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Life cycle assessment of fermented milk: yogurt production

Cristina GHINEA* and Ana LEAHU

Stefan cel Mare University of Suceava, Faculty of Food Engineering, 13 Universitatii Street, 720229 Suceava, Romania

Abstract. Yogurt is a fermented milk product, resulted through milk acidification by lactic acid bacteria, highly appreciated worldwide. In this study, life cycle assessment (LCA) methodology was applied for modelling of environmental impacts associated with yogurt production. The system boundaries include the following activities: milk processing, transport, solid waste and wastewater treatments. Functional unit set for this study is 1 kg of produced yogurt. The input and output data were collected from various sources like reports, databases, legislation. All these data were used further in the impact assessment stage performed with GaBi software which includes LCA methods like CML2001 - Jan. 2016, ReCiPe 1.08, UBP 2013, EDIP 2003 and others. Results showed that the global warming potential (GWP) determined for yogurt was 2.92 kg CO_2 eq. per kg of yogurt, while acidification potential (AP) was approximately 0.014 kg SO_2 eq. per kg of yogurt. It was observed that the main contributor to all impact categories is consumption of electricity during the yogurt production, mainly in the pasteurization, evaporation and cooling stages. 61.4% of the emissions resulted from transportation of raw materials contributes to GWP, while 38.3% to photochemical ozone creation potential (POCP). Emissions from wastewater treatment are contributing especially to the eutrophication potential (EP), while emission from solid waste landfilling are contributing mainly to POCP.

Keywords: environmental impacts; food products; milk; life cycle.

1. Introduction

Dairy and meat products represent the foods with the highest environmental burden [1, 2]. Globally, in 2018, the production of 843 million tonnes milk were estimated [3]. According to FAO [3], in this year, the largest amount of milk was produced in Asia followed by Europe and North America. In 2018, in European Union (EU), an amount of 172.2 million tonnes of raw milk was produced [4]. The cow milk represents 96.8% of the raw milk quantity produced. In EU, the main amount of milk is used for fabrication of cheese (37.7%) and butter (29.4%), and only 4.3% for acidified milk [4]. Yogurt is a fermented milk product, rich in protein, Ca, K, P and vitamins B_2 and B_{12} [5]. The production of acidified milk (yogurt and others) in 2019, in the EU28 was 8,174,040 tonnes, while in Romania in the same year were produced 225,490 tonnes. In EU, the largest countries producers of acidified milk were Germany 23%, France 17% and Spain 12%, followed by other countries with a contribution of less than 10% (for example Romania, 3%). The amount of raw milk collected in Romania, in 2018, was 1,163,161 tonnes. In the same year, 215,573 tonnes of sour milk products which include: yogurt, drinking yogurt, whipped milk and other similar fermented milk products were produced [6]. In the last years, consumption of dairy products has registered a fast growing in different parts of the world due to economic growth and income levels [7]. Yogurt is preferred as a dessert and a snack in the European countries, according to the study of Valli and Traill [8]. The environmental impacts of different dairy products were determined in various studies. Liquid pasteurized and Ultra-high temperature (UHT) milk, yogurt, cream, butter and cheese were investigated considering life cycle assessment approach by Djekic *et al*. [9]. Seven dairy plants were included in their study and they collected the data based on the questionnaire and visits to the plants [9]. Life cycle assessment (LCA) was also used for determination of environmental impacts associated with UHT milk in Portugal, Portuguese cheese or yogurt [10-12]. The environmental impacts of Turkish yogurt production were investigated by Uctug *et al*. [13], while Aggarwal *et al.* [14] determined the impacts linked with yogurt packaging. 1 kg of each specific product such as natural, favored, skimmed yogurt, Greek-style natural and favored and other types, obtained in one yogurt factory were investigated by Vasilaki *et al*. [15] in order to assess the water and carbon related environmental impacts. The aim of this study was to investigate the environmental impacts associated with production of yogurt in a Romanian dairy considering the following activities: milk processing, transport, solid waste and wastewater treatments.

2. Experimental

2.1. Goal, functional unit and system boundaries

The purpose of this study was to apply the LCA methodology for modeling the environmental impact of yogurt production. This methodology is included in the GaBi software, which was used in this study for

* Corresponding author. *E-mail address*: cristina.ghinea@fia.usv.ro (Cristina Ghinea)

determination of the impact categories values. The reference to which all input and output are referred is the functional unit (FU) [9]. FU was set for this study as 1 kg of yogurt produced.

In Figure 1 are illustrated the system boundaries considered for this evaluation. Yogurt is a fermented product that differs from cheese by that the clot is not added, the thickening produced is the result of acidification by lactic acid bacteria.

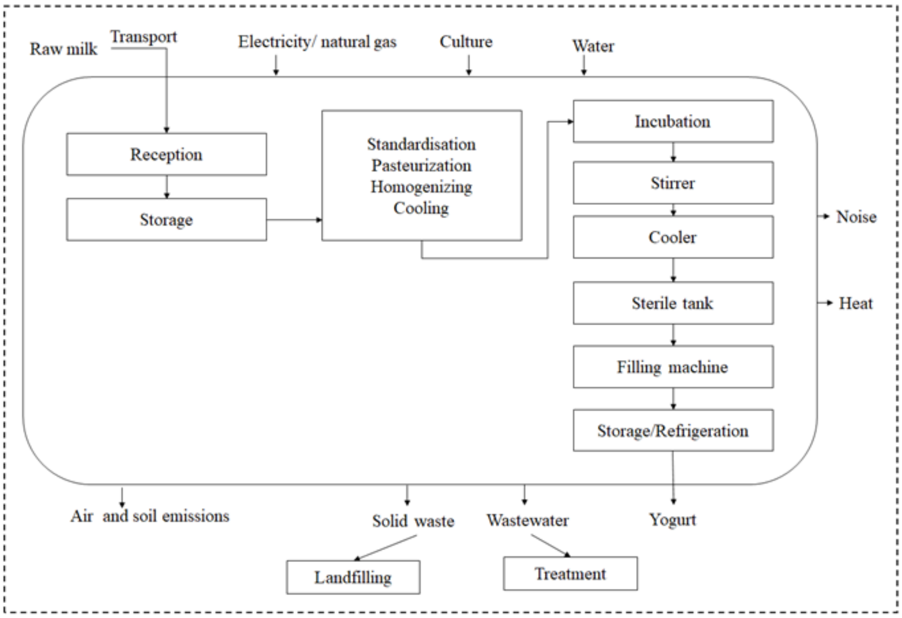


Figure 1. System boundaries adapted upon [16].

The most important ingredients of yogurt are milk, protein (powdered milk), concentrated milk, or UF milk, flavors, stabilizers [16]. The first phase of the yogurt technological process, the qualitative and quantitative reception of the raw material milk, will be carried out in the milk reception sector within the factory. Milk outflow to storage tanks is 2-3 °C and is controlled and recorded. Raw milk goes through the pasteurization stage, where it is directed into the pasteurized milk storage tanks. Pasteurized milk stored in these tanks can follow two directions: (i) one part can go to sterilization and then packing - drinking milk; (ii) another can go through the second stage of pasteurization, then packaging of yogurt [17]. According to Santonja *et al.* [16] for fermentation can be used two starter organisms – *Streptococcus salivarius* subspecies *thermophilus* and *Lactobacillus delbrueckii* subspecies *bulgaricus*. During the lactic acid fermentation (around 4 hours at 20-40 ºC, in anaerobic conditions) from lactose or other sugars is obtained lactic acid which will lead to pH decreasing, aspect important for taste, aroma and preservation of yogurt [16]. Each yogurt fermentation or storage tank in the factory is connected to a sterile air source. The dosing of the cultures necessary for the yogurt preparation is made directly in the milk supply pipe through tight enclosures, thus ensuring that the product does not in any way come in contact with sources of re-infection. In addition to avoid contamination throughout the room, pumped air is filtered through Hepa filters, which eliminates the possibility of dust particles/germs entering the room [17]. Washing and disinfection of milk processing plants is done after each production cycle. The automatic washing process consists of: (i) pre-washing with water recovered from the last rinse step (previous); (ii) washing with alkaline / acid solutions (NaOH or NH_3); (iii) intermediate washing, disinfection with hot water at 85 °C and (iv) final washing with water / final rinsing [17].

2.2. Inventory analysis

During the inventory analysis phase, all the input and output data were collected from various sources, such as reports for dairy factories, various databases, best available techniques, environmental permits and Romanian legislation. The activity profile of the factory is the exclusive milk processing. About 400 tonnes of milk per day are processed in this factory, and regarding the manufacture of yogurt, the factory has a maximum capacity of 72,000 L/day. In the dairy factory, in addition to the yogurt are obtained: approximately 150,000 L of milk for consumption per day, 100,000 L of UHT milk per day, 45,000 kg of cream per day and 6,000 kg of butter per day. Electricity consumption is 0.2 kWh/L of milk falling within the values proposed by best available techniques (BAT) 0.07 - 0.2 kWh/L of milk. The amount of water used strictly for milk processing is 700 m^3/day, while the total water quantity used in the dairy factory is 900 m^3/day. Water consumption is 1.8 L/L of milk, while wastewater is 1.7 L/L of milk [17]. BAT recommends for water consumption values between 0.6 - 1.8 L/L and for wastewater values between 0.8 - 1.7 L/L [16]. According to Santonja *et al.* [16], the product loss during processing of milk can be 3-4% and can occur during cleaning, the run-off during the start-up or from accidental spills. The plant's thermal power plant is responsible for the emissions into the air, as well as the system comprising the air treatment plant. The refrigeration plant that produces water - ice and ensures the cooling of the freezing and cooling tanks has equipment with ammonia and Freon R404A. Other sources of air pollution are the basins of the treatment plant, including the sludge dewatering area and mobile sources (the means of supplying the factory, the internal traffic) [16, 17]. In Table 1 are presented the maximum admissible values for air pollutants indicators. Determined and reference values for wastewater and soil indicators are presented in Tables 2 and 3. The adapted amounts of solid waste generated at one dairy plant per day considered in this study are illustrated in Table 4.

Table 1. Maximum admissible values for air pollutant indicators [18].

Indicators	**The emission limit values**
	mg/Nm^3
Dust	5
CO	100
SO_X	35
NO_x	300

Table 2. Quality indicators for wastewater from milk processing reported to the Romanian legislation [19].

Indicators	**Determined values [17]**	**Maximum admissible values**
pH	6.53	6.5-8.5
	mg/L	mg/L
Total suspended solids	29.37	35
CBO_5	81.62	25
CCO_{Cr}	136	125
NH_4^+	0.045	2
Extractable substance	13.2	20
NO_2^-	0.072	1
NO_3^-	2.6	25
Total phosphorus	0.096	1

Table 3. Determined [17] and reference values [20] for soil indicators.

Indi-cators	**Determined values (mg/kg dry substance)**	**Reference values (mg/kg dry substance)**		
		Normal values	Alert thresholds	Inter-vention thresholds
As	7.05	5	25	50
Cr	41.17	30	300	600
Cr(VI)	0.25	1	10	20
Cr(III)	41.17	-	-	-
Cu	56.68	20	250	500
P	69.85	-	-	-
Pb	13.60	20	250	1000
Zn	76.18	100	700	1500
SO_4^{2-}	156.98	-	5000	50000
NO_3^-	0.05	-	-	-
NO_2^-	110.95	-	-	-
NH_4^+	0.50	-	-	-

Table 4. Amounts of solid waste generated at one dairy plant per day (adapted upon [16, 17]).

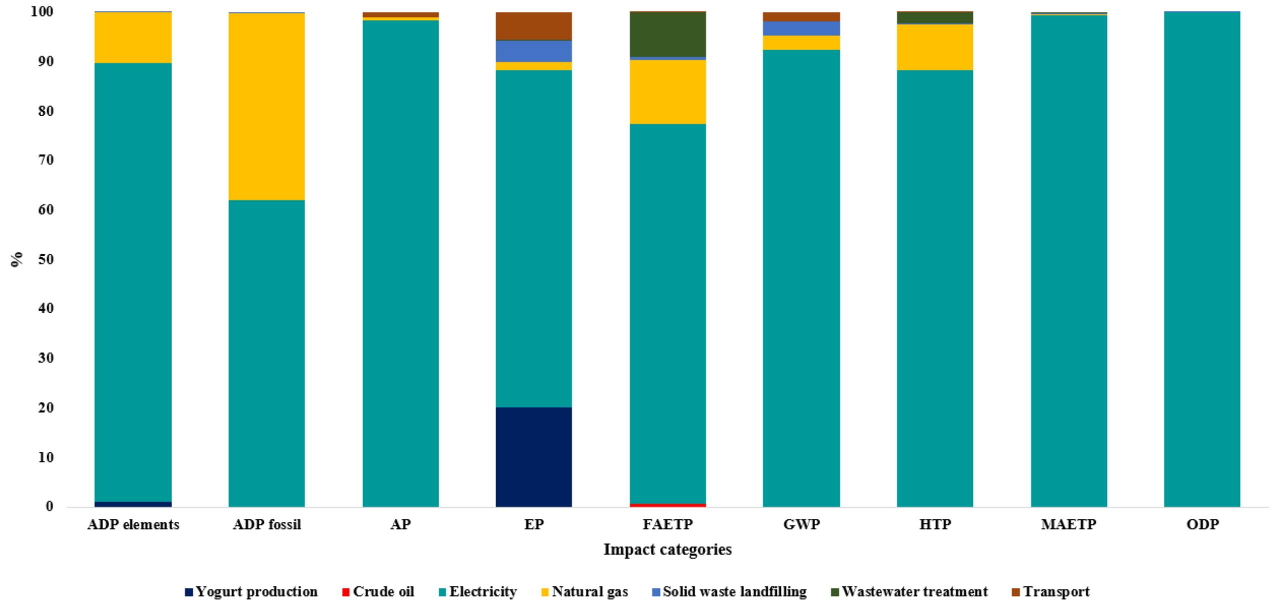
Waste type	**kg/day**
Household waste	394.52
Paper and cardboard packaging	41.10
Plastic packaging	191.78
Wooden packaging	246.58
Mixed packaging	410.96
Non-chlorinated mineral oils	1.10
Fuel oil and diesel fuel	0.55
Lead batteries	2.74
Out of use tires	1.37
Ferrous metal waste	41.10
Non-ferrous metal waste	2.74
Glass waste	0.08

2.3. Impact Assessment

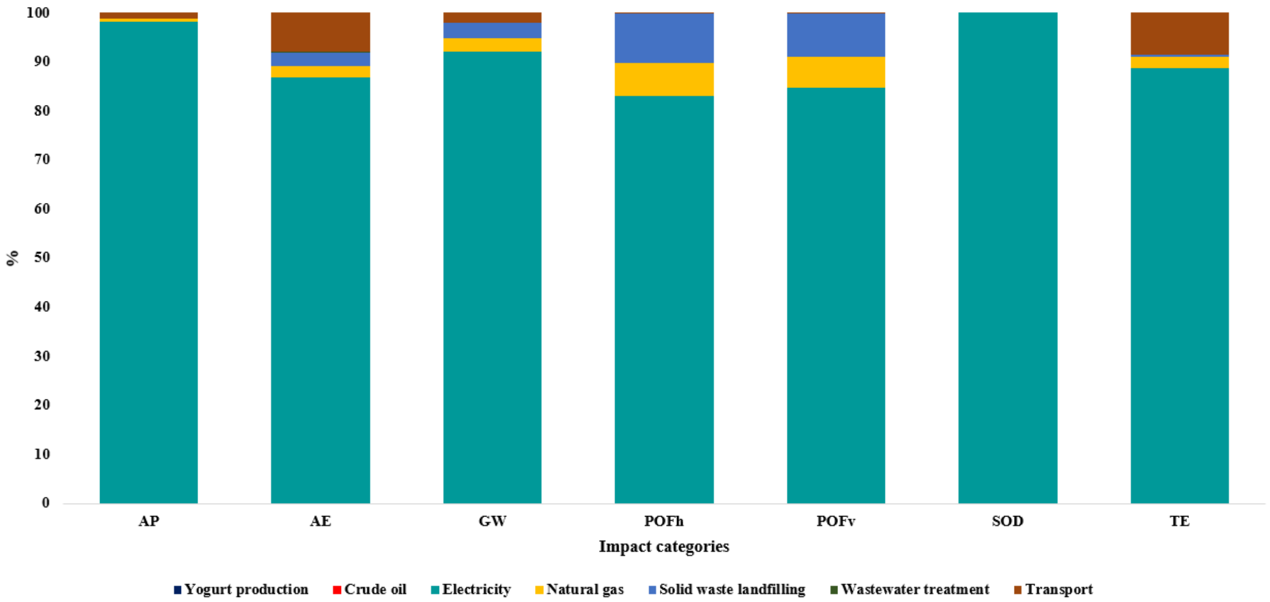
CML2001 - Jan 2016, CML96, EDIP2003, EDIP1997 and ReCiPe 1.08 LCA methods were considered in this study. The environmental impacts included in the LCA methods and selected for this study were: Abiotic Depletion - ADP elements and fossil; Acidification Potential – AP; Eutrophication Potential – EP; Freshwater Aquatic Ecotoxicity Potential – FAETP; Global Warming Potential – GWP; Human Toxicity Potential – HTP; Marine Aquatic Ecotoxicity Potential-MAETP; Ozone Depletion Potential – ODP; Aquatic Eutrophication – AE; Photochemical Ozone Formation - impact on human health and materials – POFh; Photochemical Ozone Formation - impact on vegetation – POFv; Stratospheric Ozone Depletion – SOD; Terrestrial Eutrophication – TE; Nutrient Enrichment Potential – NEP; Photochemical oxidant potential (high NOx) – POPh; Photochemical Oxidant Potential (low NOx) – POPl; Agricultural land occupation – Alo; Climate change Ecosystems – Cce; Climate change Human Health – Cch; Fossil depletion - Fd; Human Toxicity – HT; Photochemical oxidant formation – PMf.

3. Results and discussion

The GWP index determined for yogurt was 2.92 kg CO_2 eq. per kg of yogurt, which is slightly higher compared with results obtained by Djekic *et al.* [9] (1.42 to 2.63 kg CO_2 eq.), González-García *et al.* [10] (1.78 kg CO_2 eq.), lower compared with the results obtained by Uctug *et al.* [13] (4.21 kg CO_2 eq.), but equal with the index determined by Vasilaki *et al.* [15] for Greek-style natural yogurt. Electricity consumption during the yogurt production is the main responsible for GWP (Figure 2. a, b), followed by natural gas consumption, solid waste landfilling and raw material transport. Electricity is consumed during pasteurization, evaporation and cooling stages, which represents the main contributors to the GWP. In this study, the AP value obtained for yogurt was approximately 0.014 kg SO_2 eq. per kg of yogurt, which is a lower value than those obtained by Vasilaki *et al.* [15] (an average of 0.023 kg SO_2 eq.), Djekic *et al.* [9] (values between 0.0144-0.0195 kg SO_2 eq.) González-García *et al.* [10] (0.029 kg SO_2 eq.) or Uctug *et al.* [13] (0.07 kg SO_2 eq.). The main contributor to this impact category is electricity consumption required for production stages, especially for fermentation and cooling. This was observed also by Uctug *et al.* [13]. For EP we obtained 0.86 kg PO_4^{3-} eq. per tonne, which is a lower value compared with other values (24.2 [13] or 6.5 [9] kg PO_4^{3-} eq. per tonne). Yogurt production stages contributes to the EP, also electricity consumption and transportation (Figure 2.a). Results obtained by applying CML2001 - Jan 2016 and EDIP2003 methods are presented in Figures 2a and 2b, respectively. From Figure 2.a it can be observed that the main contributor to all impact categories is consumption of electricity during the yogurt production. The same aspect was observed by investigating the results obtained with EDIP2003 method (Figure 2.b). Emissions resulted from natural gas consumption contribute mainly to ADP fossil, FAETP, HTP and ADP elements. Emissions from solid waste landfilling are contributing to POFh (10%) and POFv (9%). Emissions from transport influences the values of AE and TE, with a contribution of 7.8% and 8.5% to the total values of theses impact categories (Figure 2.b).



a)



b)

Figure 2. Contribution to impact categories of different stages (yogurt production, consumption of crude oil, electricity, natural gas and water in the production of yogurt, solid waste landfilling, wastewater treatment and transport): a) CML2001-Jan 2016 and b) EDIP2003 methods

From Figure 3.a it can be observed that 61.4% of the emissions resulted from transportation of raw materials contributes to GWP, while 38.3% to POCP. Emissions from wastewater treatment are mainly responsible for EP, contributing especially to this type of impact. At POCP are contributing emissions resulted from solid waste landfilling (73.8%), while only 19.2% of emission contributes to GWP (Figure 3.a). Results obtained by applying EDIP1997 method (Figure 3.b) showed that yogurt production mainly contributes to NEP impact category. According to the results illustrated in Figure 4, abiotic depletion, followed by acidification potential and climate change are the main impact categories affected by the yogurt production. Normalized values (in PE = person equivalents) obtained by applying three cultural perspectives: egalitarian (E), hierarchist (H), individualist (I), included in the ReCiPe 1.08 method are illustrated in Figure 4.b. Since all the values are positive, it can be concluded that activities associated with yogurt production has negative impacts on the environment.

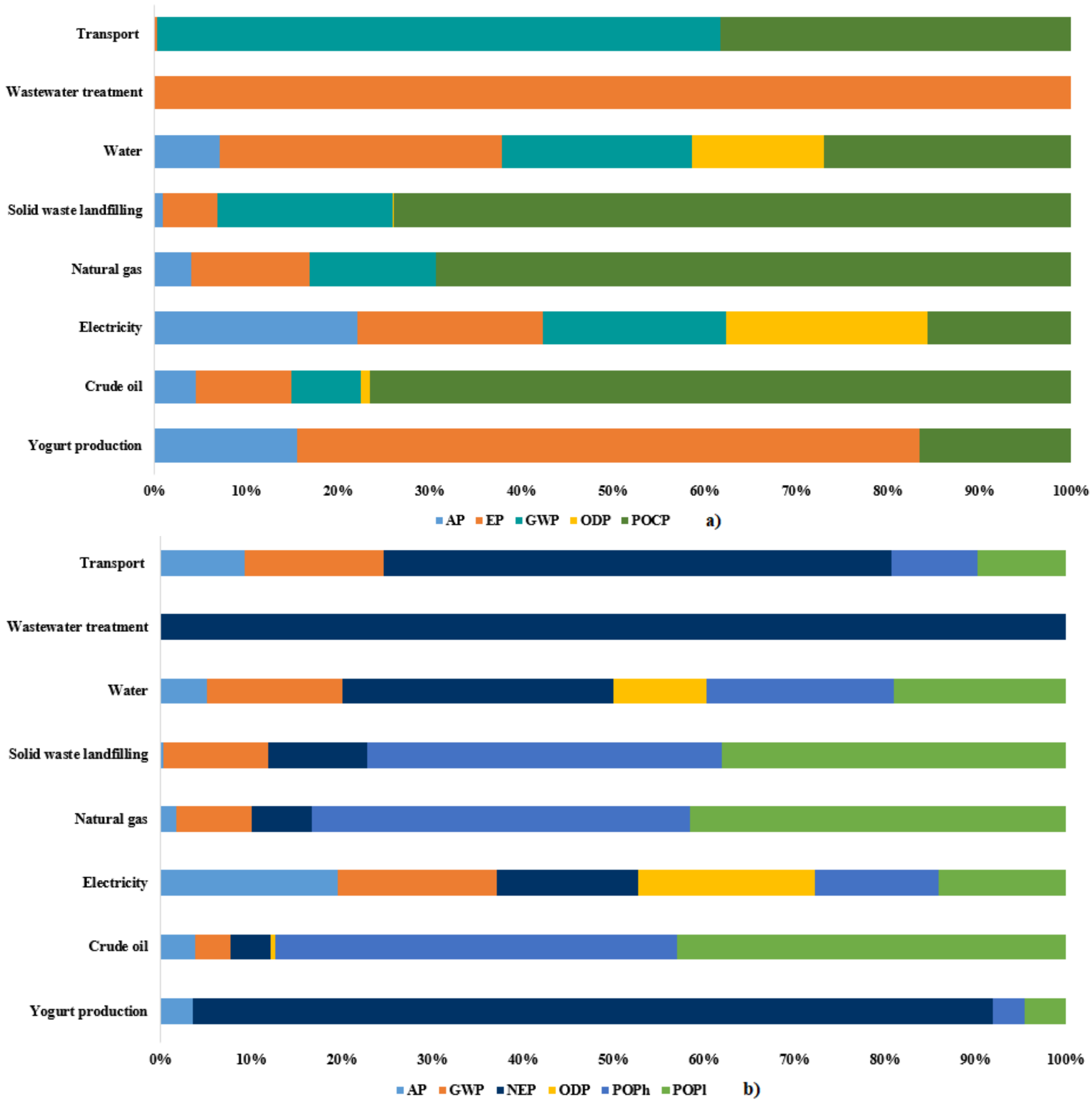


Figure 3. Contribution of different stages to impact categories included in a) CML96 and b) EDIP1997 methods.

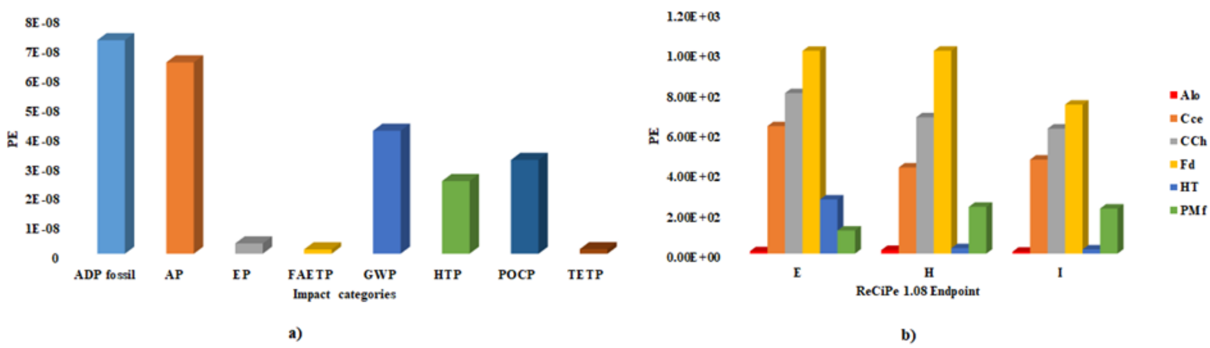


Figure 4. Normalized values of environmental impacts obtained by applying a) CML2001-Jan2016 and b) ReCiPe 1.08 (E, H, I) methods.

4. Conclusions

Environmental impacts associated with the main and secondary activities of yogurt production were evaluated in this paper. Determination of these impacts was performed by applying LCA methodology. Results showed that electricity consumption during the yogurt production is the main contributor to the all impact categories, while emissions resulted from natural gas consumption contribute mainly to ADP fossil, FAETP, HTP and ADP elements. Emissions from transport influences the values of AE and TE, solid waste landfilling contributes to POF and GWP. Wastewater treatment are mainly responsible for EP.

Conflict of interest

Authors declare no conflict of interest.

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