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ENVIRONMENTAL PERFORMANCE OF SEMI-CONFINEMENT AND PASTURE-BASED SYSTEMS FOR DAIRY COWS

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Abstract

Two dairy farms (one a semi-confinement system and the other a pasture-based system) in the same region of Spain were chosen for comparison from a life cycle assessment perspective. In both cases, cattle feeding was found to be the main contributor to environmental impact in most categories. Additionally, cow emissions to air were the principal contribution to the global warming, fine particulate matter formation and terrestrial acidification categories. Although cow productivity in the pasture-based farm was almost half that obtained in the semi-confinement farm, the impact per 1 kg_{FPCM} in the pasture-based system was notably lower in 12 of the 18 categories analysed, mainly due to the fact that the relative amount of milk and surplus calves and culled cows sold for meat production was higher in the pasture-based farm. Finally, it should be noted that given the scarcity and variability of the data found in the literature, this LCA study contributes much needed knowledge about the effect of the degree of confinement of cows on the environmental impact of milk production.

Key words: environmental impacts, LCA, milk, pasture dairy, semi-confinement dairy

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1. Introduction

Food production is a key contributor to the environmental impact associated with consumption (Scherhaufer et al., 2018). In Europe, food sector is responsible for 20-30% of the domestic environmental impact (Palmieri et al., 2017) and agricultural processes such as livestock farming make a major contribution (Scherhaufer et al., 2018).

Milk and other dairy products are consumed in large amounts in most developed countries and the volume of the dairy market is rapidly increasing in other low- and middle-income countries (Röös et al., 2016). Worldwide, annual consumption of dairy products currently averages 87 kg per person (fresh milk equivalent basis). Additionally, demand for dairy products will grow during the next 50 years; indeed, it is expected to increase to 119 kg per person by 2067 (Britt et al., 2017). In this situation, farmers not only face uncertainty about future policies and market developments; they also face the contradictory demands of increasing food production to feed the rising world population, while having to reduce the environmental impact derived from intensive farming (Darnhofer et al., 2015). Evidence shows that current food production systems are unsustainable in several ways and need substantial improvements. Compared to several plant-based alternatives, such as soy drink or rice drink, which can be considered to be functionally equivalent, cow's milk production has a greater effect on climate change (Röös et al., 2016).

Although confined systems usually achieve higher milk yields per cow than pasture-based systems, the latter have been adopted by dairy farmers worldwide due to the low costs of this feeding strategy. Nevertheless, considering the current emphasis on minimising the environmental impact of food production, an analysis is required to quantify the

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effect of pasture-based and confinement dairy production systems on the environment (O'Brien et al., 2012).

Life cycle assessment (LCA) is an ISO standardized method (ISO 14040-14044) defined as a technique for assessing environmental aspects and potential impacts associated with a product or service (Calderón et al., 2010; Laca et al., 2011; Iglesias et al., 2012). It has been demonstrated to be a convenient method for quantifying resource use and emissions in a wide range of primary and industrial sectors (Abín et al., 2018; Calderón et al., 2018; Canellada et al., 2018; Hospido et al., 2003; Vázquez-Rowe et al., 2012). In agricultural and food systems, LCA has proved to be a valuable tool for mitigating environmental impact through the adoption of corrective measures along the food chain, from the production phase to consumption (Tecco et al., 2016).

Recently, Noya et al. (2018) have stated that although several LCA studies about dairy products have been published to date, few of these have focussed on Spanish milk production. Additionally, despite it being well known that the farming system is a determining parameter for the environmental performance of dairy farms (Rojas-Downing et al., 2017), few studies have analysed dairy farms with pasture-based systems (Chobtang et al., 2016). Moreover, only a small number of studies have been published comparing pasture-based and confinement-based dairy systems (Aguirre-Villegas et al., 2017; Arnott et al., 2015; Belflower et al., 2012; Flysjö et al., 2011) and none of these in Spain. Consequently, this research has been carried out with two main objectives, firstly to add to the existing knowledge about the environmental impact of milk production in Spain and, hence, in Europe, and, secondly, to compare two contrasting milk production systems.

2. Material and methods

Two dairy farms in the same region of Spain have been selected as study cases, one with a production system typical of this region (a semi-confinement system) and the other with a pasture-based system. In each case, a detailed inventory has been obtained and it has been analysed by means of LCA in order to establish conclusions.

2.1. LCA

2.1.1. Objectives and functional unit definition

LCA methodology was employed with the aim of determining the environmental impacts of the dairy farms selected as being representative of two different milk production systems. In both cases, the functional unit was defined as 1 kg of fat- and protein-corrected milk (FPCM), calculated according to the recommendations of the International Dairy Federation (IDF, 2015).

2.1.2. System description and boundaries

The farms were in Northern Spain (Asturias), this region is under maritime climate, which is a template climate characterised by abundant precipitation year-round. Dairy farms in this area are usually semi-confinement systems of small/medium size, and usually have less than a hundred animals. The environmental assessment of both farms was carried out considering a "cradle to dairy gate" perspective.

In the semi-confinement farm, cows were housed in a stall and fed with fodder concentrate, alfalfa, hay, maize silage and meadow grass silage early in the morning and in the late afternoon. When the weather was warm (May-October), at midday, animals were allowed to graze freely on grass fields during 4 hours. At the moment of the study, the farm consisted of 48 Holstein dairy cows and 24 heifers and calves. During the year of the study, the production of milk was 365,000 L and 21 male calves and 7 culled cows were sold for slaughter (a total of 5355 kg live weight per year). The system considered included the whole life cycle involved in the production of the raw milk, i.e., farming of meadow grass silage and maize, transport and production of raw materials, consumption of energy and water, cow and diesel emissions to air and manure, slurry and wastewater management. The farm had a total of 30.45 Ha of land for farming (4.61 Ha for maize, 9.64 Ha for grass and 16.20 for other forages). Manure and slurry were employed as fertiliser, while wastewaters were used to irrigate the fields and the crops of the farm.

On the pasture-based farm, cows were left to graze freely on grass fields during the warm months of the year (May-October), whereas during the cold months (November-April) they were housed in a stall and fed fodder concentrate, maize and hay. At the moment of the study, the farm consisted of 1 Jersey and 10 Holstein dairy cows and 2 calves. During the year of the study the production of milk was 40,730 L; 6 male calves and 3 culled cows were sold for slaughter (a total of 2068 kg live weight per year), whereas 2 dead calves were managed as dangerous wastes for incineration. The system considered included farming of maize, transport and production of raw materials, consumption of energy and water, gas emissions and manure, slurry and wastewater management. The farm also had a total of 14 Ha of land for farming (2 Ha for maize and 12 Ha for grazing). Manure and slurry were employed as fertiliser, whereas wastewater was treated as municipal wastewater.

2.1.3. Inventory analysis

In both systems, values corresponding to one year of production were employed. Data were mainly collected through personal interviews with farmers. Questions were designed to obtain precise information about cropping systems and field operations, fuel consumption, number of animals and housing systems, manure storage and animal feed rations. In addition, data regarding the inputs entering the farms were acquired, including the amounts of purchased feeds and bedding materials and finally, some information was supplied by expert veterinarians or was obtained from bibliographic sources.

The following considerations were taken into account for the inventory analyses in the semi-confinement farm. In the case of animal feed, only those materials that exceeded 0.5 kg per cow per day were included in the inventory. Additionally, for the fodder concentrate, only the production of ingredients that contributed 12% or more to the total content was considered. As part of the cow feed was produced *in situ* on the farm, only the transport of the purchased feed materials was included in the analysis. Transport of other products (i.e. milk or bull calves) was not considered. Any cleaning agents that amounted to less than 12% of the total cleaning products used were disregarded. Municipal solid wastes were not taken into account in the analysis as their quantity was insignificant compared to the amount of manure. Manure and slurry were applied to the farming land. Additionally, wastewaters were employed for irrigation and so did not enter the municipal sewerage system. With regards to drugs, only propylene glycol was taken into consideration, since the amounts of other medicinal substances used on the farm were insignificant. On the farm using the pasture-based system, similar considerations were taken into account, with small differences that are detailed as follows. In this case the water consumed came from the municipal water supply system and also from a well. Wastewater was treated as municipal wastewater. The amounts of drugs and bedding material employed in this case were considered as negligible. Although municipal solid wastes were disregarded for the same reason mentioned above for the semi-confinement farm and manure and slurry were also applied to the farming land, 2 dead calves were included in the analysis as wastes for incineration, since they are considered as dangerous residues and had to be be managed in this way. An overview of the main characteristics of both systems is shown in Table 1.

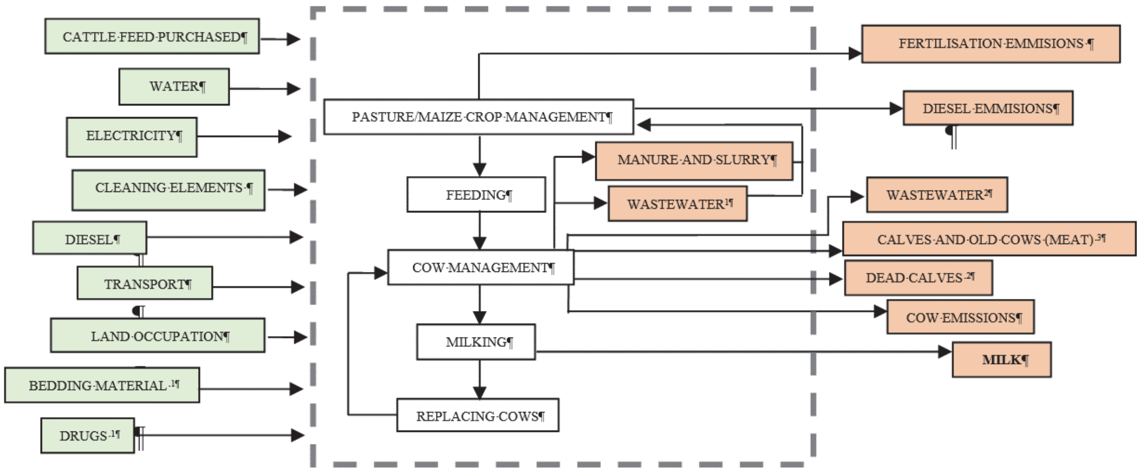
For the two systems assessed, the following assumptions should be mentioned. The crops grown on the farms were not considered in the feed subsystem, but they were included in the inventory as "land occupation". The consumption of diesel included the fuel employed in farm activities such as sowing and irrigation. Emissions of CO_2, CH_4 and N_2O, derived from diesel combustion were included, using the values reported for agricultural vehicles in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), whereas carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM) were calculated according to the maximum emissions established in the Euro standards of the European Union for heavy-duty vehicles as defined in Directive 70/156/EC (Reşitoğlu et al., 2015). According to the Technological Institute of Renewable Energies of Spain, each bovine animal releases to air 6.05 kg of CO_2, 0.12 kg of CH_4 and 0.002 kg of NH_3 per day (ITER, 2008) and these values were used to calculate cow emissions to air. Manure and slurry were applied to the farming land, which avoided the use of commercial fertilizers.

However, this activity originated emissions to the air, mainly ammonia. One kg of milk cow slurry contains 3.08 g of nitrogen (Parera i Pous et al., 2010) and, according to Misselbrook et al. (2000), during and after manure and slurry application to agricultural land about 30% is emitted as ammonia to the atmosphere, so these data were employed to calculate fertilization emissions. Heifers born on the farm were employed for replacement, whereas bull calves and culled cows were sold for slaughter. Since the main activity of the farm is milk production, they were considered as a co-product.

Thus, the allocation factors for the dairy farms were calculated for milk as indicated by the International Dairy Federation (IDF, 2015) and values of 0.91 and 0.69 were obtained for semi-confinement and pasture-based systems, respectively. These allocation factors were employed to subsequently correct the inventory data. Inventory data have been organized into the subsystems shown in Fig. 1 and detailed in Tables 2 and 3.

Table 1. Summary of main characteristics of farm systems analyzed (average values per one year are shown)

Farm characteristics		***Semi-confinement***	***Pasture-based***
Livestock		48 milking cows (Holstein) 24 heifers and calves	11 milking cows (1 Jersey and 10 Holstein) 2 heifers and calves
Cow's diet	Feed purchased (t per animal and year)	Fodder concentrate (maize, soy, wheat, barley and sunflower seed) (2.28 t) Alfalfa (0.94 t) Maize silage (0.94 t) Hay (0.57 t)	Fodder concentrate (maize, soybean flour, barley, colza, wheat bran, cottonseed, beet pulp and calcium soaps) (0.75 t)
	Feed produced in situ	Meadow grass silage Maize silage Free grazing (sporadically)	Maize Hay Free grazing (May-October)
Farming land (Ha)		30.45	14
Productivity (t_{FPCM} per animal and year)		7.3	3.6
Manure and slurry (t per animal and year)		21.6	21.6



[1]Only for the semi-confinement system
[2]Only for the pasture-based system
[3]Considered in both systems to calculate the allocation factor for milk production.

Fig. 1. Boundaries of semi-confinement and pasture-based dairy systems

Table 2. Inventory data for the semi-confinement farm, expressed per functional unit (FU = 1 kg_{FPCM})

Inputs	
Cattle feed purchased (48% fodder concentrate (32% maize, 20% soy, 19% wheat, 16% barley, 13% sunflower oil), 20% alfalfa, 20% maize silage, 12% hay) (g)	648
Water (tap water) (L)	5.42
Electricity (Wh)	57.6
Diesel (production) (g)	8.64
Cleaning elements (62% sorbitol, 17% detergents, 13% NaOH, 8% phosphoric acid) (g)	0.926
Bedding material (85% sawdust, 15% straw) (g)	13.2
Drugs (propylene glycol) (g)	0.205
Transport by track (75% alfalfa, 15% maize, 10% hay) (kg.km)	108.2
Land occupation (85% pasture, 15% maize) (m^2.a)	0.79
Outputs	
Fertilization emissions (derived from the application to the farming land of manure and slurry) (ammonia) (g)	4.53
Cow emissions to air (98.03% CO_2, 1.94% CH_4, 0.03% NH_3) (g)	419.5
Diesel emissions to air (derived from diesel combustion) (99.1968% CO_2, 0.0057% CH_4, 0.0358% N_2O, 0.5591% CO, 0.0502% HC, 0.1487% NO_x, 0.0037% PM) (g)	27.9

Table 3. Inventory data for the pasture-based farm, expressed per functional unit (FU = 1 kg_{FPCM})

Inputs	
Cattle feed purchased (fodder concentrate (32% maize, 22% soybean flour, 17% barley, 10% colza, 7.3% beet pulp, 5% wheat bran, 4.4% cottonseed, 2.3% calcium soaps) (g)	207
Water (L) (82% well water, 18% tap water)	4.27
Electricity (Wh)	5.94
Diesel (production) (g)	10.04
Cleaning elements (52% NaOH, 43% NaClO, 5% HCl) (g)	0.362
Transport by track (kg.km)	4.55
Land occupation (83% pasture, 17% maize) (m^2.a)	2.07
Outputs	
Fertilisation emissions (derived from the application to the farming land of manure and slurry) (ammonia) (g)	5.45
Cow emissions to air (98.03% CO_2, 1.94% CH_4, 0.03% NH_3) (g)	504.8
Diesel emissions to air (derived from diesel combustion) (99.1973% CO_2, 0.0056% CH_4, 0.0370% N_2O, 0.5588% CO, 0.0494% HC, 0.1482% NO_x, 0.0037% PM) (g)	32.4
Dead calves (managed as dangerous wastes for incineration) (g)	1.55
Wastewater (for treatment) (L)	0.755

2.1.4. Impact assessment

Impact assessment of both systems was carried out with the LCA SimaPro v8 software package using the ReCiPe 2016 Midpoint (H) V1.01 method, which included 18 impact categories (global warming, stratospheric ozone depletion, ionizing radiation, ozone formation-human health, fine particulate matter formation, ozone formation-terrestrial ecosystems, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, mineral resource scarcity, fossil resource scarcity and water consumption) (Huijbregts et al., 2016).

The advantages of this method include (i) the broadest set of midpoint impact categories and (ii) the use of impact mechanisms that have global scope (Santos et al., 2017). The databases employed were USLCI and EcoInvent v3.

3. Results and discussion

3.1. Environmental performance of the semi-confinement system

In this system each cow produced 7308 kg_{FPCM}, which is a productivity slightly higher than that reported by Wang et al. (2018) for the North China Plain (7000 kg of FPCM per cow). In addition, when meat is considered as a co-product, the allocation factor was 0.91, a value similar to that reported by the International Dairy Federation (IDF, 2015) as a typical value for the allocation factor of milk when considering meat as a co-product (0.88).

Fig. 2 shows results obtained with the ReCiPe method, which revealed cow feeding as the factor with the highest environmental loads in almost all categories considered. Indeed, feed was responsible for more than 50% of the damaging impact in 13 of the 18 categories evaluated and more than 20% in the remaining 5 categories. Specifically, it contributed more than 90% of the environmental impact of the following categories: marine eutrophication, freshwater eutrophication, stratospheric ozone depletion, mineral resource scarcity and water consumption. When the contribution of cow feeding to the impacts is analyzed in detail, it is seen that fodder concentrate is the main culprit for the impact of this subsystem in all the analyzed categories, excepting terrestrial acidification. This is in accordance with results found in the literature and in fact, many studies focusing on the environmental aspects of dairy farming have concluded that the forage production stage is the main contributor to environmental pollution (Fathollahi et al., 2018). More specifically, the impact in land use originated by fodder concentrate was mainly due to the use of soy as an ingredient. In this context, Cesari et al. (2017) also reported soybean meal as the greatest contributor to the land use change subsystem when it was employed in the formulation of feeds for broilers, while Abín et al. (2018) found that the soybean used as an ingredient in laying hen fodder was responsible for almost 70% of the contribution of hen feeding to the natural land transformation category.

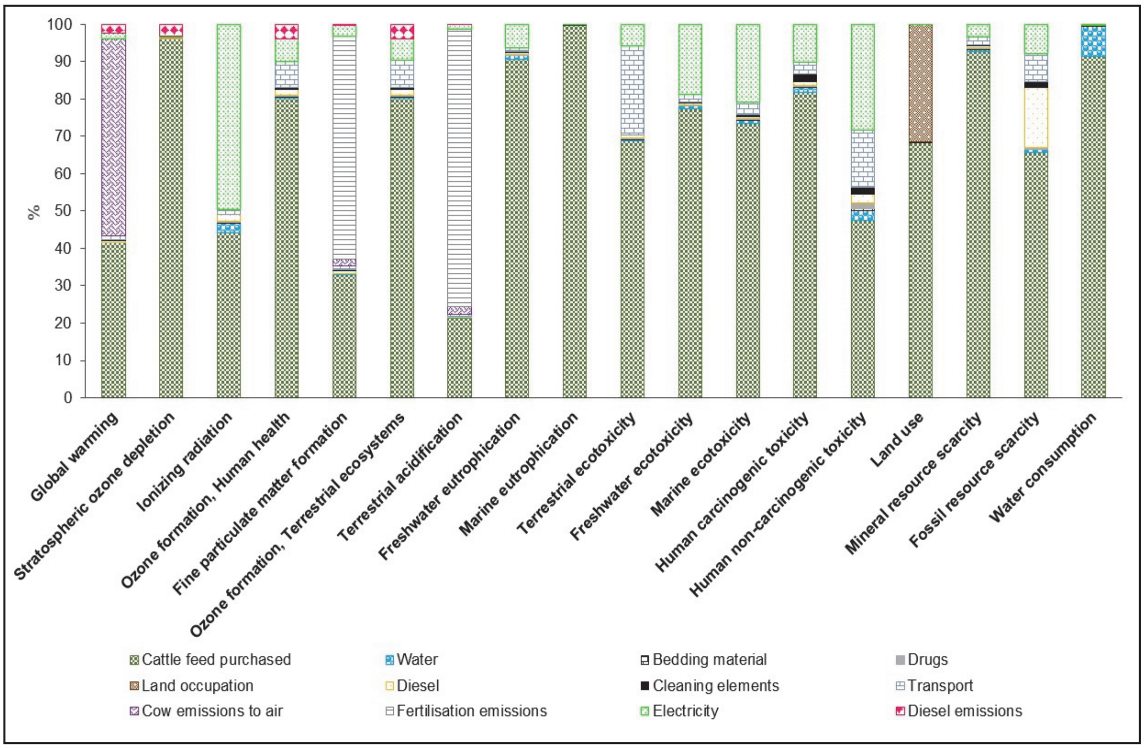


Fig. 2. Characterization results for a semi-confinement dairy farm obtained using ReCiPe Midpoint

Also noticeable is the harmful impact of direct cow emissions (mainly originated by enteric fermentation) on the climate change category (53%), which is easily understandable, since it is well known that CH_4 emissions are associated with extensive cattle production (de Oliveira and Bourscheidt, 2017; Coates et al., 2017). Additionally, emissions originated by the release of NH_3 to the air due to fertilization with manure and slurry were responsible for 74% and 60% of the harmful impact in the terrestrial acidification and the fine particulate matter formation categories. In agreement with results mentioned above, Noya et al. (2018) stated that animal feed production together with on-farm emissions were the main environmental hotspots in cradle-to-farm gate production of milk.

Other important subsystems that can be observed in Fig. 2 are detailed below. Electricity contributed 50% to ionising radiation. It must be remembered that in Spain nuclear energy is the second most important source of electricity (MINETUR, 2017) and the use of radioactive material within nuclear reactors generates additional ionising radiation. Electricity was also responsible for 28%, 21% and 19% of impact on human non-carcinogenic toxicity, marine ecotoxicity and freshwater ecotoxicity, respectively. Diesel production was accountable for 16% in the fossil resource scarcity category and transport originates 24% and 15% of the impact in terrestrial ecotoxicity and human non-carcinogenic toxicity categories, respectively.

This can be attributed to the fact that the precursor reactants of photochemical oxidants are mainly nitrogen oxides (NOx) and VOCs emitted from fuel use (Narumi et al., 2009). In addition, it contributed around 7% to the harmful impact of the ozone formation (human health and terrestrial ecosystems) and the fossil resource scarcity categories. As expected, the impact in the land use category was due to the production of the purchased cow feed and to the land occupation due to the crops cultivated *in situ* (68% and 31%, respectively).

3.2. Environmental performance of the pasture-based system

Each cow produced 3618 kg_{FPCM} per year in the pasture-based system, a value that is approximately half than that found for the semi-confinement system. This agrees with data found in the literature, since it has been reported that confined animals, which have less or no access to pasture, produced more milk per cow than those cows that are grazed freely (O'Brien et al., 2018).

The generation of co-products in dairy farms usually reduces the environmental impact associated with milk production. Indeed, Marton et al. (2016) reported that mixed cow dairy production systems (systems that combine milk production with cash crop and livestock production) in Switzerland showed lower environmental impacts than those of specialized dairy farms. In the pasture-based system, the live weight of animals sold for slaughter with respect to milk produced was higher than in the semi-confinement system. That is why the allocation factor for the pasture-based farm was 0.69, a value considerably lower than that found for the semi-confinement system. Hence, the live weight of culled cows and bull calves sold for slaughter is a determining parameter in dairy farm performance.

When the inventory data of the two systems are compared (see Tables 2 and 3), the major differences found in some subsystems are noticeable. Certainly, the production of 1 kg_{FPCM} in the pasture-system required less purchased feed, electricity, cleaning products and transport in comparison with the semi-confinement system. Specifically, on semi-confinement farms, three times more purchased feed, almost ten times the amount of electricity and more than twenty times the transport was needed for the production of 1 kg of FPCM in comparison with the pasture-based system. On the other hand, the pasture-based farm required more than 2.5 times the land needed by the semi-confinement system.

The results obtained with the ReCiPe method in the case of the pasture system can be seen in Fig. 3. Again, cow feeding, i.e. the fodder concentrate subsystem (the rest of feed is produced *in situ*), was found to be the main contributor to the environmental loads of almost all categories considered. To be specific, feed was responsible for more than 80% of environmental impacts in 12 of the 18 categories analyzed.

Direct cow emissions contributed 77% to the impact in the climate change category, whereas indirect emissions from manure and slurry were responsible for 89% and 78% of the harmful impact in the terrestrial acidification and the fine particulate matter formation categories. Electricity represented 23% of the ionizing radiation impact and diesel accounted for 36% in the fossil resource scarcity category. In this case, the effect of transport was negligible, since most of the feed is produced on the pasture-based farm and so the transport of raw materials to the farm is quite low. This was also the reason why the land occupation subsystem was responsible for 80% of the adverse impact in the land use category, which is to be expected, since changes in land use are closely related to food supply and environmental loads from agriculture (Lehmann et al., 2013). Finally, the beneficial effect in the water consumption category due to the treatment of wastewater should be noted, although it also implies some harmful contributions, i.e., to ecotoxicity and eutrophication categories.

3.3. Comparison of both systems

The comparison of the environmental performance of the two dairy systems is shown in Fig. 4. As can be seen, lower environmental impacts were associated with the pasture system in all the studied categories, excepting terrestrial acidification, human non-carcinogenic toxicity and land use. In the case of terrestrial acidification and human non-carcinogenic toxicity, the impact of both farms was almost the same (indicated in Fig. 4 as 100%), whereas regarding land use, the semi-confinement system impact was 4% lower than that of the pasture-based system. It is noteworthy that in 12 of the 18 categories analyzed, the environmental impact derived from milk production was 50% lower in the pasture-based system and, according to these data, the pasture-based dairy farm was clearly more environmentally friendly than the semi-confinement system. These results agree with those of O'Brien et al. (2012), who compared a confinement dairy farm and an intensively grazed seasonal grass-based dairy system in Ireland and concluded that all total environmental impacts were greater for the confinement system. On the contrary, Flysjö et al. (2011) was not able to detect great differences in carbon footprint between a pasture grazing system in New Zealand and an indoor housing system with the use of concentrate feed in Sweden.

In our case, the pasture-based system reduced the impact in the global warming category by 18% (see Fig. 4). As can be seen from the study published by Arnott et al. (2015), determining which dairying system has least environmental impact is a difficult issue because there is no agreement between the studies that have been published.

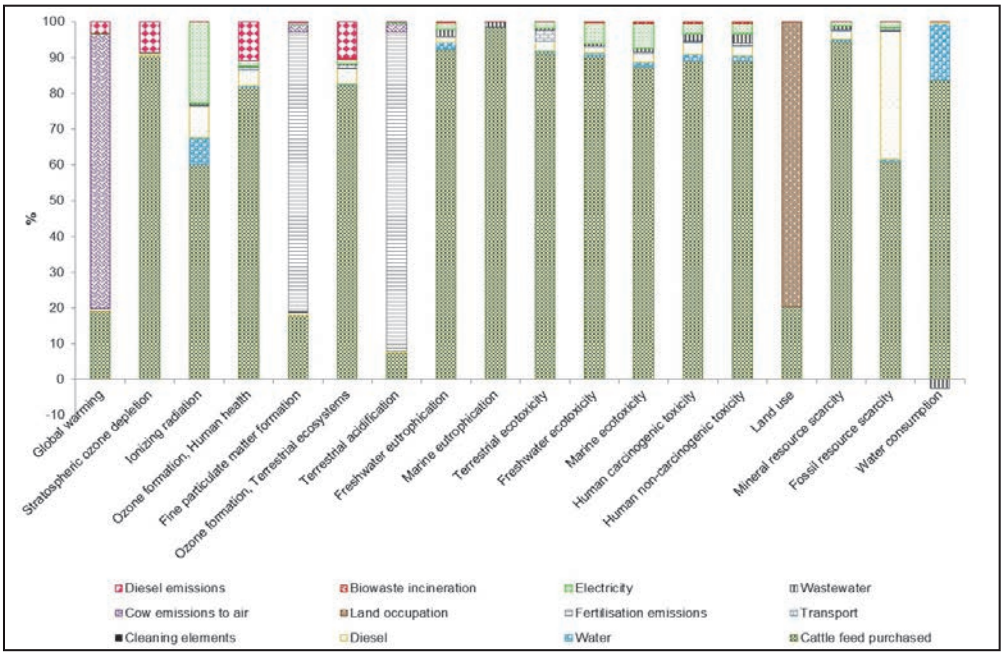


Fig. 3. Characterization results for the pasture-based dairy farm obtained using ReCiPe Midpoint

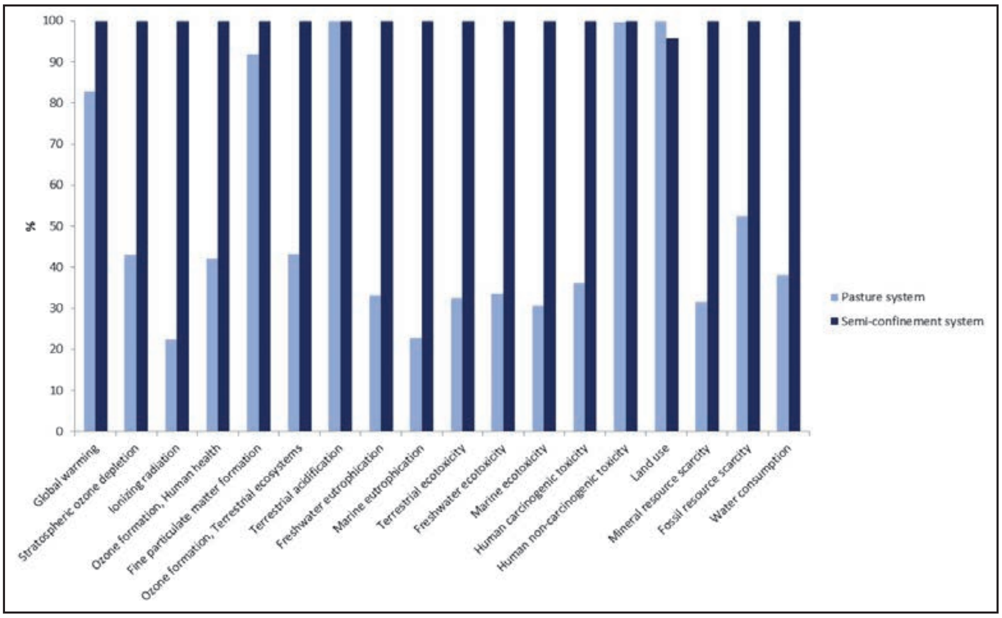


Fig. 4. Comparison between the environmental impacts derived from the production of milk in two systems here analyzed: semi-confinement (dark blue bars) and pasture-based (light blue bars)

These authors reported that two studies in Northern Ireland and Canada found similar GHG emissions for confinement and grazing systems (Arsenault et al., 2009; Ferris 2007), three studies in the USA and the EU found that emissions were higher for confinement systems (Guerci et al., 2013; O'Brien et al., 2012; Rotz et al., 2010) and, on the contrary, higher GHG emissions were found in Scotland for the grazing system (Ross et al., 2014). Regarding eutrophication potential, two studies in Europe reported that confinement systems had a higher eutrophication potential (Guerci et al., 2013; O'Brien et al., 2012), whereas a third study in Canada found the two systems to have similar potentials (Arsenault et al., 2009). The impacts in the eutrophication category found in our investigation were notably lower for the pasture-based system (see Fig. 4).

A key aspect for the environmental loads of the milk produced on one form or another is the productivity of the animals, which is closely related to the feeding system and the cow breed. Wang et al. (2018) reported that the productivity of milking cows showed a strong negative correlation with the global warming potential, the eutrophication potential, the acidification potential, the non-renewable energy use and the land occupation categories.

These results are not in agreement with the data reported here, since despite the fact that productivity is rather lower in the pasture-based farm, as was mentioned above, the pasture-based system entailed lower environmental impacts in almost all the studied categories. It is a clear example of a case where the benefits derived from the higher productivity of a semi-confinement system did not completely compensate for the higher impacts associated with the system and lower meat production as a co-product. The variable results described in the literature indicate that widening the knowledge base on the environmental performance of different dairy systems is still a matter of great interest.

4. Conclusions

In the dairy farms analysed here, feed production and on-farm emissions derived from enteric fermentation and manure and slurry management were the main contributors to most impact categories. These results are similar to those reported for different dairy production systems, not only in Spain, but also worldwide.

When the two dairy systems were compared, and, although cow productivity on the pasture-based farm was almost half of that obtained on the semi-confinement farm, lower environmental impacts were associated with the pasture system in all the studied categories. In addition to productivity, the amount and composition of the purchased fodder and the number of animals sold for meat as coproduct are key aspects that determine to a great extent the impact associated to milk production.

Finally, it is essential to remark that the few analyses found in the literature focusing on comparing confinement and pasture-based farms showed contradictory results, which endorses the need to increase the number of studies on this topic to obtain more robust conclusions.

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