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LIFE CYCLE ASSESSMENT (LCA) ON EUROPEAN SKIMMED MILK POWDER PROCESSING PRODUCTION PLANT

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Abstract

The dairy industry consists one of the most energy intensive food industries, with milk powder production being the most energy consuming process. The aim of this work is to present the state of the art skimmed milk powder production processing chain in order to identify the processes with high environmental and energy impact. A life cycle assessment (LCA) has been performed to analyse the environmental footprint and energy balance derived from the skimmed milk powder (medium heat) production on the post-harvest chain. Therefore, a comparative gate to gate LCA was performed within the boundaries of the processing plant (i.e. standardization/separation, homogenization, pasteurization, evaporation, spray drying). In this study, two scenarios were evaluated on their environmental performance: a) the conventional production of skimmed milk powder (SMP) with the inclusion of Reverse Osmosis (Scenario 1) and b) the production of SMP exclusion of Reverse Osmosis (Scenario 2). The standard framework of LCA was followed according to the ISO 14044, which is also in line with the International Reference Life Cycle Data System (ILCD) Handbook. LCA study was performed on Gabi 6 software with databases from within the food industry. Inventory data were collected from the industry and completed using the literature and databases, impact categories were evaluated adopting a CML method with the energy analysis carried out based on the cumulative energy demand (CED).

Key words: *Dairy Processing, Energy Consumption, Life cycle Assessment (LCA), Skimmed Milk Powder, Spray Drying.*

INTRODUCTION

In recent years "green" economy aiming at a sustainable development without degrading the environment, avoiding the resources depletion and ensuring the prevention of human health and well-being. This trend has been the evident practice around the globe in all aspects of industry. As a consequence, governments, non-governmental organizations, companies and civil society are becoming interested in increasing the knowledge of how a product is processed and what is the environmental impact of its production. That implies taking into account the whole chain of a product's life cycle and all relevant external effects, in order to be able to make improvements that promote sustainability and environmental friendly production.

In accordance to this tendency, the dairy value chain has been actively working towards the reduction of greenhouse gas (GHG) emissions derived from the production, collection and processing of milk and delivery of dairy products, while satisfying the needs of the marketplace in the most sustainable manner. In compliance to that direction, various organizations such as International Dairy Federation (IDF, 2005 & 2010) and European Commission (EC) are supporting the evolution of efficient and sustainable businesses and technologies that contribute to a GHG emissions reduction.

The food industry is a major consumer of water and energy. It was positioned third in terms of water consumption and wastewater discharge, after the chemical and refinery industries. In the European Union about 31% of total GHG emissions are estimated to come from the food chain (EC, 2006). Dairy industry is considered to be the most energy and water consuming sector of the food industry (EC, 2008), with a consumption exceeding 8% of the total EU energy consumed.

The whole dairy value chain is divided into different segments (Figure 1, right), with each one of the segments having different impact on energy consumption (Figure 1, left). It is apparent that processing stage is the most energy intensive step of the dairy chain. This study is dealing with the post-harvest chain and the production of skimmed milk powder (SMP) and intends to evaluate the environmental state of the dairy processing plant.

Among the tools available to evaluate environmental performance, LCA has gained recognition as the most powerful tool for the comparison of environmental impacts of products, technologies or services with a view to their whole life cycle (cradle to grave) or to a targeted part of that life cycle (cradle to gate, gate to gate or gate to grave). The present study focuses on the application of LCA for the evaluation of SMP production by two different scenarios. In short, a comparative LCA study of the conventional dairy processing production of SMP in European area is performed. The inclusion or exclusion of reverse osmosis (RO) process in the dairy plant route forms the two different scenarios.

The study is based on the methodology for LCA, as specified in the standardized documents of ILCD, ISO and BSI:

- ILCD: International Reference Life Cycle Data System Handbook (2010)
- ISO: Environmental management–LCA-Requirements and guidelines (2006)
- PAS 2050: Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (2008)

MATERIALS AND METHODS

Goal and Scope

The goal of this study was to evaluate the current technologies on skimmed milk production on their environmental performance. In this study two different production lines were examined, the conventional production of skimmed milk powder (SMP) with the inclusion of Reverse Osmosis (Scenario 1) and the production of SMP exclusion of Reverse Osmosis (Scenario 2). In the LCA the energy, water and environmental profile of the conventional dairy processing scenarios were evaluated within the boundaries of the dairy plant, while material and energy inputs and outputs on farming, packaging, distribution and retail were not taken into consideration in the assessment. The impact of the incorporated processes on human health, natural environment and natural resources caused by interventions between Techno-sphere and Ecosphere during operations was assessed against all relevant impact categories resulting from the analysis. Finally, the scope of the study was to provide data on the evaluation of the sustainability performances of the current state of skimmed milk production.

Function and Functional Unit

The functional unit selected is 1 kg of produced Skimmed Milk Powder unpacked, which was output related, while the function was the production of Skimmed Milk Powder in a dairy processing plant.

Description of Conventional Dairy Processing Plant

The system boundaries included all relevant life cycle stages and processes that were operated within the techno-sphere and related to the functional unit. The examined system was defined as everything involved in the production of skimmed milk powder in the limits of the dairy processing plant. It was a gate to gate LCA methodology and the impact derived from the transportation of the raw milk to the plant was included. Mass and energy balance flows was collected, as well as, data on the amount of waste and emissions to water and air. In addition, the mode and distance of all transportation within the system were taken into account. However, in the study buildings and machinery, and personnel and other capital goods were not taken into consideration.

The production line of the standard way to produce skimmed milk powder is depicted in Figure 2. In brief, milk from farm was transported to the dairy site with different batches (from different farms) being mixed and stored at the bulk storage/mixing unit. Raw milk enters the separator (cold or hot) and cream was separated from the skimmed milk. In separator, standardization of skimmed milk was performed with the addition of cream. The flow of cream that leaves the system was further processed, but since the current study aims for skimmed milk powder, the flow of cream was not further taken into account. The skimmed milk was pasteurized and stored in buffer silo after pasteurization. Although storage after each process step unit was not necessary, most factories apply storage as a safety margin. Pasteurization and preheating before evaporation was combined into one single step. A 3-stage evaporator was applied, while a combination of evaporation and reverse osmosis could also be combined. Although the potential for energy saving it was hardly implemented in milk powder plants.

This work examines both scenarios:

Scenario 1: Dairy Plant with RO
Scenario 2: Dairy plant without RO

A buffer tank for the storage of the concentrated milk coming out of the evaporator was applied. The drying part consisted of a 2 stage drying, a spray dryer followed by a fluidized bed dryer. The air exiting both dryers was filtered by a cyclone, preferably combined with a filter (depending on the exhaust air restrictions).

Life Cycle Inventory Analysis

The inventory analysis involves the compilation and qualitative/quantitative identification of inputs and outputs for a given product system throughout its life cycle or for a single process. The Life Cycle Inventory model has been implemented through GaBi 6. The data collection was related to the functional unit of 1 kg of produced SMP as defined in the goal and scope step. Primary data concerning the flows of the conventional dairy processing plant was collected in first stage through questionnaires and in second stage from similar operations and published data. It was based for a production rate of 200 kg SMP per hour, for a dairy operating 20 hours/day, while the remaining 4 hours/day were set for cleaning. In general, data collection and manipulation included:

- directly measured data, through completion of data sheet questionnaires;
- data from simulation tools (WU, 2015), which forms a credible model of industrial situation;
- specific data for milk industry from Food database of Gabi 6;
- literature data;

The inputs for all the operations were used in the calculation of mass balances linking all the subsystems in the system and estimating the outputs of each subsystem and of the overall system. Processes in the background system were inventoried on the basis of data taken from the dedicated database of the software GaBi 6 (Gabi and Ecoinvent databases). The LCI is fully described in the following paragraphs for both scenarios. Milk from farm is transported to the dairy site by a truck with a capacity of more than 32 t gross weight and 24.7 pt payload for 35 km with different batches (from different farms). Raw milk enters the plant and at first stage heads for bulk storage/mixing, which requires electrical energy of 0.6k Wh per ton per day. Raw milk is lead for separation and standardization to obtain skimmed milk. In this study, a cold separator is utilized, which requires 24.2 MJ/h Motor energy, 35 kg/h operating water and 69 kg/h cooling water. Skimmed milk after cold separation is pasteurized with requirements of 58 MJ/h thermal energy, brine solutions 4300 L/h (it is assumed that 10.000 L are recirculated in the system for 5 years utilization) and 58MJ/h cooling energy for the brine recirculation. In case of a plant implementing RO (Scenario 1) pasteurized skimmed milk is lead for reverse osmosis, a process that requires 12.9 MJ/h electricity and cooling water 0.3 m^3/1000 kg input milk. In case of a processing plant without RO (Scenario 2) this process is excluded. Buffer Silo is utilized for short storage between pasteurization or RO and evaporator and requires no energy due to solid insulation. Pre-heater is applied afterwards and requires 280MJ/h thermal energy and is set prior evaporation. In scenario 2, where no RO is performed the amount of required thermal energy is 509 MJ/h. Concentrated milk enters the 3-stages evaporator which requires 360 MJ/h thermal energy and 72 m^3/h cooling water in case of Scenario 1, where RO occurs. In Scenario 2, 541 MJ/h thermal Energy and 13 L/kg SMP produced cooling water are required. Prior Spray drying, short storage in a Buffer Tank is following and similar to the other buffer equipment requires no energy due to solid insulation. Spray drying is a 2-stage procedure with spray dryer being the first followed by fluidized bed dryer and cyclones. Spray dryer requires 758 MJ/h thermal energy and 90 MJ/h electricity. Fluidized bed dryer requires 53 MJ/h thermal energy and 115 MJ/h electricity, while Cyclone/Bag Filter requires 9.86 MJ/h electricity.

Cleaning in Place (CIP) is performed for the whole system and in total requires 0.889 MJ thermal Energy (Pasteurization, Separation, Evaporator, Dryer), 0.007 kg alkaline detergents, 0.003 kg acidic detergents and 20 kg water for cleaning per kg of SMP product. A transportation of 140 km by truck was assumed for both detergents, while a waste plan for solids with 40% landfilling, 40% incineration and 20% recycling is considered. Waste water treatment plan was considered for the whole system based on readily available plan of Gabi or the treatment of industrial waste water using the chemical reduction/oxidation process.

Life Cycle Impact Assessment (LCIA)

The LCIA identifies and evaluates the amount and significance in the potential environmental impacts arising from the examined scenarios and LCI. Inputs and outputs were assigned to impact categories and their potential impacts were quantified according to characterization factors and categorised in midpoint categories. The choice of the impact categories was based on the recommendations of the Product Environmental Footprint (PEF, 2012) and on the scope of the study. The corresponding impact categories considered include Global Warming Potential (GWP), Acidification Potential (AP), Water Depletion (WD) and Primary Energy Demand (PED), among others.

RESULTS AND DISCUSSIONS

The results of the LCIA are presented in Table 1 by reporting, for both scenarios, the total value of each impact category. The goal was to evaluate the environmental impact of the two scenarios examined and identify the important differences between the two. From this study the main outcomes can be summarized in the following:

- The GWP (100 years) in Scenario 1 (1.271145183 kg CO2-eq) contributed 11.5% less than the GWP of Scenario 2 (1.417186565 kg CO2-eq.).
- PED in Scenario 1 (23.5607 MJ) contributed 11.2% less than Scenario 2 (26.2075785 MJ).
- POF in Scenario 1 (0.001654927 kg NMOVC eq.) contributed 9.3% less than Scenario 2 (0.001808785 kg NMOVC eq.).
- EP in Terrestrial in Scenario 1 (0.005989512 mol N eq.) contributed 8.7% less than Scenario 2 (0.006509838 mol N eq.)
- AP in Scenario 1 (0.000139725 kg PM2.5-eq.) contributed 4.7% less than Scenario 2 (0.000144701 kg PM2.5-eq.)
- PM/RI in Scenario 1 (0.000139725 kg PM2.5-eq.) contributed 3.6% less than Scenario 2 (0.000144701 kg PM2.5-eq.)
- WD in Scenario 1 (1.17682958 m3) contributed 1% less than Scenario 2 (1.188108965 m3)

The above calculated differences were mainly due to the smaller amounts of energy and water requirements on evaporator and pre-heater process. The remaining examined impact categories (ARD, Ecotoxicity, Human toxicity cancer, Human toxicity non-cancer, Freshwater Eutrophication and Marine Eutrophication) proved to have identical results with minimal higher impact (less than 0.1%) in case of Scenario 2, while the only impact category that had minimal higher impact in Scenario 1 is ODP. In addition, Spray Drying (spray dryer, fluidized bed and cyclone/bag filter combined) had the highest contribution in GWP, PM/RI, AP, POF, Terrestrial Eutrophication, WD and PED with percentages more from 30% up to 45%. Moreover, the waste water treatment and CIP were the processes with the next higher impact for the above mentioned impact categories with percentages in the range of 14% to 24.2% and 11.7% to 18%, respectively, while the Evaporator came next for the same categories with contribution from 6.8% up to 17.5%.

In ODP for both scenarios the 78% was derived from the waste water treatment process due to iron chloride, and 21% was derived from pasteurization due to cooling energy. As far as ARD was concerned, for both scenarios the major contributors are pasteurization and waste water treatment processes with 49% and 34%, respectively. In case of pasteurization 98% of the impact is due to the cooling energy utilized, while in waste water treatment process 90% is due to iron chloride use. Finally, in Ecotoxicity, Human toxicity (cancer), Human toxicity (non-cancer), Eutrophication (Freshwater) and Eutrophication (Marine) for both scenarios the >98% is derived from the waste water treatment.

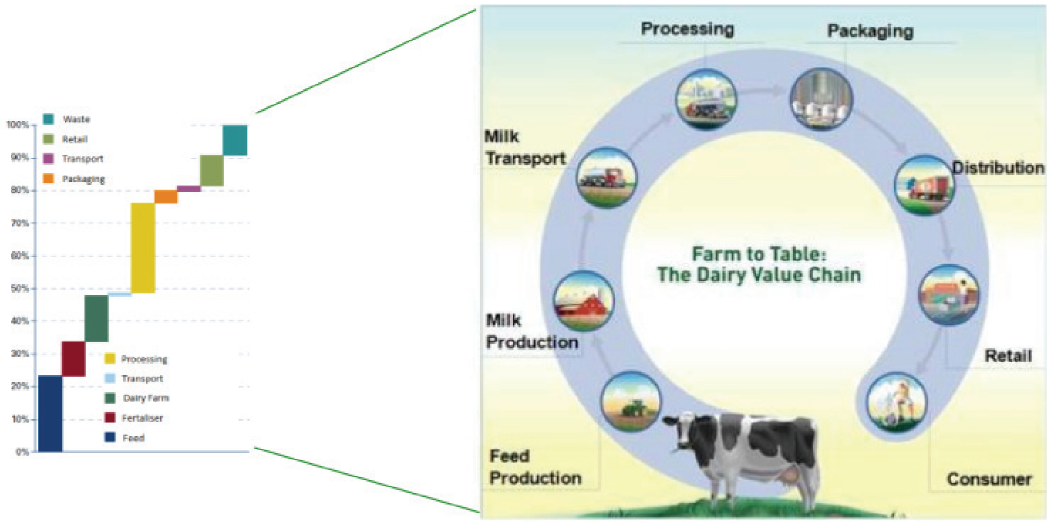

Figure 1. Dairy value chain (right) and energy consumption of segments (left).

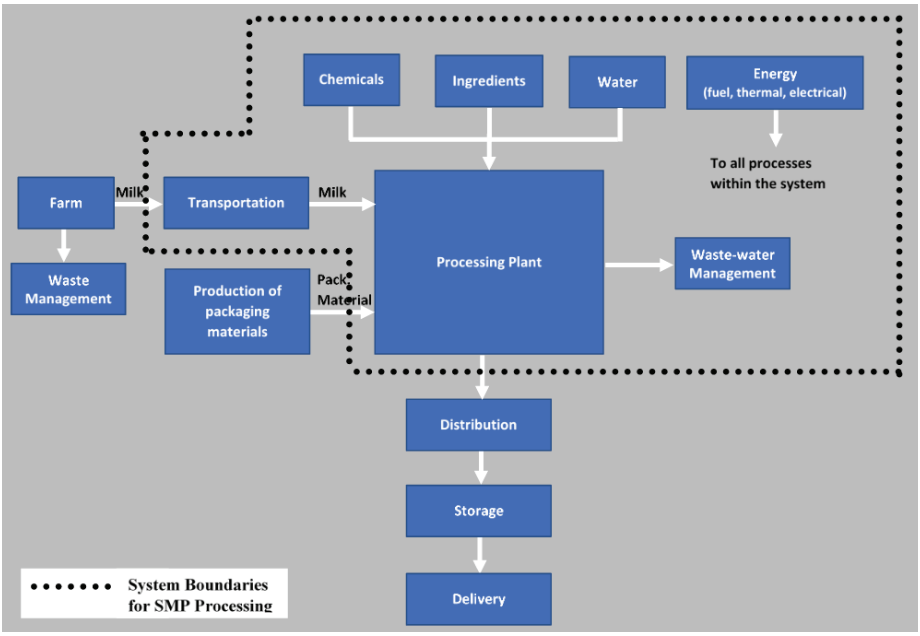

Figure 2. The boundaries of the system examined.

Table 1. Life Cycle Impact Assessment for the production of 1kg of Skimmed Milk Powder under the two Scenarios examined.

Impact Category*	Units	Scenario 1	Scenario 2	Impact of SC2 compared to SC 1
GWP	kg CO2-eq.	1.2711	1.4171	11.5% ↑
ODP	kg R11-eq.	2.28E-08	2.28E-08	≈0%
PM	kg PM2.5-eq.	0.000139725	0.0001447	3.6% ↑
AP	kg SO2-eq.	0.002161627	0.0022636	4.7% ↑
RD	kg Sb eq.	2.16E-06	2.20E-06	1.8% ↑
ECOTOXICITY	CTUe	25.11449628	25.116724	≈0%
HT (Carc.)	CTUh	5.30E-07	5.30E-07	≈0%
HT (non-carc.)	CTUh	4.39E-06	4.39E-06	≈0%
POF	kg NMOVC eq.	0.001654927	0.0018088	9.3% ↑
EP (FreshWater)	kg P eq.	0.000735751	0.0007362	≈0%
EP (Marine)	kg N eq.	0.006022652	0.0060257	≈0%
EP (Terestrial)	mol N eq.	0.005989512	0.0065098	8.7% ↑
WD	m3	1.176829588	1.188109	1% ↑
PED	MJ	23.56070008	26.207579	11.2% ↑

*GWP: Global Potential; ODP: Ozone Depletion Potential; PM: Particulate Matter Formation; AP: Acidification Potential; RD: Resource depletion, mineral and fossil; HT (carc.): Human Toxicity (carcinogenic); HT (non-carc.): Human Toxicity (non-carcinogenic); POF: Photochemical Oxidant Formation; EP: Eutrophication Potential; WD: Water Depletion; PED: Primary energy demand from renewable and non-renewable Resources

CONCLUSIONS

A comparative LCA was performed for two scenarios of the conventional production of SMP restricted to the dairy processing plant, based on the methodology for LCA, as specified in the standardized documents of ISO 14044 and ILCD Handbook. LCA study was performed on Gabi 6 software with databases from within the food industry. The function is the production of Skimmed Milk Powder in a dairy processing plant and the functional unit selected is 1 kg of produced Skimmed Milk Powder unpacked.

Overall, LCA analysis lead to the generic conclusion that inclusion of RO is beneficial in environmental terms. Although this is not a widely accepted practice in current dairy plants, it should be reconsidered. The Spray Drying proved to be the process causing the heaviest environmental burden, followed by CIP and waste water treatment processes. This is mainly due to the energy and water requirements.

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