (NO_2)	0.11	0.11	0.002	0.04	g	
Dinitrogen monoxide (N_2O)	0.10	0.11	0.004	0.04	g	
Composting emissions to air						*(MITECO, 2012)*
Methane (CH_4)	0.79	1.00	3.33	6.76	g	

(*continued on next page*)

Table 2 (*continued*)

PRINCIPAL INPUTS OF THE SYSTEMS						
SUBSYSTEM	P1	P2	P3	P4	UNITS	Source
Dinitrogen monoxide (N_2O)	0.05	0.06	0.20	0.41	g	
Ammonia (NH_3)	0.05	0.06	0.20	0.41	g	
Solid wastes						*from producer*
Waste to landfill	2.38	0.89	0.000	3.10	g	
Plastic wastes						*from producer*
HDPE plastic to recycling	11.53	–	0.61	–	g	
PET plastic to recycling	0.24	–	–	–	g	
Paper wastes						*from producer*
Paper waste to recycling	7.62	–	–	–	g	

obtained electricity from its own solar panels, in case of P3 electricity was supplied by an external company, and P2 and P4 did not use electricity. The mulch was usually a low density polyethylene plastic film (PEBD), except for P2, which employed polylactic acid (PAL). Polyethylene plastic has a lifetime of about ten years, whereas polylactic acid is a biodegradable organic plastic and its lifetime is significantly shorter, five years.

All producers apply different commercial organic and conventional fertilisers. Pesticides were not used to eliminate plugs in any case. Fertilisers were included in the analysis by means of calculating active ingredients of each product (Mohamad et al., 2014). Emissions to land derived from fertilisation have been included considering that 20% the any applied product leachates to the soil (INIA, 2013). Emissions from fertiliser to the atmosphere (NH_3, NO_2 and N_2O) were estimated following the methods employed by the Intergovernmental Panel on Climate Change (IPCC) and Ministry of Agriculture, Fisheries and Food (MAPA) of Spain. The emissions have been calculated employing the emissions factors established 0.09, 0.003 and 0.1 for NH_3, NO_2 and N_2O, respectively (Aalde et al., 2006; Lasco et al., 2006; MITECO, 2012).

All growers harvested and pruned manually. Different tools and machines were employed in orchards, as mowers or mulchers and none of the producers employed tractors or heavy machinery. Emissions derived from fossil fuels consumption on clearing processes and transport *in situ* were included considering IPCC and national inventory (MITECO, 2019; Waldron et al., 2006) and secondary emissions (N_2, CO, NO_x, SO_x and hydrocarbons) were estimated according to (Reşitoglu and Altinişik, 2015).

Compost emissions came from the *in situ* decomposition of vegetal waste from the weed removal during street cleaning and from the management of organic wastes. It was considered that 100% of organic waste was degraded. Compost emissions were calculated considering that 1 kg of wet treated waste emits 4 g CH_4, 0.24 g of NO_2 and 0.24 g of NH_3 (MITECO, 2012). It is remarkable that 50% of farmers incinerated the pruning wastes, which entails the emission of different gases to the atmosphere. Incineration emissions were determined employing the methodology described by the Regional Government of Andalusia (SINAMBA, 2009). Pruning and vegetable waste data were estimated following related studies (Espa et al., 2017; Maticorena Quispe, 2017). Organic matter added to soil from composting/decompose *in situ* was also taken in consideration. It was calculated considering that 60% of organic matter is humidity, and 50% of dry matter is assimilated to the substrate. This nutritional contribution would represent between 50% and 96% of total organic matter added to soil by farmers (MITECO, 2006).

The CO_2 uptake was calculated considering the Brigitta and Elliot's CO_2 uptake rate and Sharpblue's leaf surface (Mesa, 2015; Nemeth et al., 2017). The CO_2 uptake by plants contributes to plants and fruits growth (the carbon removed by pruning was taken into account by considering the management of this waste). Carbon uptake was calculated by Sharpblue's area (1.82 m^2) and Brigitta's net photosynthetic capacitation rate (8 $\mu mol/m^2$*s) for a full productivity year.

2.2.3. Impact assessment

Environmental impacts were obtained from inventory data using Simapro 8.1.3 software (Pré-Consultants, 2010). The methods selected for the quantification of environmental impacts were ReCiPe 2016 Midpoint (H) V1.01/Characterization and ReCiPe 2016 Endpoint (H) V1.01/Damage assessment. Ecoinvent 3.4 and Agri-footprint version 4.0 databases have been employed. Based on Midpoint (H) method, 18 categories of environmental impact were stablished, i.e., global warning (GW), stratospheric ozone depletion (SOD), ionizing radiation (IR), ozone formation human health (OFHH), fine particular matter formation (FPMF), ozone formation terrestrial ecosystems (OFTE), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TEC), freshwater ecotoxicity (FEC), marine ecotoxicity (MEC), human carcinogenic toxicity (HCT), human non-carcinogenic toxicity (HNCT), land use (LUC), mineral resource scarcity (MRS), fossil resource scarcity (FRS) and water consumption (WC). Endpoint (H) method reflects environmental impacts at the end of the chain employing three categories: human health (HH), ecosystems quality (EC) and resources depletion (RD) (Huijbregts et al., 2016).

2.3. Carbon footprint (CF)

Carbon footprint was determined by using the Greenhouse Gas Protocol (GHG) V.1.02, and the Ecoinvent 3.4 and Agri-footprint version 4.0 databases, available in Simapro 8.1.3 software. GHG Protocol method allows calculation of fossil CO_2eq. (from combustion of fossil resources), biogenic CO_2eq. (from biological sources), CO_2 eq. from land transformation and CO_2 uptake. According to ISO 14067 indications, in this study, only fossil and biogenic CO_2 have been considered to obtain the CF value.

2.4. Alternative scenarios (improvement actions)

The simulation of alternative scenarios has been carried out to evaluate the effect of different improvement strategies. In the present study, one alternative scenario has been proposed for each orchard based on information obtained from the LCA.

3. Results and discussion

3.1. Environmental performance of blueberry production systems

Contribution analysis based on the Midpoint characterization results, when the environmental behaviour of four blueberries crops was analysed by LCA, are shown in Figs. 2–5. Tables S1, S2, S3 and S4 summarized the characterizations results in the units of each indicator. Despite the fact that all the crops had a similar blueberry production in the studied year (between 5.0 and 6.7 tons), some differences can be observed due to the employment of different management practices.

So, in P1, the most impactive subsystem was fertiliser production which affects noticeably almost all categories specially SOD, TEC and MRS with contributions higher than 70%. This is due to the production of fertilisers, which in this crops were used above the nutritional needs

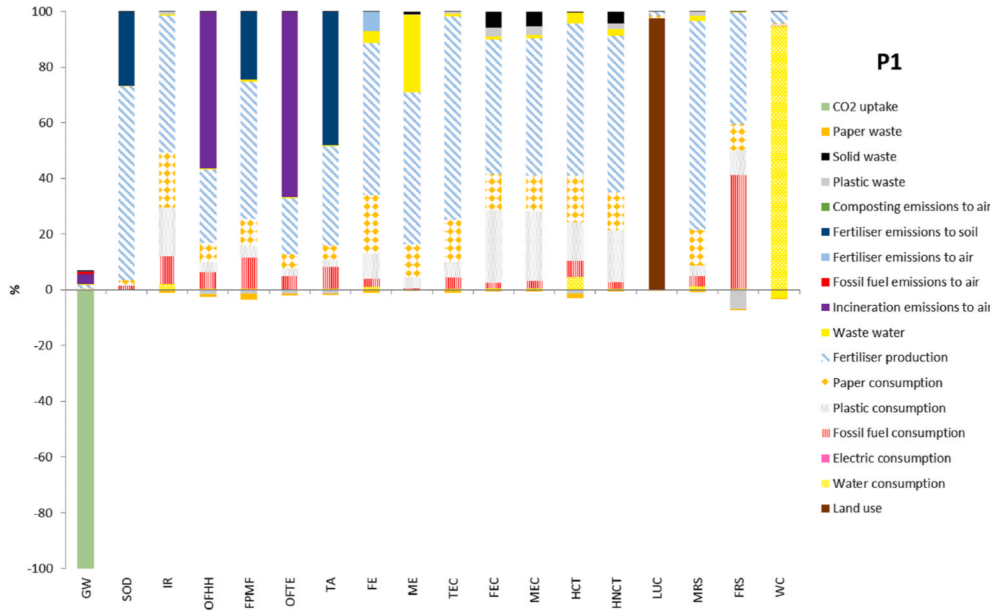

Fig. 2. Contribution analysis based on the characterization results obtained for the P1 system using Recipe Midpoint (H) method (FU: 1 kg blueberry).

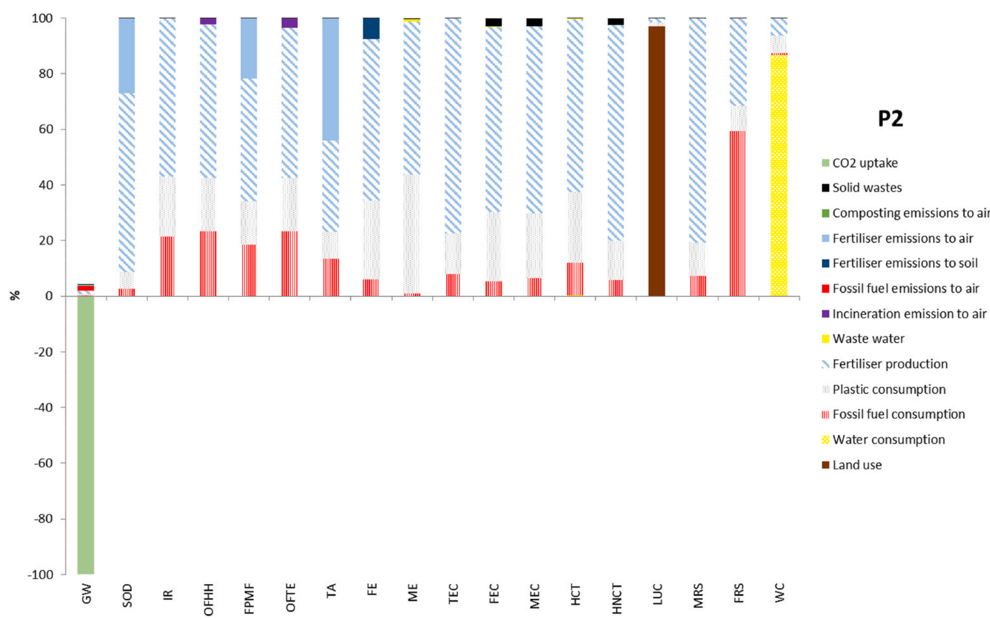

Fig. 3. Contribution analysis based on the characterization results obtained for the P2 using Recipe Midpoint (H) method (FU: 1 kg blueberry).

of the plant. Other important subsystems were fossil fuel, plastic and paper consumption and incineration. Fossil fuel consumption contributed 40% in FRS. P1 employed recycled box and cardboard, however plastic consumption and paper consumption still contributed above 20%, in several categories, i.e. IR and FE (paper consumption) and FEC and MEC (plastic consumption). Finally, the emission to air caused by incineration of pruning remains added important impacts to OFTE (68%) and OFHH (57%) categories.

In P2, the three subsystems that caused the greatest impacts in almost all categories were again fertiliser production, plastic consumption and fossil fuel consumption. The plastic used in P2 was polylactic acid (PAL) and, although it is a biodegradable organic plastic, it requires being removed every five years and, its production contributed above 20% to the IR, FE, ME, FEC, MEC and HCT categories. In this farm, fossil fuels consumption and derived emissions were caused firstly by the elevate consumption of fuel for clearing practices, and secondly, by using fuel vehicles to transport products and materials between parcels.

The principal remarkable impact in P3 was electric consumption with contributed above 60% in most categories. Other subsystems such as waste water, land use, fossil fuel consumption and water consumption were important for ME, LUC, FRS and WC categories, respectively. It should be noted that composting *in situ* of pruning remains only caused negative impact on GW, with a small contribution (32%) with respect to the total negative impacts.

Finally, the subsystems more harmful in P4 were similar to P1 and P2, being fertilisers consumption the most important. Fossil fuel consumption was the main burden for FRS category. In this crop, solid waste management contributed in more than 20% in the FEC, MEC and HNCT categories. This is due to the fact that P4 did not separate the waste for its subsequent deposit in recycling containers, but instead sent them to landfill.

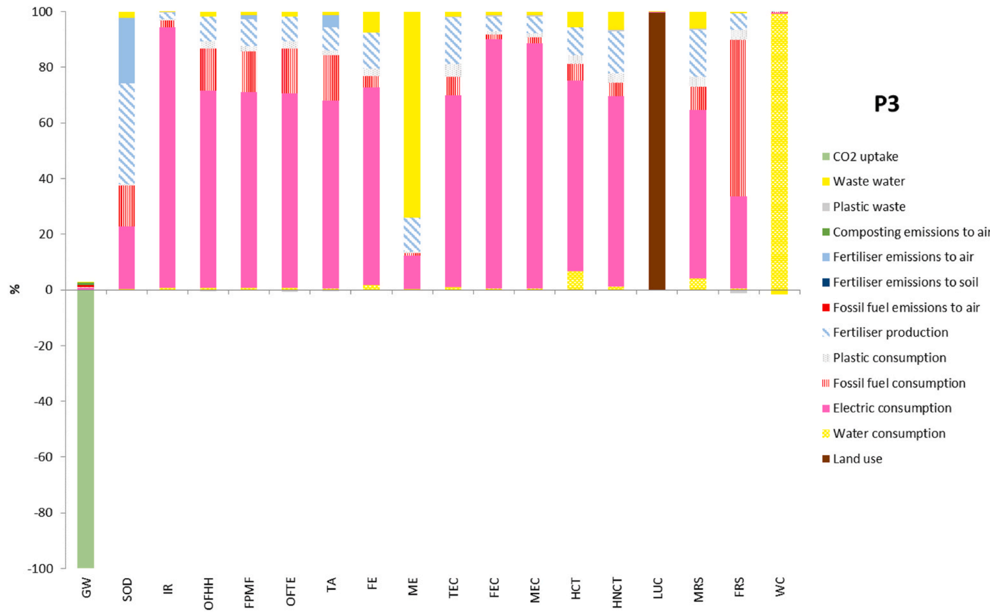

Fig. 4. Contribution analysis based on the characterization results obtained for the P3 system using Recipe Midpoint (H) method (FU: 1 kg blueberry).

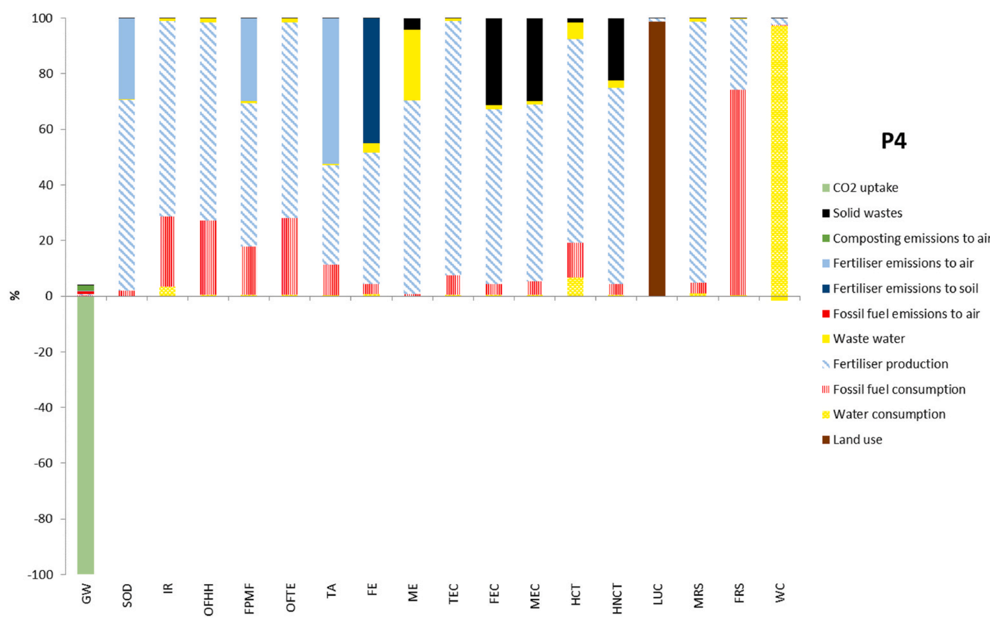

Fig. 5. Contribution analysis based on the characterization results obtained for the P4 system using Recipe Midpoint (H) method (FU: 1 kg blueberry).

It should be noted that in all crops, the subsystems CO_2 uptake exerted a beneficial contribution on GW category due to the plants growth and fruit production. However, this contribution is not taken into account for the calculation of the CF according to ISO 14062 indications.

Fig. 6 compares the environmental impacts related to the production of blueberry in each orchard showing important differences in most categories. P1 resulted to be the most pollutant in 12 out of 18 categories (OFHH, OFTE, FE, ME, TEC, FEC, MEC, HCT, HNCT, LUC, MRS, WC). This is due to the high consumption of fertilisers, the emissions derived from the incineration of pruning remains and the lower productivity per land surface. P2 was the most harmful in four categories (SOD, FPMF, TA, FRS) with impacts slight higher than P1. This is due to the high fertilisers consumption together with the high fossil fuel consumption. P3 and P4 were the environmentally less harmful orchards. P3 was the most pollutant only in the category IR, due to the higher electricity consumption. The better environmental behaviour observed in P3 and P4 was due to several factors. Firstly, the higher productivity, and, secondly, beneficial management practices, i.e. adjusting fertilisation to plants necessities, less consumption of fossil fuels and composting of organic wastes (prune).

Fertilisers were responsible for the main environmental impact in P1, P2 and P4, although not in P3. In this last case, only two type of commercial products were used for fertilising, far away from the eleven commercial products used in P1. In addition, the amount of fertilisers used in P3 and P4 were lower, more adjusted to the necessities of the plants, without any decrease of the productivity, which is even higher than in P1 and P2. Application and consumption of fertilisers affected principally in eutrophication (FE, ME), ecotoxicity (TEC, FEC, MEC) and MRS. The principal emissions to air by fertilisation come from nitrogenous compounds that interact with soil components forming ammonia

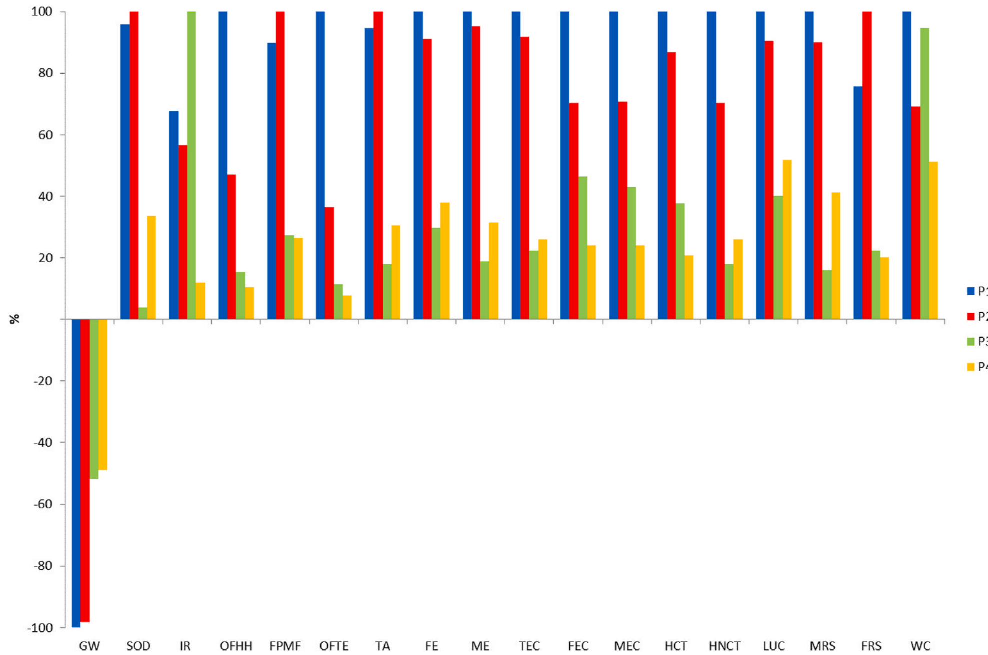

Fig. 6. Comparison of characterization results obtained for different systems using Recipe Midpoint (H) method (FU: 1 kg blueberry).

(NH_3), nitrogen dioxide (NO_2) and dinitrogen monoxide (N_2O). Fertiliser emissions to soil of N, P, K are influenced by lixiviation process. The GHG emissions from the fertilisers are mainly driven by the energy used for production of commercial organic fertilisers, as reported by Cordes et al. (2016). Finally, it should be pointed out that the use of ecological fertilisers (P1, P2, P3) or chemical fertilisers (P4) did not reveal notable differences in the LCA results. This can be due to the fact that ecological and conventional fertilizers used in these orchards do no differ much in their chemical composition. Moreover, both kinds are rich in nitrogenous compounds, which usually entails a large contribution to environmental impacts (Xaing et al., 2007), so that the effect of these nitrogenous compounds could mask small differences in LCA originated by other chemical ingredients.

The consumption of fossil fuels appeared as a significant output because the crops studied used gasoline for clearing processes. The amount of fossil fuel employed in the crops was between 0.04 and 0.19 L per FU. These data are slight higher than those obtained by Nikkhah et al. (2016), who concluded that the amount of diesel fuel to produce 1 kg of tea was 0.03 L, and Pishgar-Komleh et al. (2011), who reported 0.025 L of gasoline and diesel fuel to produce 1 kg of rice. Pishgar indicated that diesel was mainly used for machinery operations and tractors, as occur in the present study. Asturian organic and conventional crops were characterized by tilling, pruning and harvesting manually, restricting fossil fuel use to brushcutting machinery and transport. Its consumption influenced all studied categories, more significantly for FRS. This is in line with Mohamad et al. (2014), who reported that soil management, in organic crops, required more frequent use of machines to tillage because is forbidden the use of chemical herbicides, which contributed to all impact categories, particularly to fossil fuel depletion.

Management of vegetable waste could be classified as a priority in Asturian blueberry orchards. Only two crops (P1 and P2) incinerated pruning waste. Incineration of pruning was the cause that made P1 to have the highest impacts in OFHH and OFTE. Total emissions from incineration were 905 g and 16 g per FU per year in P1 and P2, respectively. Incineration impact in P2 was not so significant because it burnt only 250 kg of wastes per year and composted 250 kg per year. P1 and P2 employed 35 g and 27 g of plastic materials per FU, respectively. On P1, recycled plastic materials were used in direct or on-line sale packaging. As already mentioned previously, P2 plastic consumption came from biodegradable organic plastic replacement. P3 and P4 sell almost all their productions to cooperative marketing, not directly to consumer. Moreover, plants' ridges were covered with PP mulching, which has a useful life of 5–10 years. Both strategies reduced significantly plastic use on P3 and P4 crops.

It is remarkable the higher positive environmental impact of CO_2 uptake on P1 and P2. Our study found significant differences in the amount of pruning waste generated in each orchard, values of 0.99 kg in P1, 0.08 kg in P2, 1.24 kg in P3 and 1.10 kg in P4 per plant and year. So, P1 and P2 pruned less that other crops, thus increasing the carbon stocks in the living biomass above ground and under the soil as a result of growth. These means a greater CO_2 uptake, less composting emissions and a positive effect on LCA analysis.

3.2. *Carbon footprint of blueberry*

Fig. 7 shows the comparison between CF values obtained for the four orchards analysed. They have been calculated considering fossil and biogenic CO_2-eq emissions, based on ISO 14067, so CO_2 uptake by plants, which appears on Figs. 2–5, has not been taken into account for CF calculation.

Results regarding CF values obtained in this work have been compared to those found in literature. Most CF values reported in literature for berries are between 0.20 and 0.80 kg CO_2-eq. per kg of fruit (Cordes et al., 2016; Schein, 2012). CF values obtained in P3 and P4 are within this range (0.32 and 0.42 kg CO_2-eq/kg blueberry, respectively). However, higher values were obtained in P1 and P2 (1.66 and 0.93 kg CO_2-eq/kg blueberry, respectively). The studies carried out in Chile (Cordes et al., 2016; Rebolledo-Leiva et al., 2017) found that blueberry CF varied from 0.23 to 1.22 kg CO_2-eq, similar to Asturian results. Clune et al. (2017) obtained similar CFs for other berries, such as raspberries (0.84 kg CO_2-eq) or strawberries (0.50–1.50 kg CO_2-eq).

In our study, analysis of CF shows that there are three subsystems that significantly contributed to the total GHG emissions in all orchards: fertilisers consumption, fossil fuel emissions to soil and fossil fuel consumption. These results correspond with those identified by several authors, who reported that greenhouse gas emissions from vegetables and fruit were caused by fertiliser production, nitrogen emissions from soils after N-fertiliser, energy consumption and fuel consumption

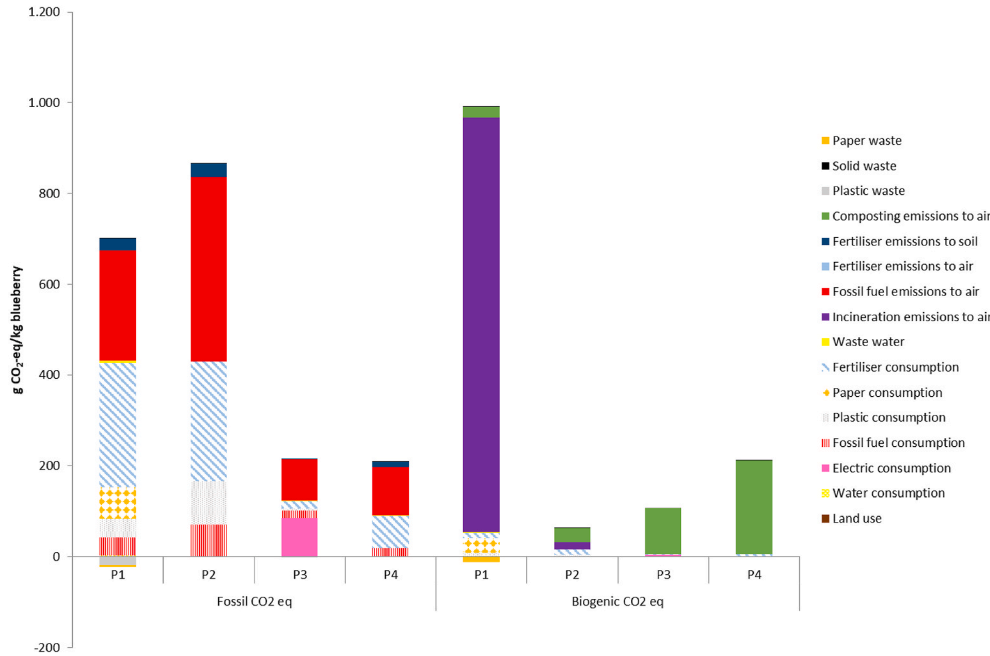

Fig. 7. Comparison of carbon footprint obtained for the different systems using Greenhouse Gas Protocol (FU: 1 kg blueberry).

(Cerutti et al., 2014; Girgenti et al., 2013; Ingrao et al., 2015; Keyes et al., 2015; Maraseni et al., 2010; Meier et al., 2015; Nikkhah et al., 2016). The principal negative environmental impacts detected by these authors were organic fertilisers (from 43% to 56% of contributions) and energy use for field operations (from 35% to 43% of contributions) such as clearing or harvesting fruits. Results obtained in the present work indicated that the contribution of fertilisers emissions to environmental impacts are not very important in any of the systems studied. Additionally, it is observed that composting emissions contributed to CF in all cases, especially in P3 and P4.

In the case here analysed, fertiliser application to the land varied between 1 and 31 kg N, 22 and 44 kg K_2O and 6 and 29 kg P_2O_5 per hectare and year. These wide ranges can be explained because of the different topography and nutritional properties of the soil. Agricultural Research and Development Regional Service (SERIDA) recommendations for Asturian orchards in full production are a total fertiliser contribution of 90 kg N, 45 kg P_2O_5 and 90 kg K_2O per hectare and year, values quite higher than those employed in the case studies. International orchards reported contributions of 25–100 kg N, 0–67 kg P_2O_5 and 0–112 kg K_2O per hectare and year in conventional as well as organic systems, being essential considering the soil conditions. These ranges are in accordance with the amount of fertilises used in the crops analysed in this work (Jequier, 2015; Sebastián, 2010; Strik, 2016). Besides, In P1 is remarkable the high negative impact of incineration emissions to air caused by prune burning, with a contribution of 57% of GHG emissions. This subsystem appears in P2 with a contribution of only 1%. It is not surprising, if it is taken into account that P2 only burns 250 kg of pruning waste per year, far away from the 6000 kg burned in P1. In P2 and P3 the contributions of plastic consumption and electricity, respectively, are also important.

Fossil fuel consumption and the derived emissions to air are caused by the employment of gasoline for machinery and, in P2 and P4, diesel used for transportation within the crops. As can be observed in Table 2, fossil fuel consumption per FU varies greatly; for example, P2 consumed 0.19 l of gasoline and diesel compared to 0.04 and 0.05 l employed by P3 and P4, respectively. The fossil fuel emissions subsystem contributed to GHG emissions with percentages that range from 15% to 56% due to the carbon dioxide released and in less extent to methane and dinitrogen monoxide.

Fertiliser production, specially N, P, K-fertilisers, contributed to fossil and biogenic emissions, with ranges from 5% to 28%. P1 and P2 had a similar fertiliser production, approximately 147 g and 153 g per FU, respectively. In both cases, an excess of fertilisers was applied to the crops. On the other hand, in P3, this subsystem only contributed 5% to the CF. This producer only consumed two types of commercial organic fertilisers and incorporated organic matter from pruned composting.

As can be observed on Table 1, the amount of vegetable waste produced varied significantly between orchards, from 1.5 to 14 ton. Composting emissions, were caused by degradation of brushcutting, pruning and plants replaced *in situ*. In P3 and P4, methane, dinitrogen monoxide and ammonia emissions had a similar contribution to the CF, above 30%, far way, 1% and 3% found in P1 and P2, respectively.

It is noteworthy that from an environmental perspective, it was not observed any differences between the organic orchards and the conventional one. In fact, the crop without organic certification (P4) showed the second lower CF, with a general better environmental behaviour than P1 and P2 (both organic certificated).

According to FAO. Good agricultural practices (GAP) are "*practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products*" (FAO, 2003). So, it has been found that the use of these GAP according to FAO has greater influence on the environmental impacts derived from blueberry production than the organic certification itself. Indeed, GAP include different aspects food safety, protecting the environment and soil and the health, safety and welfare of citizens. In this context, European Commission has defined a list of agricultural practices to protect the environment, such as reducing the use of chemical pesticides and fertilisers and avoiding the deterioration of soil fertility (Europena Commission, 2021b; FAO, 2016). This is consistent with Meier et al. (2015) and Milà i Canals (2003), who concluded that using LCA it was not possible to obtain conclusive differences between, the general environmental performance of conventional and organic agricultural products.

3.3. Improvement opportunities

LCA and CF results indicated that P1 was the most pollutant orchard due to the incineration of pruning wastes, whereas the least impacting orchards were P3 and P4, which employed good agricultural practices, controlled plant nutritional requirements and used composting to treat the vegetable wastes. Taken into account the most impacting subsystems in each orchard, viable improvements have been proposed and the alternative scenarios have been analysed. Table 3 shows the changes achieved in CF and each impact category considered for LCA. As a modification in the fertilization system could affect productivity and it cannot be changed without a deep analysis on soil and plants necessities, this subsystems, were kept unchanged in the alternative scenarios. Results obtained when these improvement proposals are implemented give idea of real environmental improvements that can be achieved in other similar orchards.

In P1, it was proposed to compost the pruning wastes instead of incinerate them. National Law 22/2011 of waste and contaminated soils (MMA, 2011) stablishes that burning must be carried out without endangering human health and without damaging the environment. European Commission in the European Green Deal prioritises other alternatives of waste management over incineration or landfill disposal. The circular economy action plan is one of the main aspects of this deal to maintain the value of resources, returning them into the production cycle at the end of their use (European Commission, 2020b). Actual research focus their efforts on valorisation of agricultural residues, which involves very diverse practices, for example, co-composting these wastes with sludge (Vico et al., 2018), employing them as substrates to obtain biofuel (Ţenu et al., 2021) and extracting phenolic compounds from them (Henriques et al., 2017), among others. Composting 6000 kg of vegetable waste would lead to a potential reduction of 765 g of CO_2-eq per kg of blueberry, which means a reduction of around 46% of blueberry CF. Additionally, the composting of pruning wastes would also reduce environmental impacts in the categories OFHH and OFTE.

Paradoxically the improvement suggested for P2 was the substitution of PAL plastic by polypropylene (PP) weed-proof mesh. PP mesh is a dense and resistant woven raffia that makes passage of water and air to soil but locks light passage preventing weeds from growing. It has an average duration much higher than PAL, between 5 and 25 years (for the alternative scenario, it was considered a duration of 10 years). It was found that CF moderately would decreased from 928 g to 839 g of CO_2-eq. In addition, the environmental impacts would have decreased in 17 categories, especially on ME, with a 42% reduction.

In P3 it has been considered installing a wind turbine for electricity generation instead of buying electricity in the open market. This alternative scenario would decrease CF from 321 g to 233 g of CO_2-eq per kg of blueberry. Besides, the harmful impacts would decrease in 15 of the 18 studied categories, especially in IR, FEC and MEC, with reductions above 85%.

Finally, it is difficult to propose any environmental measure for P4, because its environmental behaviour is already well above standard results. In order to reduce the fossil fuel consumption, it was proposed to change the conventional vehicle used within the crop by an electrical vehicle. In this new scenario fossil fuel emissions would be almost eliminated although electricity consumption increase. So, CF only would decrease from 422 g to 413 g of CO_2-eq per kg of blueberry. Impacts would also decrease slightly in FRS category (−8%). However, impact would increase on 13 categories, in low percentages, except for IR category that would increase 51%. In order to achieve a real environmental improvement, the use of electrical vehicle should go together with an increase of the renewable energy in the national electricity mix. As a member of the European Union, Spain is bound by EU targets for energy and climate change. One of its 2030 objectives is to achieve a 74% share of renewables in electricity generation (in 2019 was 38%) (European Commission, 2020c).

The environmental impacts associated to blueberry production has been also determined by Endpoint (H) method, which reflects the impacts in terms of damage to human health (HH), damage to ecosystems (EC) and of resource depletion (RD) (De Marco et al., 2018) (Fig. S1). Endpoint results revealed that the four orchards analysed had a similar environmental behaviour, with fossil fuel consumption, fertilizer production and land use systems being responsible of the greatest impacts. These impacts were notable, especially on resource depletion category and, in addition, P3 and P4 were the less pollutant crops regarding RD category. Again, in all cases, the beneficious effect of CO_2 uptake and

Table 3
Reductions achieved in each impact category and carbon footprint with the improvements proposed for each scenario.

	Improvement	GW[a]	SOD	IR	OFHH	FPMF	OFTE	TA	FE	ME	TEC	FEC	MEC	HCT	HNCT	LUC	MRS	FRS	WC	CF reduction
P1	*Composting*	3%	–	–	−58%	–	−68%	–	–	–	–	–	–	–	–	–	–	–	–	**−46%**
P2	*plastic PP*	–	−6%	−22%	−17%	−15%	−17%	−9%	−28%	−42%	−15%	−18%	−15%	−24%	−10%	−1%	−12%	−6%	−6%	**−10%**
P3	*wind turbine*	0.01%	−23%	−94%	−71%	−71%	−70%	−68%	−71%	−12%	−69%	−89%	−88%	−69%	−68%	–	−57%	−33%	–	**−28%**
P4	*electrical vehicle*	0.00%	–	51%	9%	6%	9%	3%	6%	1%	6%	19%	17%	13%	5%	–	2%	−8%	–	**−2%**

[a] *Although these results were positive, not represent harmful emissions to atmosphere. It denoted the opposite, a decrease on GHG emissions, which were compensated with CO_2 uptake.*

recycling processes should be remarked, in particular, on human health and ecosystems categories.

Comparing real and proposed improved scenarios at endpoint level, small differences were found in all the production systems analysed. A light improvement of alternative scenarios was observed on RD category for P3 and P4, which corresponds with reductions of environmental impacts of 4% and 2%, respectively. This small differences may be due to the fact that proposed improvements carried out on alternative scenarios (compost the pruning, substitution of PAL, green electricity generation and electrical vehicle use) did not involve the most impacting subsystems in endpoint analysis. On the contrary, and as it was commented above, Midpoint (H) methodology showed the beneficial effect of the improvements in many of the categories analysed, since midpoint method shows the impact earlier along the cause-effect chain before the endpoint impacts are reached. Hence, midpoint analysis could be very useful to take short-term decisions to improve the performance of blueberry production systems.

4. Conclusions

For blueberry orchards sited in the same Spanish region and with similar sizes have been analysed by LCA and some differences could be observed in the obtained results depending mainly on fertilisers consumption and waste management.

The environmental impacts associated with from fertilisers and fossil fuel consumption were important in the four blueberry crops analysed. In addition, it is remarkable the negative effect of incinerating pruning waste being much less impacting composting them. Other remarkable subsystems were plastic, paper and electric consumption.

The carbon footprint of the blueberries produced in the crops under study was between 0.32 kg and 1.66 kg of CO2-eq per kg blueberry produced. It must be pointed out that although the productivity was moderated (between 2500 and 6000 kg/ha), the CFs in the 75% of analysed orchards were in the range of other blueberry crops on literature (0.20 kg–1.22 kg CO2-eq per kg berry). Only P1 orchard was out of this range due to the incineration emissions. Curiously, the lowest CF was not associated with the highest productivity, but it seems to be more conditioned by the use of good environmental practises.

Based on LCA results viable improvement actions have been implemented on alternatives scenarios and CF values could be reduced between 2% and 46% in the four systems analysed. Taking into account results obtained, some recommendations can be given to improve the environmental behaviour of blueberry production at low scale. One of the good agricultural practices that could be employed to reduce environmental impacts is to control fertilisation input and replace chemical fertilisers by organic natural products i.e. (compost) by means of designing a fertilisation plan according to the plants' necessities. Secondly, emission to atmosphere could be reduced by eliminating on-site incineration, as a way of treating organic waste, and substituting it by composting. A significant reduction of fossil fuel consumption and emissions could be possible via the substitution of conventional machinery for electrical. Replacing the electrical production system by "clean" energy (solar panels, wind turbine, etc.) is also recommendable. Finally, packaging materials should be reduced as possible and recycled materials should be used.

This work provides information about the environmental behaviour of blueberry production at low scale, very little studied before. It proves that low size orchards and moderate productivities are compatible with low environmental impacts, provided that friendly agricultural practices are employed. LCA methodology may be used to support policy and decision-making for the implementation of sustainable practices in order to lead to a more sustainable crops production.

CRediT authorship contribution statement

Reina Pérez: Investigation, Formal analysis, Writing – original draft. **Amanda Laca:** Methodology, Conceptualization, Writing – review & editing. **Adriana Laca:** Conceptualization, Data curation, Writing – review & editing. **Mario Díaz:** Funding acquisition, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.130594.

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