Abstract The dairy sector is an important manufacturing and economic sector in Portugal. However, manufacturing of dairy products is also a source of environmental impacts. Life Cycle Assessment (LCA) has proved to be a useful tool for the environmental performance evaluation of dairy products. The aim of this LCA study is to assess the environmental impacts of yogurt produced in Portugal. A “cradle-to-gate” approach is adopted and the functional unit is 1 kg of yogurt at the gate of the yogurt factory. The results show that environmental “hot spots” of the system under study are associated with the production of the milk-based inputs (i.e. raw milk and powdered milk), ranging between 71 % and 96 % of the total impact, depending on the impact category, mainly due of CH\textsubscript{4} from enteric fermentation, CO\textsubscript{2} from diesel consumption, N\textsubscript{2}O and NH\textsubscript{3} atmospheric emissions as well as NO\textsubscript{3} and PO\textsubscript{4}\textsuperscript{3-} water emissions coming from manure management and fertilizers use. Furthermore, on-site emissions arising from yogurt factory (mainly from wastewater production and fossil fuel consumption), and packaging production, also have important environmental burdens.
1. INTRODUCTION

In Portugal, the dairy sector represents 11.3% and 13.5% of the agricultural and food industry production business volumes, respectively [1]. A key issue for both livestock producers and the dairy industry is to ensure that manufacturing is conducted in an environmentally sustainable manner. Life Cycle Assessment (LCA) is an internationally standardized methodology that allows evaluating the potential environmental impacts over the whole life cycle of a product [2]. LCA studies have been conducted on raw milk production and dairy products systems [3],[4],[5],[6],[7],[8],[9]. This methodology has been identified as a useful tool to assess the environmental impacts of different milk and dairy production systems and to identify major contributors to the environmental burdens [10]. In this study, LCA was chosen to assess the environmental performance and to identify the hotspots of yogurt production, which is the second most important dairy product in Portugal (in terms of both production and consumption).

2. MATERIALS AND METHODS

2.1. Functional unit and system boundaries

The functional unit is 1 kg of packaged yogurt, at the dairy factory gate, ready to be delivered. The analysed product consists in a mix of all types of yogurts produced in the factory (e.g. firm, creamy and liquid). The system under study (Fig.1) constitutes a cradle-to-gate analysis, encompassing the whole supply chain starting with the cultivation of animal feed and ending with the yogurt at the gate of the yogurt factory.

Thus, environmental impacts associated with retailing and consumption activities are outside of the system boundaries. The system is divided in two subsystems: raw milk production (SRM) and yogurt manufacturing (SYM). SRM comprise all the raw milk production phases, including crops cultivation for fodder production and direct emissions.
from dairy farm. $S_{YM}$ involves the whole transforming process of raw milk into yogurt, from the reception of raw milk until yogurt expedition. Additives production (starter culture, aroma and fruit) was not considered due to a lack of data, but its transport was included. The transport of other inputs was also included. Infrastructure, equipment and medicine production were excluded.

2.2 Allocation

The dairy farm is multi-functional as both raw milk and meat (surplus calves, heifers and culled cows) are produced. Thus, an economic allocation was applied based on the market prices of raw milk and meat (Tab. 1). Economic value is one of the most frequent relationships used to allocate between milk and meat [3],[4],[5],[6]. The obtained allocation factor for raw milk was 93%. This high value is explained by the recent low market price of calves (from dairy farms) in Portugal.

The yogurt factory is also multi-functional as both yogurt and cream are produced. The produced cream is sold to other food industries, representing about 6% of the total annual production. Since its market price was not provided by the factory (due to confidentiality issues), a mass allocation was adopted in this case using an allocation factor of 94% for yogurt. Nevertheless, the material flows exclusively related to yogurts, such as packaging materials, powdered milk and sugar, were entirely allocated to the yogurt flow.

Table 1 – Allocation criteria applied in the system under study.

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Mass flows</th>
<th>Price</th>
<th>Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Economic</td>
<td>Mass</td>
</tr>
<tr>
<td>$S_{RM}$: raw milk production</td>
<td>Raw milk</td>
<td>1.00 kg</td>
<td>0.32 €/kg</td>
</tr>
<tr>
<td></td>
<td>Bull calves (1 week old)</td>
<td>4.4E-5 heads</td>
<td>100 €/head</td>
</tr>
<tr>
<td></td>
<td>Heifers (1 year old)</td>
<td>2.56 g (LW)</td>
<td>3.5 €/kg (CW)²</td>
</tr>
<tr>
<td></td>
<td>Cull dairy cows</td>
<td>0.027 heads</td>
<td>500 €/head</td>
</tr>
<tr>
<td>$S_{YM}$: yogurt manufacturing</td>
<td>Yogurt</td>
<td>1.00 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cream</td>
<td>0.061 kg</td>
<td></td>
</tr>
</tbody>
</table>

¹ LW - live weight; ² CW - carcass weight (1 kg of LW = 0.57 kg CW)

2.3 Data collection

The raw milk production data are based on a typical dairy farm of mainland Portugal, consisting in an intensive production system where cows are housed in freestall barns. The choice of the typical farm was based on expert judgements, considering the management practices at the farms, the geographical area and the farm size. The milk yield is around 9,000 kg of milk per cow per year. The fodder used for animal feeding is maize and ryegrass silage, concentrates and straw. Cattle at the farm produce solid and liquid manure (approx. 97 % is liquid). Liquid manure is collected in underground tanks and a portion is applied in the silage crops at the dairy farm. Solid manure is stored in a dry lot and after is sent to other farms, along with surplus liquid manure to apply to agricultural fields placed in the surroundings of the dairy farm (5 km). Emissions arising from manure applied outside the dairy farm were
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included in the subsystem S_{RM}, using the same calculation methodology that was applied to the remaining manure as mentioned below. During the digestive process, cattle produce enteric methane (CH_{4}). During manure management (handling and storage), CH_{4}, ammonia (NH_{3}) and nitrous oxide (N_{2}O) are emitted to air. The silage crops are also fertilized by application of N, P and K-based fertilizers. The use of manure and mineral fertilizers in the fields causes the volatilization of NH_{3} and N_{2}O and the run off or leaching of phosphate (PO_{4}^{3-}) and nitrate (NO_{3}^{-}) to the receiving water bodies. All these emissions were included in this study and computed following the IPCC guidelines [11], except the PO_{4}^{3-} emissions which were calculated based on emission factors from Thø and Wenzel (2007) [12]. Diesel consumption and associated emissions into the air (from machinery used for crop cultivation, fertilization and manure application) are included in the inventory data and were taken from IPCC [11] and EMEP/EEA [13].

The dairy factory analysed is representative of yogurt production in Portugal and uses the best available technology economically achievable (BAT). The inventory data provided by the factory include consumption of raw materials (raw milk, powdered milk and sugar), thermal energy, electric energy, cleaning agents, packaging materials (cardboard, LDPE films, PS, HDPE, aluminum and wooden pallets), as well as disposal of waste. Emissions to air resulting from natural gas used for heat production were calculated using emission factors taken from IPCC [11] and EMEP/EEA [13]. Emissions to water resulting from the waste water generated were provided by the factory. Background inventory data were obtained in ecoinvent [14] and GaBi [15] databases.

3. RESULTS

The midpoint ReCiPe 2008 methodology was adopted for the environmental impact quantification [16]. The selected impact categories were: Climate Change (CC), Freshwater Eutrophication (FE), Marine Eutrophication (ME) and Terrestrial Acidification (TA). The contributions of elements/phases for the total environmental impact of the yogurt are presented in figure 2.

According to the results, the raw milk production (S_{RM}) is the dominant contributor to the environmental burdens of yogurt (Fig. 2a). The contribution of the milk-based inputs (i.e. raw milk and powdered milk) ranges between 71% and 96% to the total impact, depending on the impact category. Analysing S_{RM} in detail (Fig. 2b), the impact categories CC and TA are dominated by on-farm emissions, while FE and ME are dominated by feed production. Regarding the impact of the total system on CC (1.55 kg CO_{2} eq/ kg of yogurt), the results show that the major contributions for this category are CH_{4} emissions (49% of total impact) derived from enteric fermentation of the ruminant livestock, and CO_{2} emissions (36% of total impact) mainly caused by fossil fuel burning in agricultural operations, mineral fertilizers production, packaging production, and electricity consumption in the yogurt factory.
Concerning FE, around 65% of the total impact of the system (0.123 g P eq/ kg of yogurt) is caused by PO$_4^{3-}$ released from runoff due to on-field manure and P-based fertilizer application, as well as from the mineral fertilizers production. P emissions also contribute for this category (35% of total impact) also due to the emissions from agriculture and from the waste water generated in the yogurt factory.

For ME, farming activities (feed and fodder production) have the largest contribution for the total impact (8.75 g N eq/ kg of yogurt), mainly from NH$_3$ volatilization of land applied manures and fertilizers, and NO$_3^-$ lost via runoff and leaching from agricultural soils.

Finally, the total TA resulting from yogurt production (0.032 kg SO$_2$ eq/kg of yogurt) is essentially caused by NH$_3$ emissions (92% of the total impact) from manure management and from manure and mineral fertilizers application.

4. DISCUSSION AND CONCLUSION

The results obtained in this study show that the production of 1 kg of yogurt in Portugal contributes with 1.55 kg CO$_2$ eq to CC. This value is in the range of the values from other studies that have been performed using LCA approach to estimate the contribution of the yogurt to CC (from 1.20 to 1.60 kg CO$_2$ eq per kg of yogurt at the dairy factory gate) [6],[7],[8],[9]. However, it is difficult to know if the impact is actually as similar as it seems, since the results are taken from different studies which have differences in underlying assumptions and methodology.

The identified environmental “hot spots” of yogurt production are associated to raw milk production, in particular with animal feed production and on-farm related emissions (mainly due to enteric fermentation and manure management). These results are consistent with previous studies [6],[7],[8],[9]. The contribution of yogurt manufacturing is essentially due to
CO$_2$ emissions from fossil fuel consumption at yogurt factory and from plastic production [7],[8],[9], as well as due to emission of N and P compounds to water arisen from waste water at the factory. Therefore, the reduction of global environmental impacts could be achieved by applying mitigation strategies focused on the major problems identified. The agricultural system of milk production is a complex, dynamic and interactive system. At the dairy farm, the management of nutrients and manure is a key aspect to the eco-efficiency and requires a global view of the system. Thus, at the farm level, guidelines on feed that take into account nutritional and environmental aspects must be provided [5]. The formulation of animal diet must be optimized both by the reduction of concentrated ingredients with a high environmental impact (e.g. use of byproducts) and by the reduction of nutrient surplus, improving the balance of protein fed that is required by individual animal or animals group [4],[5],[17],[18]. Nitrogen losses can also be reduced through frequent manure removal and avoiding deep litter systems, as well as through the use of a covered manure structure [18]. Moreover, low-emission technologies should be adopted in manure management (e.g. acid treatment of manure, floor designs for separating faeces and urine) and manure spreading (e.g. trailing hose and direct injection). The use of fertilizers in the forage crops should be optimised (e.g. adopting precision farming techniques). Another important aspect is the high replacement rate (culling cows) that should be reduced [17]. At the factory level, packaging designs and alternative manufacturing of packages are the target areas that should be researched to improve the environmental impact of yogurt [19].

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