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EVALUATING THE ENVIRONMENTAL IMPACT OF TWO BEEF PRODUCTION SYSTEMS USING LIFE CYCLE ASSESSMENT

Sara Belo[1]*, Ana Dias [1], Manuel Feliciano[2], Fernando de Sousa[2], José Almeida[3], Henrique Trindade[3] and Luís Arroja[1]

1: Department of Environment and Planning & CESAM
University of Aveiro
Campus Universitário de Santiago
3810-193 Aveiro, Portugal
e-mail: sarabelo@ua.pt, acdias@ua.pt; arroja@ua.pt web: http://www.cesam.ua.pt

2: School of Agriculture & CIMO
Polytechnic Institute of Bragança
Campus de Santa Apolónia - Apartado 172
5301-854 Bragança, Portugal
e-mail: msabenca@ipb.pt, fsousa@ipb.pt, web: http://www.cimo.esa.ipb.pt

3: Escola de Ciências Agrárias e Veterinárias & CITAB
University of Trás-os-Montes e Alto Douro
5001-911 Vila Real
e-mail: jalmeida@utad.pt; htrindad@utad.pt web: http://www.citab.utad.pt

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Abstract *Beef production has been identified as an important source of environmental impacts. Life Cycle Assessment (LCA) has been applied worldwide to identify key processes/phases for environmental improvement in beef production. In this study, LCA is used to assess the environmental impacts of beef produced in two different production systems, namely extensive and intensive fattening. A "cradle-to-gate" approach is adopted and the functional unit is 1 kg of beef carcass weight at the farm gate. The results show that the environmental "hot spots" are related with feed production and on-farm related emissions in both systems. The results also suggest that the use of extensive production during the fattening stage has lower environmental impacts per kg of carcass. The largest differences between the two systems were found in marine eutrophication category.*

1. INTRODUCTION

Beef production is the most important activity of the livestock sector in Portugal, representing 17 % and 7% of the livestock and the agricultural production business volumes, respectively [1]. However, meat and meat products have the greatest environmental impact in the food and drink sector [2]. Life Cycle Assessment (LCA) has been applied in different locations worldwide to quantify the environmental impacts and identify key processes/phases for environmental improvement in beef production [3],[4],[5],[6],[7],[8]. In this study, LCA is performed to assess the beef produced in Portugal. Two production systems are analyzed: S1) an extensive system in which animals in the pasture have access to concentrate feeds; S2) an extensive system with a period of growing animals until weaning on pasture and a confined rearing and fattening stage in intensive system (feedlot). The aim of this study is to quantify the environmental impacts of both these beef production systems and to identify the environmental hotspots.

2. MATERIALS AND METHODS

2.1. Functional unit, system boundaries and allocation

The functional unit is 1 kg of beef (carcass weight, CW) at the farm gate. It was considered the carcass yield of 57% to convert the live weight (LW) at the farm gate to CW. The system under study (Fig.1) constitutes a cradle-to-gate analysis, encompassing the whole supply chain starting with the production of animal feed up to farm gate. Each one of the production systems analysed are constituted by two subsystems (S1= $S_{BC} + S_{EXT}$; S2 = $S_{BC} + S_{INT}$).

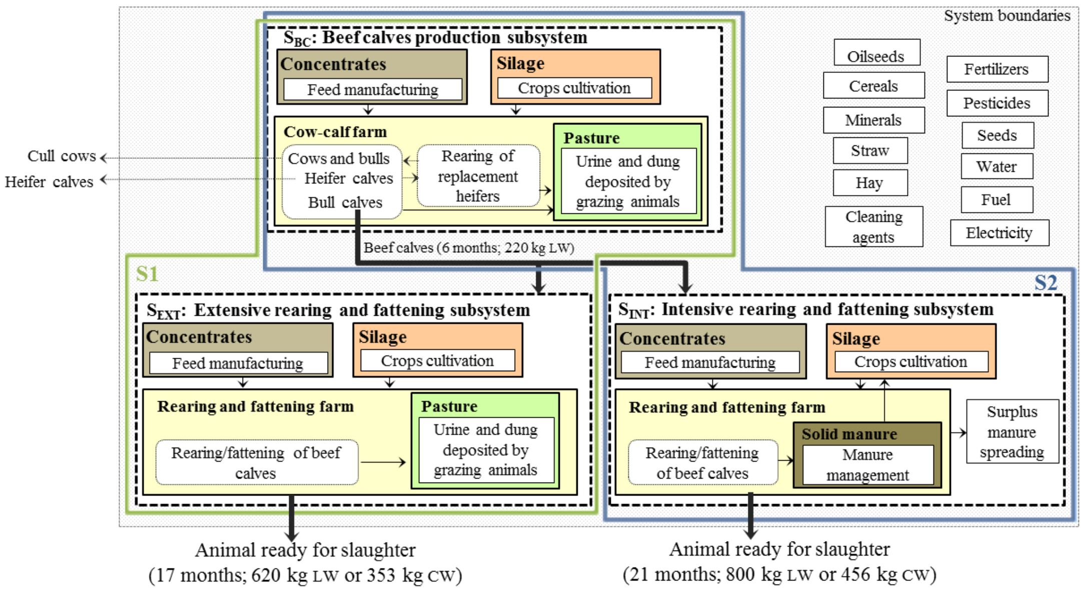

Fig.1 – Systems boundaries of the beef production systems assessed. S1= $S_{BC} + S_{EXT}$; S2 = $S_{BC} + S_{INT}$.

The beef calves production subsystem (S_{BC}), common to both systems, is followed by the extensive (S_{EXT}) and the intensive production (S_{INT}) fattening stage subsystems. S_{BC} comprises the beef calves production (all animal required to produce beef calves are considered: cows, bulls, heifers calves and bull calves), including the animal feed production, the diesel production and direct emissions from the farm. S_{EXT} and S_{INT} involve the fattening stage, from the reception of weaned beef calves until the animals are ready to slaughter, including the production of animal feed, direct emissions from the farm, emissions from surplus manure application (in off-farm land, energy use and cleaning agents use. The transport of the inputs was included, but infrastructures, equipment and medicine production were excluded from the analysed systems.
The beef calves production subsystem is multi-functional as weaned calves (males and females) and cull cows are produced. Thus, a sensitivity analysis was conducted to estimate the environmental impacts for beef production using two allocation criteria: an economic allocation based on the market prices of those outputs and a mass allocation based on the animal live weight produced (Tab.1).

Tab. 1 - Allocation criteria applied in the systems under study.

Outputs	**Mass flows**		**Price**	**Allocation**	
				Economic	**Mass**
S_{BC}: Beef calves production subsystem					
Weaned beef calves	1.00	kg LW	2.44 €/kg LW	52.2%	43.4%
Weaned heifer calves	0.766	kg LW	2.44 €/kg LW	39.9%	33.2%
Cull dairy cows	0.538	kg LW	1.20 €/kg CW	7.9%	23.4%

2.2 Data collection

Beef production data are based on Portuguese typical farms. The farms were selected based on expert judgements, considering the management practices at the farms, the geographical location and the farm size. The data used for the inventory of S_{BC} were obtained in a farm located in southern Portugal that produces calves to the weaning with 6 months of age (220 kg LW) in extensive production. Then, weaned beef calves are reared and finished in this farm in extensive system (S_{EXT}) and slaughtered with 17 months of age (620 kg LW), or sent to another rearing and fattening farm situated in the north of Portugal. In the last case, beef calves are transported approximately 300 km to be reared and fattened in intensive production (S_{INT}) and slaughtered with 20 months of age (800 kg LW). Cattle at S_{BC} and S_{EXT} are grazing all year, depositing urine and dung in the pasture. In addition, they are also fed with concentrates, silages and hay. In $S_{INT,}$ animals are produced in intensive system and they are exclusively fed with concentrates and silages in confined feedlots. The solid manure produced is collected from the houses and stored in a dry lot. A fraction of the stored manure is applied in crop cultivation (silage crops) at the farm, reducing the use of mineral fertilizers. The remainder (the surplus manure) is applied to fields in the surroundings of the farm, but related emissions were included in this subsystem (S_{EXT}). CH_4, N_2O, NH_3, NO_3^- and PO_4^{3-} emissions resulting from enteric fermentation, manure management and mineral and organic fertilizers applied into the soil (in the crops cultivation and pasture) were included in this study and computed following the IPCC guidelines [9], except the PO_4^{3-} emissions which were calculated based on emission factors from Nemeck and Schnetzer (2012)[10]. Nitrogen and phosphorus excretion estimates used to calculate the pollutant emissions were obtained from a Portuguese ordinance [11]. Diesel consumption and associated emissions into the air (from machinery used for animal handling, crop cultivation, and organic and mineral fertilizer application) are included in the inventory data and were taken from IPCC [9] and EMEP/EEA [12]. In addition, the inventory data include the consumption of animal feed, electricity, water, cleaning agents, seeds, pesticides and mineral fertilizer consumption. Background inventory data were obtained in Ecoinvent [13] and GaBi [14] databases.

4. RESULTS

The *midpoint ReCiPe* 2008 methodology was adopted for the environmental impact quantification [15]. The selected impact categories were: Climate Change (CC), Freshwater Eutrophication (FE), Marine Eutrophication (ME) and Terrestrial Acidification (TA). These impact categories are commonly addressed to provide a comprehensive picture of the environmental profile of agricultural products [6]. The results in the figure 2 show the environmental impact of 1 kg of beef (CW) at the farm gate for the analysed systems, using two allocation criteria, as well as the contributions of elements/phases for the total impact.

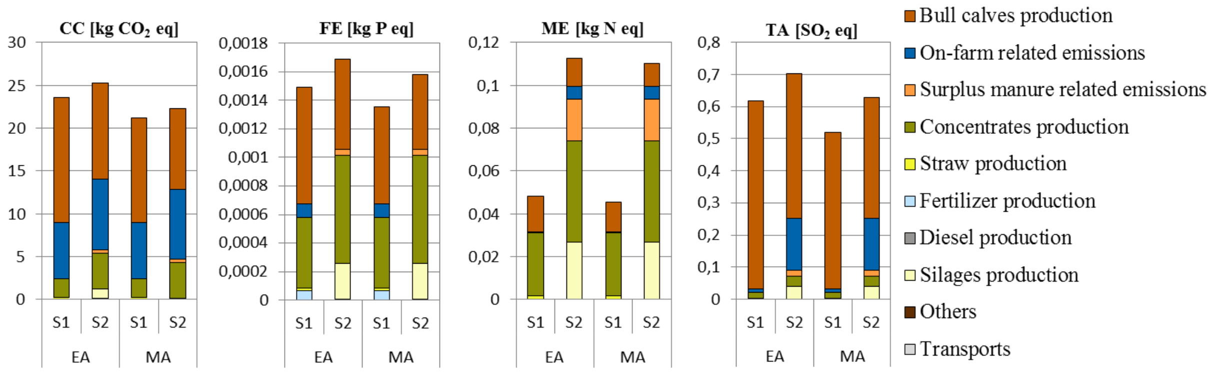

Fig. 2 - Environmental impact assessment for each beef production system (S1 and S2), with two allocation methods: EA – economic allocation, MA – mass allocation.

The values obtained using mass allocation are lower than those obtained with economic allocation. It was expected because the product under assessment (meat from beef calves) is an expensive co-product. For example, in the CC category, the obtained values using mass allocation are 10.4% and 11.9% lower than using economic allocation to S1 and S2 systems, respectively.

According to the results, feed production, on-farm emissions and beef calves production are the hotspots of the beef production. In both production systems, CH_4 emission is the main contributor to CC (54 % and 56 % of the total impact of S1 and S2, respectively), followed by a substantial contribution by N_2O. CH_4 emissions result mainly from enteric fermentation, whose emissions are related with the quality of the animal diet. N_2O emissions mainly result from manure management and N-based fertilizer application into soils, as well as from mineral fertilizer production. Therefore, N_2O emissions are higher in the intensive production due to the manure management (housing and storage) due to the higher amount required of feed components. For FE and ME categories, elements/processes related with feed production (silage and concentrates) in the fattening phase are the main contributors to the total impact in both systems, essentially due to fertilizers use. The ME impact of S2 is about 134-143% higher than that of S1 mainly due to NO_3^- and NH_3 emissions from manure management and its application into land. In the case of S1 the dung and urine are directly deposited by grazing animals.

The beef calves production (S_{BC}) also has an important contribution, ranging between 35 % and 95 % to the total impact. Analysing S_{BC} in detail (Fig.3), the results are in line with fattening subsystems. The impact categories CC and TA are dominated by on-farm emissions, while FE and ME are dominated by feed production.

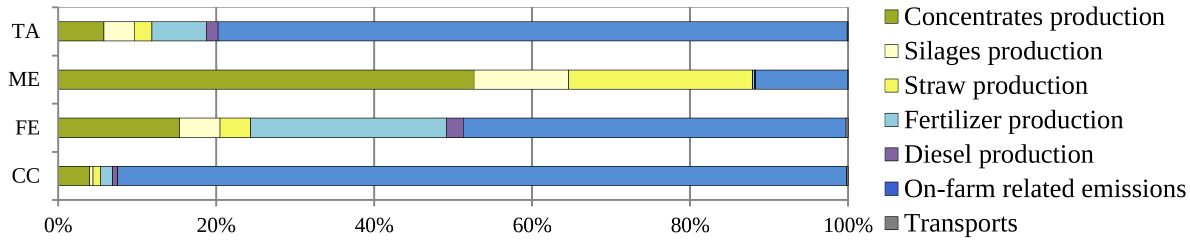

Fig. 3 - Relative contributions for the total impact of S_{BC} subsystem.

5. DISCUSSION AND CONCLUSION

The estimated greenhouse gas (GHG) emissions between 21.1 and 25.2 kg CO_2 eq kg of beef (CW) for production systems using extensive and intensive fattening phase is within the range of earlier estimates obtained in other LCA studies: 22.0–27.3 kg CO_2 eq/ kg of beef (CW) [4],[5],[6]. However, the variation in GHG intensities reflects not only differences in the farming systems, but also dissimilar assumptions, approaches, and methodologies in calculating emissions [4]. For these reasons, it is not appropriate to compare GHG emissions across studies with the aim of identifying more GHG efficient production systems. Nevertheless, the identified environmental "hot spots" of beef production chain are consistent with all previous LCA studies of beef production at the farm gate. The key-processes are associated with feed production and on-farm related emissions (mainly due to enteric fermentation, manure management and application) [4],[5],[6],[7],[8]. Comparing the analysed beef production systems, the results suggest that the extensive use of pasture during the fattening stage has the potential to reduce the environmental impacts per kg of carcass. The largest differences between the two systems were found in ME category due to the amount and type of fertilizers used to produce animal feed and the emissions resulting from the manure management, respectively.

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