



Life cycle assessment and water footprint scarcity of yogurt

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Abstract

The dairy sector presents various environmental impacts and a transition towards more ecological processes is required. This might be achieved through life cycle assessment, a tool used to evaluate the environmental impacts of a product throughout its life cycle. This paper aims to assess the environmental performance from cradle-to-grave of a dairy product, 1 kg of yogurt. To model the life cycle inventory and life cycle impact assessment phases, the SimaPro software and the IMPACT 2002+ method are used, respectively. Water scarcity is assessed using the Available Water REMaining (AWARE) consensus methodology. The results show that the milk production accounts for the highest impacts due to animal crops, whether imported or cultivated. The latter crops require fertilizers, which contribute by 72.3% to global warming, 72.5% to terrestrial acidification/nutrication, and 64.4% to aquatic eutrophication. Imported crops contribute to all impact categories except for non-carcinogens and terrestrial/aquatic ecotoxicity, for which a positive contribution on the environment is observed due to the use of organic fertilizers for the crops production. Environmental impacts are also imposed on the other categories due to crops production and fuel consumption. It is shown that the use of organic fertilizers and reduction of the distance of importation could be two potential ways to decrease the environmental load for some impact categories. For the water scarcity, the water consumed to produce 1 kg of yogurt is 285 L and the feed production stage contributes to 97.71% of the total water scarcity ($2.00E+01$ m³ world eq).

Keywords Life cycle assessment · Dairy products · Food production · Water scarcity · Sustainability

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1 Introduction

According to the United Nations (UN) organization, the current world population is expected to increase to 9.8 billion by the end of 2025 with a yearly increase of approximately 83 million individuals (UN, 2017). Due to this population growth, a constant increase for nutritional products is expected. Over the past decade, consumers started to be more aware about the quality of the food, its production and manufacturing, and its environmental impacts. Regarding the dairy sector, a 30% increase in the demand for dairy products is predicted by 2024 (OECD/FAO, 2015). To supply such demand, the production capacity must be intensified.

The Lebanese dairy sector has grown and diversified throughout the years, proving its economic standing as a key player in the agro-industrial sector. The dairy industry has long been part of the history of the Bekaa Valley, known as the dairy basin of Lebanon accounting for 150 to 200 tons of milk a day. More specifically, Lebanese yogurt accounts for 18.75% of total dairy production by mass. Six dairy companies provide 75% of the local demand (Mikhael, 2016).

The dairy sector emits a significant amount of greenhouse gases (GHGs) due to the use of various resources for production (Meneses et al., 2012). Within the animal production sector, the dairy milk sector presents the highest GHGs emissions (28–30%) compared to the beef production (28–29%) and the pork production (25–29%) sectors (Weiss and Leip, 2012). Within the manufacturing sector, the dairy industry is considered the fifth largest consumer of energy (Munir et al., 2014). Moreover, the dairy sector presents various environmental impacts due to agricultural activities, industrial applications, water and energy consumption, transport, and packaging disposal. The main environmental indicators for the dairy industries are milk production, transport, energy needs, water-to-milk ratio, energy-to-milk ratio, wastewater generation, chemical cleaning agents, and packaging (Djekic et al., 2014). These environmental indicators could have several environmental impacts, such as eutrophication, acidification, global warming, ozone layer depletion, photo-oxidant formation, and human toxicity. The International Dairy Federation (IDF) considers global warming, acidification, and eutrophication as the main environmental damages since they are the most common indicators related to the dairy sector (IDF, 2015). To take into account these impacts, a sustainable improvement of this sector is needed to identify the environmental threats and try to reduce them as much as possible. In order to meet these arising challenges, a transition to a greener process is needed to account for the environmental impacts of a product from cradle to grave; that is, from the extraction of raw materials to its disposal. Life cycle assessment (LCA) is a comprehensive tool that evaluates all aspects of the environment, from raw material extraction to end of life (ISO, 2006a). This methodology is used to identify hotspots and improve the production chain by reducing the overall environmental impacts imposed by the production process.

2 Literature review

Around the world, research on dairy products is emerging, and relatively limited studies are done on yogurt. For example, several LCA studies have focused on the environmental impacts of milk production. Eide (2002) evaluated liquid milk from three Norwegian dairies, while Fantin et al. focused in 2012 on the evaluation of high-quality Italian milk (Eide,

2002; Fantin et al., 2012). These studies highlighted that the agriculture phase and raw milk production in farms dominated all impact categories. In addition, other LCA studies evaluated the environmental impacts of cheese production. Berlin published in 2002 the first LCA study on Swedish semi-hard cheese, while Finnegan et al. conducted an LCA study in 2017 for 16 different cheese types (Berlin, 2002; Finnegan et al., 2018). Both studies confirmed that raw milk production was the main contributor to the following impact categories: acidification, eutrophication, and global warming. Moreover, the Brazilian case study on the evaluation of the impact of cheese production on the environment conducted by Santos et al. in 2017 confirmed that the environmental impacts of the cheese life cycle were at the level of raw milk produced in the farm and not at the dairy factory (Santos et al., 2017). Furthermore, Djekic et al. (2014) study was carried out on six types of dairy products: cheese, cream, yogurt, butter, pasteurized milk, and ultra-high temperature milk for seven Serbian dairy factories. A total of 29 cradle-to-grave LCAs were performed to quantify impacts on three subsystems: dairy farm, dairy plant, and wastewater treatment. The environmental impacts studied were global warming, acidification, ozone layer depletion, photochemical smog, eutrophication, and human toxicity. The results were consistent and confirmed that milk production in dairy farms presented the largest contribution for all impact categories, particularly in the following categories: global warming, acidification, and eutrophication (Djekic et al., 2014). Another LCA study reported on yogurt in literature is in 2013 by González-García et al. The main conclusions of this study were that milk production has the highest environmental loads and energy requirements, accounting for 91% of the acidification potential (AP), 92% of the eutrophication potential (EP), and 62% of the global warming potential (GWP) (González-García et al., 2013a, 2013b). To date, few studies about cradle-to-grave LCA and water footprint of yogurt can be found in the literature. First, a comprehensive water footprint assessment on a dairy farm and five processing plants was performed in China. However, the water footprint assessment focused on volume rather than scarcity impacts and did not investigate the yogurt itself but rather the dairy industry chain (Bai et al., 2018). The second study was performed by Owusu-Sekyere et al. (2017) to investigate the water footprint of yogurt and different dairy products in South Africa. However, this study used the method of blue, grey, and green water to evaluate the scarcity and did not include any other impact categories. The third study found in literature focused on the carbon and water footprint of yogurt for the context of Catalonia in Spain (Vasilaki et al., 2016). It investigated the water footprint using the water stress index method developed by Pfister et al. (2009). To the best of our knowledge, this paper is a pioneer in evaluating the water scarcity impacts using the Available WATER REMAINING (AWARE) method developed by the Water Use in Life Cycle Assessment (WULCA) consensus working group (Boulay et al., 2015, 2018).

In the Middle East, only one LCA study for yogurt was found in the literature. The LCA on 1 ton of yogurt was performed in Turkey; however, it lacked many components present in the current study. First and foremost, it does not include a water scarcity analysis in which detailed calculations lead to obtaining the total amount of water consumed for the production of 1 kg of yogurt. Furthermore, in the Turkish study, the results were modelled based on six impact categories only (global warming, acidification, eutrophication, photochemical oxidant creation, ozone layer depletion, and human toxicity), whereas this paper investigates 15 impact categories (Üçtuğ et al., 2019).

This current research, the first of its kind in Lebanon for the agri-food industry, highlights the environmental performance of 1 kg of Lebanese yogurt produced by Skaffarm and consumed in Lebanon through a cradle-to-grave LCA study. This work can help promote the implementation of LCA at industrial levels, especially that LCA

is still a new field for the Lebanese context and only few studies have been published to date (El Bachawati et al., 2016; Tannous et al., 2018; Koura et al., 2020; Saba et al., 2020).

3 Materials and methods

A life cycle assessment (LCA) is performed to determine and analyse the potential environmental impacts derived from 1 kg of yogurt (commonly named “Laban”) produced by the industry Skaffarm located in Zahle (Bekaa region) and consumed in Lebanon. In particular, yogurt in this paper refers to a firm white product, similar to plain Greek yogurt. Calculations needed to build the life cycle inventory model are all dependent on the average yearly milk production at the industry (i.e. 72.62E+04 kg), and more specifically the average yearly yogurt production (i.e. 89.0E+03 kg).

The LCA methodology used in this study is based on the ISO 14040 series of standards, which include the following phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation (ISO, 2006a).

3.1 Goal and scope

Following ISO 14040 and ISO 14044 frameworks (ISO, 2006a, 2006b), this non-comparative study intends to quantify the environmental performance and the water scarcity of 1 kg of yogurt through its entire life cycle, i.e. from cradle to grave. Therefore, the considered life cycle stages are the feed production, milk production, yogurt production, packaging, distribution, consumption, and disposal. The study is intended for internal application, but also for external applications to encourage the use of LCA in Lebanese industries.

The functional unit (FU) is used to quantify the function and provide a reference relating the inputs and outputs used for reference flow calculations. The FU used is as follows: “1 kg of yogurt in a transportable container”, which means 1 kg of yogurt produced in the industry and its packaging. The system boundary adopted in the study is cradle-to-grave (from raw materials extraction to end-of-life) and is represented in Fig. 1.

3.2 Life cycle inventory

The life cycle inventory is modelled using the SimaPro (v.9.0) software (Goedkoop et al., 2013). Primary data are gathered from the site visit done to Skaffarm, such as the electricity needed for the whole industry, the amount of milk produced by the cattle, the amount of fertilizers and pesticides used during the agriculture of oat and maize, etc. Table 1 shows a pedigree matrix based on Weidema and Wesnaes (1996) indicating and explaining the data quality indicators for the primary data in terms of reliability, completeness, and temporal, geographical, and technological correlations. To determine the secondary data, the ecoinvent database 3.3, European Lifecycle Database (ELCD), and United States Life Cycle Inventory (USLCI) libraries are used (ecoinvent, 2016; European Life Cycle Database, 2006; U.S. Life Cycle Inventory Database, 2012). Examples of secondary data are the amount and type of fuel needed for electricity production. The data are selected from the ecoinvent database to represent as much as possible the country where the process is occurring. Nevertheless, for some processes, no country-specific data are available in ecoinvent. Therefore, in those cases, global (GLO) or rest of the world data

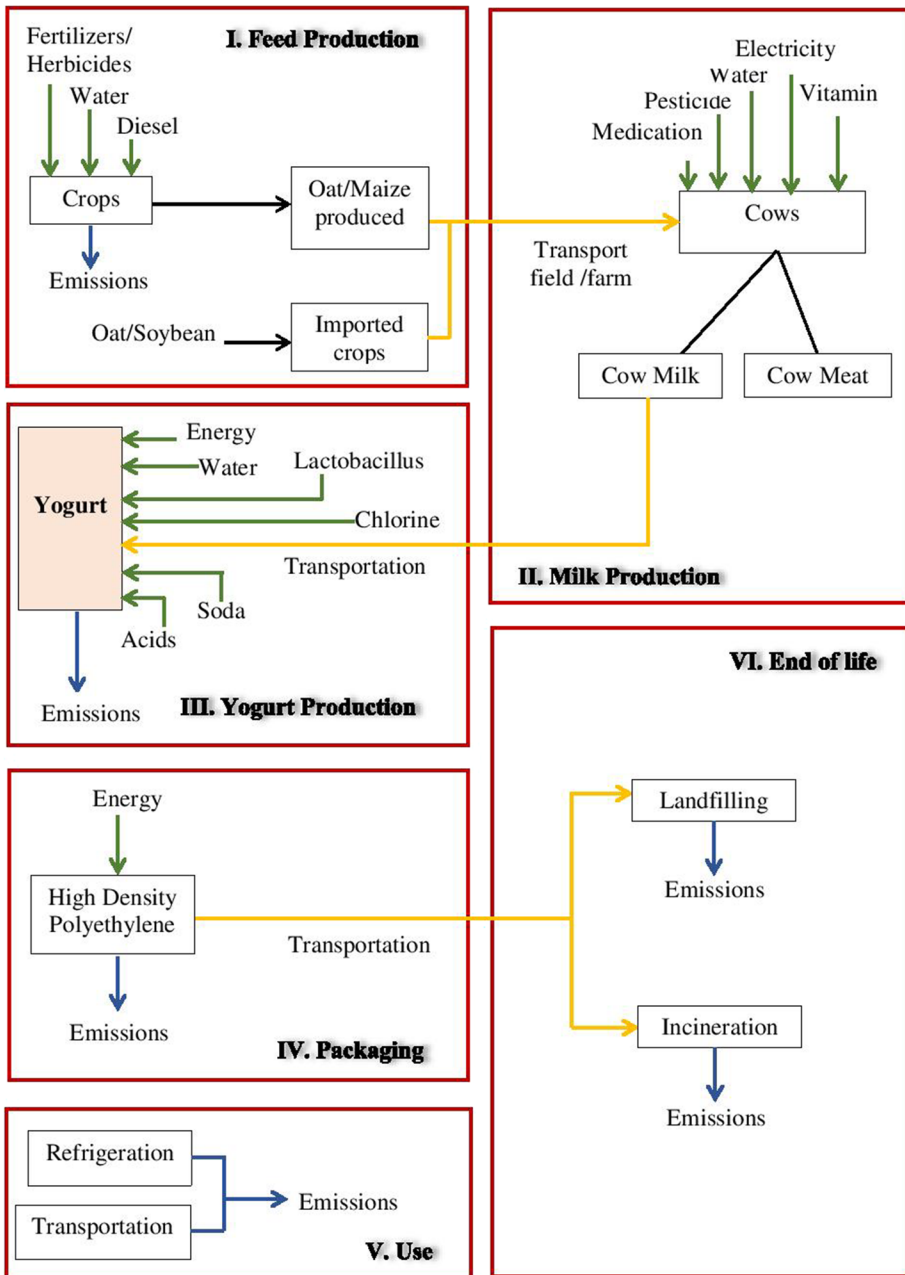


Fig. 1 Yogurt system boundaries

(ROW) are taken into consideration. Other data are collected from the literature such as the economic allocation of milk and calves, the percentage of plastic incinerated and

Table 1 Pedigree matrix for primary data

Data quality indicators	Score	Explanation
Reliability	2	The data have been directly obtained by making a site visit to the industry producing the yogurt; data are based on yearly average measurements of cow feed and production (milk and yogurt). Assumptions are made regarding the use phase data. Transportation distances are computed based on assumptions regarding the port of origin of materials in the considered country.
Completeness	2	The data are determined from a Lebanese industry located in the Bekaa region (most known for its dairy production). These are representative data from a smaller number of sites but for an adequate period.
Temporal correlation	1	The data from the industry correspond to the year of study.
Geographical correlation	2	The data are for Lebanon, in particular for the industry in Bekaa (i.e. data from area under study). The port of origin of imported raw materials for transportation is assumed.
Further technological correlation	2	The data are from the industry itself for the feed production, milk production, and yogurt production stages. Packaging data are obtained from the industry producing it. End-of-life scenarios reflect Lebanese waste treatment scenarios.

landfilled in Lebanon, and the transport allocation from the market to the consumer (Thoma et al., 2013; Abbas et al., 2017; European Commission, 2018).

The feed production phase includes the production of oat and maize needed for cattle feed. To produce the agricultural products, several inputs are required such as grain seeds for cultivation, water for irrigation, and diesel for water pumping. In addition, fertilizers and herbicides are supplied to the soil as nutrients and are essential for plant growth. Based on the data obtained from Skaffarm, the types of fertilizers and herbicides used in the farm are nitrogen/phosphate and phenolic, respectively. It is worth mentioning that oat seeds, maize seeds, fertilizers, and herbicides are imported from Italy. Once oat and maize are produced, they are transported from the field to the farm using agricultural trucks.

Since the crops produced in the farm do not supply the farm demand, other types of grains for the cows feed are imported from Latin America such as maize grain and soybean. In addition, cow manure, considered a by-product, is being reused as a fertilizer. Therefore, it is represented by the following process in SimaPro: “nitrogen fertilizer supply from manure”.

Data obtained from the farm are expressed as mass of material consumed per one milking cow, per day. To calculate the data with respect to the functional unit, each input is multiplied by the number of milking cows considered, i.e. 125, then converted to 1-year consumption. Afterwards, the fraction of yogurt from milk production is calculated knowing that the yearly production of yogurt and milk are $89.0E+03$ kg and $72.62E+04$ kg, respectively. Furthermore, the amounts of maize and oat needed to produce 1 kg of yogurt are also calculated to be $22.3E-01$ kg maize and $3.35E-01$ kg oat. Moreover, an economic allocation is considered for the two co-products, milk and calves, according to Thoma et al. (2013). The economic allocation fractions for milk and calves are 90% and 10%, respectively. The inventory of this stage modelled in SimaPro is represented in Table 2.

The milk production stage includes the production of cow milk. To this end, water is used for cows and farm cleaning. The pesticide used to control pests in dairy cattle and the cows medicine (e.g. butyrolactone compounds) are imported from Spain but represented in SimaPro as rest of world (RoW) due to the lack of available data for Spain. As for the vitamin C, represented by inorganic chemical, it is also taken into consideration as a supplement for the cows and is imported from Latin America. In addition, electricity required in the farm is also accounted for and is represented by the Lebanese electricity grid (LB).

Table 2 Feed production data

Output	Ecoinvent process	Quantity	Unit
3.35E-01 kg Oat	Water	2.21E-01	m ³
22.3E-01 kg Maize	Diesel, market group for, GLO	8.85E-04	kg
	Oat seed, for sowing {GLO} market for oat seed, for sowing Alloc Def, U	9.3E-03	kg
	Maize seed, for sowing {GLO} market for Alloc Def, U	2.23E-03	kg
	Nitrogen fertilizer, market for, GLO	2.97E-02	kg
	Phosphate fertilizer, market for, GLO	3.35E-02	kg
	Phenoxy-compound, market for, GLO	2.23E-06	kg
	Maize grain, feed production, GLO	2.83E-01	kg
	Soybean, feed production, GLO	1.70E-01	kg
	Nitrogen fertilizer, nutrient supply from manure, solid, cattle, GLO	2.5E+01	kg

Table 3 Milk production data

Output	Ecoinvent process	Quantity	Unit
1.60E-01 kg Milk	Water	4.10E-02	L
	Pesticide unspecified, production, RoW	4.46E-05	kg
	Butyrolactone, market for, GLO	2.86E-06	kg
	Chemical, inorganic, production, GLO	1.13E-02	kg
	Electricity, medium voltage, LB	3.10E-02	kWh

Table 3 represents all inputs considered to obtain 1.60E-0.1 kg milk, which is the amount of milk needed to produce 1 kg of yogurt at Skaffarm.

Yogurt production includes all activities taking place in the dairy factory such as milk pre-treatment, homogenization, pasteurization, incubation, cooling, filling, storage, and refrigeration. The output of this stage is the production of yogurt. The inputs include additives such as salt culture (*Lactobacillus*) for lactose fermentation represented by yeast paste. Water is also an essential input used as a softener, and for processing and cleaning. The following products are used for the Cleaning in Place (CIP): soda represented by soda ash, acid represented by nitric acid, and chlorine. It should be noted that CIP soda, CIP acid, and chlorine are imported from Germany; whereas the additive salt culture is imported from Denmark. Electricity for refrigeration and production activities is also taken into consideration and is represented by the Lebanese electricity grid. Table 4 represents the yogurt production data as entered in SimaPro.

The 57 g yogurt packaging is high-density polyethylene (HDPE) produced in Berdawni Plast located in Roumieh, Lebanon. Since plastic moulds are imported mainly from Saudi Arabia and Qatar, the average distance by ship is calculated and used. Furthermore, the process in Berdawni Plast is injection moulding which is also included in the modelling. For the container cap, 2 g of polypropylene granules are considered (Table 5).

Table 4 Yogurt production data

Output	Ecoinvent process	Quantity	Unit
1 kg yogurt	Water	7.13E-03	m ³
	Chlorine liquid, production, GLO	7.75E-03	kg
	Soda Ash, market for, GLO	6.69E-04	kg
	Nitric acid, without water, in 50% solution state, GLO	6.69E-04	kg
	Yeast paste, from whey, at fermentation/CH S	2.67E-06	kg
	Electricity, medium voltage, LB	1.55E-01	kWh

Table 5 Yogurt packaging data

Output	Ecoinvent process	Quantity	Unit
57 g yogurt packaging	High-density polyethylene resin, at plant/RNA	5.50E+01	g
	Injection moulding, market for, GLO	5.50E+01	g
	Polypropylene granulate, market for, GLO	2.00E+00	g

The distribution includes the delivery of the final product to the market using refrigerated trucks; therefore, it considers the electricity required for refrigeration and the diesel consumed by the trucks (Tables 6 and 7). Since yogurt is only distributed in Bekaa according to the industry, the distance from the start to the end of Bekaa is accounted for (i.e. 121 km as per Google Maps (Google, n.d.)). This value is multiplied by 1.057 kg of yogurt and container and divided by 1000 to obtain the ton.km (tkm) unit. Similarly to González-García et al. (2013a, 2013b), the fraction of yogurt unsold in the market represents a small amount and constitute small losses, and therefore is excluded from the study due to the lack of availability of data.

The use phase (Table 7) includes the transportation by car of the yogurt from the market to the consumer (Nielsen et al., 2003). It also includes the activities done by the consumer after the purchase, i.e. yogurt refrigeration. It is assumed that the maximum refrigeration period is 7 days (National Food Safety Database, 2011). Here it should be noted that the transport of yogurt from market to consumer is allocated to 5% of the distance transported since it is assumed that the consumer buys many other products aside yogurt (i.e. 10 km is multiplied by 5% to account the distance market-consumer) (European Commission, 2018).

The end of life stage (Table 8) includes waste management of the plastic containers. It also includes the transportation of the containers to the final waste management destination, i.e. from Zahle to Beirut landfill. It should be noted that two options are considered in the final disposal stages: landfill and incineration. The landfilling and incineration percentages are based on the literature depending on the amount of plastic landfilled and incinerated in Lebanon, i.e. 70% and 30%, respectively (Abbas et al., 2017).

Table 6 Yogurt distribution data

Output	Ecoinvent process	Quantity	Unit
Distribution of 1 kg Yogurt	Freight, lorry, with refrigeration machine, 7.5–16 ton, EURO4, GLO	2.56E-01	tkm

Table 7 Yogurt usage data

Output	Ecoinvent process	Quantity	Unit
Refrigeration and transport of 1 kg yogurt	Refrigeration, small, A	6.8E+00	1.day
	Passenger car, EURO4, RoW	5.00E-01	km

Table 8 End of life data

Output	Ecoinvent process	Percentage (%)	Waste type
Landfilling	Waste polyethylene {RoW} treatment of waste polyethylene, sanitary landfill Alloc Def, U	70	Polyethylene
Incineration	Waste polyethylene {RoW} treatment of waste polyethylene, municipal incineration Alloc Def, U	30	Polyethylene

Transportation (in tkm) is calculated by multiplying the transportation distance by the amount of the material being transported. Table 9 represents the mass and distance of each material used in the modelling.

3.3 Life cycle impact assessment

The life cycle impact assessment (LCIA) method used to calculate the potential environmental impacts of 1 kg of yogurt is IMPACT 2002+. It translates the results of the life cycle inventory (LCI) to 15 different impact categories such as global warming, eutrophication, and acidification (Jolliet et al., 2003). As for the assessment of use and depletion of water resources within LCA, the consensus AWARE method from WULCA working group is followed. In this paper, the water scarcity is calculated in m³ world equivalent for each process used to model the life cycle of yogurt. In particular, the water scarcity is computed by multiplying the quantity of water consumed for each process included in the system boundaries by the AWARE (Available Water REmaining) factor specific to the country where the process takes place and specific to the type of activity (agricultural or non-agricultural) (AWARE Factors, 2018; Boulay et al., 2018). To this end, the direct consumption of water at different life cycle stages and the indirect consumption of water due to other processes such as transport and power generation are considered. Indirect water consumption is determined using the ecoinvent database. The total water scarcity footprint is then evaluated as the sum of the water scarcity for all the considered life cycle processes.

4 Results and discussion

The following subsections discuss the environmental contribution of the materials/processes included in the yogurt life cycle to the different impact categories at the level of characterization. The results are also compared with available literature and different assumptions are tested using sensitivity analyses.

4.1 Contribution to environmental impacts

Figure 2 shows the characterization results for the whole yogurt life cycle including the packaged yogurt production, use phase (consumer product transport and refrigeration at home), and disposal (landfilling or incineration). Table 10 indicates the impact score for each impact category, during each life cycle stage and for the product's entire life cycle. It can be clearly seen that packaged yogurt production shows the highest contribution for all impact categories. Plastic disposal shows little environmental impact in comparison with packaged yogurt production. For example, for terrestrial acidification/nutrication impact category, 88.7% of the impact is due to the packaged yogurt production (5.83 E-02 kg SO₂eq), 5.5% for plastic disposal (3.60 E-03 kg SO₂eq), and the rest is for refrigeration and consumer transport (3.86 E-03 kg SO₂eq).

Figure 3 represents the percentage contribution of the different life cycle stages to the water consumption and water scarcity. Tables 11, 12, 13, and 14 display the quantity of water consumed by each process, the AWARE factor, the country where the process takes place, and the water scarcity in m³ world equivalent. The total amount of water consumed to produce 1 kg of yogurt is 285 L while the water scarcity is 2.00E+01 m³ world eq. The water scarcity contribution is 97.71% (1.96E+01 m³ world eq) for the feed production

Table 9 Transportation data

Material	From-To	Ecoinvent process	Mass (kg)	Distance (km)	tkm
Oat seed	Italy-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	9.3E-03	3684.7	3.42E-02
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	9.3E-03	55.2	5.13E-04
Maize seed	Italy-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.23E-03	3684.7	8.22E-03
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	2.23E-03	55.2	1.23E-04
Nitrogen fertilizer	Italy-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.97E-02	3684.7	1.10E-01
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	2.97E-02	55.2	1.64E-03
Phosphate fertilizer	Italy-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	3.35E-02	3684.7	1.23E-01
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	3.35E-02	55.2	1.85E-03
Herbicide	Italy-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.23E-06	3684.7	8.22E-06
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	2.23E-06	55.2	1.23E-07
Maize grain	Latin America-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.83E-01	10,758.0	3.04E+00
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	2.83E-01	55.2	1.56E-02
Soya	Latin America-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	1.70E-01	10,758.0	1.82E+00
	Beirut-Zahle	Transport, freight, lorry 16-32 metric ton, EURO4 {GLO} market for Alloc Def, U	1.70E-01	55.2	9.36E-03
Produced crops	Field-Farm	Transport, tractor and trailer, agricultural {GLO} market for Alloc Def, U	2.57E+00	10.0	2.57E-02
	Spain-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	4.46E-05	5031.1	2.24E-04
Pesticide	Beirut-Zahle	Transport, tractor and trailer, agricultural {GLO} market for Alloc Def, U	4.46E-05	55.2	2.46E-06
	Spain-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.86E-06	5031.1	1.44E-05
Medication	Beirut-Zahle	Transport, tractor and trailer, agricultural {GLO} market for Alloc Def, U	2.86E-06	55.2	1.58E-07
	Latin America-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	1.13E-02	10,758.0	1.22E-01
Vitamin C	Beirut-Zahle	Transport, tractor and trailer, agricultural {GLO} market for Alloc Def, U	1.13E-02	55.2	6.24E-04

Table 9 (continued)

Material	From-To	Ecoinvent process	Mass (kg)	Distance (km)	tkm
Cleaning in Place Soda	Germany-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	6.69E-04	7649.0	5.12E-03
Cleaning in place acid	Germany-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	6.69E-04	7649.0	5.12E-03
	Beirut-Zahle	Transport, freight, lorry 7.5–16 metric ton, EURO4 {GLO} market for Alloc Def, U	6.69E-04	55.2	3.69E-05
Chlorine	Germany-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	7.75E-03	7649.0	5.93E-02
	Beirut-Zahle	Transport, freight, lorry 7.5–16 metric ton, EURO4 {GLO} market for Alloc Def, U	7.75E-03	55.2	4.28E-04
Lactobacillus	Denmark-Beirut	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.67E-06	8160.0	2.18E-05
	Beirut-Zahle	Transport, freight, lorry 7.5–16 metric ton, EURO4 {GLO} market for Alloc Def, U	2.67E-06	55.2	1.47E-07
HDPE	Qatar/KSA- Berdawni plast	Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	5.50E-02	2095.5	1.15E-01
Containers	Berdawni plast-Zahle	Transport, tractor and trailer, agricultural {GLO} market for Alloc Def, U	5.70E-02	48.1	2.74E-03

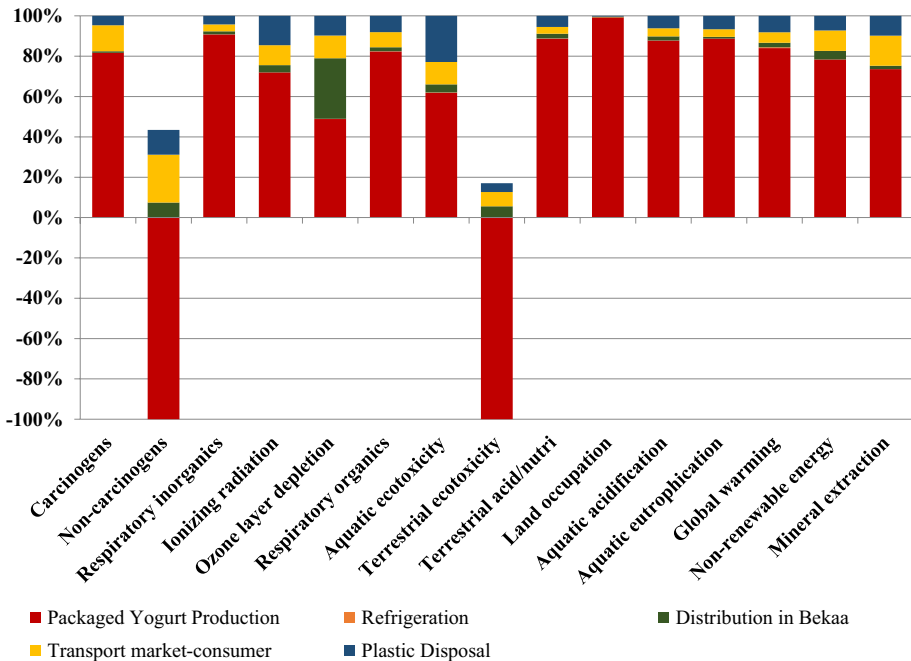


Fig. 2 Characterization results for the yogurt life cycle

stage, 2.04% ($4.08\text{E}-01 \text{ m}^3 \text{ world eq}$) for the yogurt production stage, and it is negligible for the remaining stages (i.e. 0.06% for milk production and 0.19% for packaging, distribution, use, and end-of-life). For the feed production, the water footprint scarcity is mainly due to the amount of water consumed during irrigation and the high value of the AWARE factor.

Figure 4 shows the characterization results of packaged yogurt production, i.e. yogurt production and its packaging. Similarly to Wang et al. (2016), the packaging stage shows little or no environmental contribution for all impact categories except for carcinogens for which the packaging stage contributes to 38.3% ($1.93\text{E}-02 \text{ kg C}_2\text{H}_3\text{Cl eq}$) of the impact and the rest for the yogurt production stage. The reason is that in the packaging stage, the high-density polyethylene is contributing to 86.7% to carcinogens, which is reflected in the packaged yogurt production. In addition, the milk production stage in the yogurt production is accounting for 87% ($2.70\text{E}-02 \text{ kg C}_2\text{H}_3\text{Cl eq}$) for carcinogens as explained in “maize production” and “imported seeds” stages, which is also reflected here in the packaged yogurt production.

For the packaging stage, the injection moulding process done in Berdawni Plast, required for yogurt plastic containers production, is presenting the major contribution to the environment as shown in Fig. 5. The highest contribution can be seen for the following impact categories: 95.4% ($1.22\text{E}+00 \text{ Bq C-14 eq}$) for ionizing radiation, 89.6% ($1.43\text{E}-05 \text{ kg PO}_4\text{-P lim}$) for aquatic eutrophication, and 85.5% ($6.99\text{E}-09 \text{ kg CFC-11 eq}$) for ozone layer depletion. Ionizing radiation is caused by different electromagnetic waves such as X-rays, α -rays, and β -rays present in the injection moulding process required to produce plastic containers (Khalil, 2010). Furthermore, aquatic eutrophication is caused by

Table 10 Impact value per life cycle stage and for the yogurt life cycle. Maize production and imported seeds are sub-stages included in milk production, which is included in yogurt production. Packaged yogurt production includes yogurt production and packaging. Yogurt life cycle includes packaged yogurt production, distribution, use, and disposal

Impact category	Maize production	Imported seeds	Milk production	Yogurt production	Packaging	Packaged yogurt production	Distribution, use	Disposal	Yogurt life cycle
Carcinogens (kg C ₂ H ₃ Cl eq)	2.65E-03	1.97E-02	2.70E-02	3.10E-02	1.93E-02	5.02E-02	8.40E-03	2.85E-03	6.15E-02
Non-carcinogens (kg C ₂ H ₃ Cl eq)	4.14E-03	-2.71E-02	-1.56E-02	-1.49E-02	1.26E-03	-1.37E-02	4.27E-03	1.68E-03	-7.74E-03
Respiratory inorganics (kg PM _{2.5} eq)	2.10E-04	2.46E-03	3.05E-03	3.75E-03	1.96E-04	3.95E-03	2.14E-04	1.84E-04	4.35E-03
Ionizing radiation (Bq C-14 eq)	1.31E+00	4.26E+00	7.80E+00	8.03E+00	1.28E+00	9.31E+00	1.75E+00	1.88E+00	1.29E+01
Ozone layer depletion (kg CFC-11 eq)	1.22E-08	6.34E-08	9.86E-08	1.07E-07	8.17E-09	1.15E-07	9.77E-08	2.30E-08	2.36E-07
Respiratory organics (kg C ₂ H ₄ eq)	3.16E-05	8.10E-04	8.89E-04	9.06E-04	1.74E-04	1.08E-03	1.26E-04	1.05E-04	1.31E-03
Aquatic ecotoxicity (kg TEG water)	2.82E+01	-6.83E+00	7.01E+01	7.41E+01	5.46E+00	7.96E+01	1.97E+01	2.95E+01	1.29E+02
Terrestrial ecotoxicity (kg TEG soil)	8.76E+00	-9.17E+01	-6.77E+01	-6.69E+01	1.47E+00	-6.54E+01	8.27E+00	2.86E+00	-5.42E+01
Terrestrial acidification/nutrication (kg SO ₂ eq)	4.93E-03	4.10E-02	5.39E-02	5.57E-02	2.61E-03	5.83E-02	3.86E-03	3.60E-03	6.58E-02
Land occupation (m ²)	2.99E-02	1.50E+00	1.56E+00	1.56E+00	2.12E-03	1.57E+00	5.80E-03	6.12E-03	1.58E+00
Aquatic acidification (kg SO ₂ eq)	1.07E-03	8.16E-03	1.10E-02	1.17E-02	7.97E-04	1.25E-02	8.69E-04	8.75E-04	1.42E-02

Table 10 (continued)

Impact category	Maize production	Imported seeds	Milk production	Yogurt production	Packaging	Packaged yogurt production	Distribution, use	Disposal	Yogurt life cycle
Aquatic eutrophication (kg PO ₄ -P lim)	9.92E-05	5.48E-04	8.06E-04	8.40E-04	1.60E-05	8.56E-04	4.48E-05	6.38E-05	9.65E-04
Global warming (kg CO ₂ eq)	1.41E-01	1.89E+00	2.26E+00	2.37E+00	1.75E-01	2.55E+00	2.38E-01	2.45E-01	3.03E+00
Non-renewable energy (MJ primary)	1.60E+00	7.66E+00	1.21E+01	1.36E+01	5.68E+00	1.92E+01	3.52E+00	1.78E+00	2.45E+01
Mineral extraction (MJ surplus)	1.43E-02	2.17E-02	6.00E-02	6.14E-02	1.18E-03	6.25E-02	1.41E-02	8.35E-03	8.50E-02

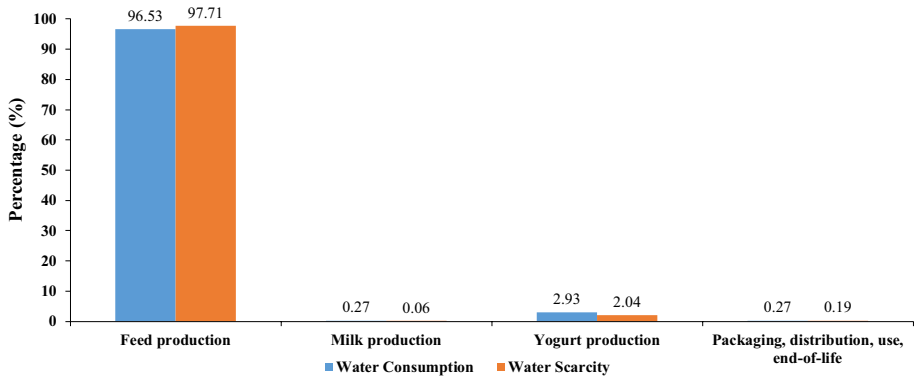


Fig. 3 Percentage contribution of the different stages to water consumption and water scarcity

phosphorus discharges into groundwater, oceans, and rivers, whereas ozone layer depletion is caused by CFC emissions during the propylene processing.

Another highly contributing process is the high-density polyethylene (HDPE). It has an important contribution for many impact categories: carcinogens (86.7%; 1.67E-02 kg C₂H₃Cl eq), respiratory organics (85.9%; 1.68E-04 kg C₂H₄ eq), non-renewable energy (75.2%; 4.27E+00 MJ primary), and global warming (57%; 9.98E-02 kg CO₂ eq). Carcinogens and respiratory organics impact categories are caused by acenaphthene emissions into the air, oceans, and rivers. When this substance reaches water, it can be directly transported to humans via groundwater contamination. In addition to acenaphthene emissions, benzene and formaldehyde are emitted causing environmental impacts in carcinogens and respiratory organics. Regarding non-renewable energy impact category, it is caused by the consumption of crude oil and natural gas. Furthermore, HDPE impacts in global warming are due to carbon dioxide (CO₂) and methane (CH₄) emissions into the air.

Figure 6 represents the yogurt production stage. This stage includes the different inputs needed to produce 1 kg of yogurt. The major contributing input is the production of milk at the dairy farm level. Another major environmental contributor as indicated in Fig. 6 is electricity. The latter, used in the industry, is mainly affecting respiratory inorganics impact category by 18% (6.75E-04 kg PM_{2.5} eq), and carcinogens impact category by 12.1% (3.75E-03 kg C₂H₃Cl eq) due to particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs) that are emitted in the air because of the diesel combustion needed for electricity production. In addition, non-renewable energy impact category is affected by 9.6% (1.31E+00 MJ primary) due to coal, natural gas, and crude oil extraction.

Figure 7 for the milk production stage shows positive environmental contributions for imported crops for three impact categories: non-carcinogens, terrestrial ecotoxicity, and aquatic ecotoxicity, for the reasons previously explained. In addition, the imported seeds contribute to 95.1% (1.48E+00 m²) and 90.2% (8.02E-04 kg C₂H₄ eq) of the impacts for land occupation and respiratory organics impact categories, respectively. This is because imported seeds need terrestrial lands for cultivation. For respiratory organics, methanol and methane released to air are the major reason behind this high contribution. It can also be seen that maize production at farm has a high contribution for mineral extraction (53.1%; 3.19E-02 MJ surplus) due to the mining activities needed to obtain nitrogen and phosphate fertilizers, and for aquatic ecotoxicity (81.9%; 5.74E+01 kg TEG water) due to the emissions of fluorine and anthracene to water. Several authors agreed that the agriculture

Table 11 Amount of water consumed and water scarcity impacts for the feed production life cycle stage. First row indicates direct water consumption

Ecoinvent process	Quantity per FU	Aware factor (m ³ world eq /m ³)	Amount of water consumed per FU	Water scarcity (m ³ world eq)
Water	2.21E-01	Lebanon	2.21E-01	m ³ 1.92E+01
Diesel, market group for, GLO	8.85E-04	Lebanon	3.60E-08	m ³ 1.82E-06
Oat seed, for sowing {GLO} market for oat seed, for sowing Alloc Def, U	9.29E-03	Italy	8.75E-05	m ³ 4.06E-03
Maize seed, for sowing {GLO} market for Alloc Def, U	2.23E-03	Italy	6.96E-06	m ³ 3.23E-04
Nitrogen fertilizer, market for, GLO	2.97E-02	Italy	2.77E-03	m ³ 1.29E-01
Phosphate fertilizer, market for, GLO	3.35E-02	Italy	1.97E-03	m ³ 9.15E-02
Phenoxy-compound, market for, GLO	2.23E-06	Italy	4.24E-07	m ³ 1.97E-05
Maize grain, feed production, GLO	2.83E-01	Brazil	4.81E-02	m ³ 1.28E-01
Soybean, feed production, GLO	1.70E-01	Brazil	5.91E-04	m ³ 1.57E-03
Nitrogen fertilizer, nutrient supply from manure, solid, cattle, GLO	2.50E+01	Lebanon	1.50E-04	m ³ 7.61E-03
Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	4.25E-02	Italy	8.05E-07	m ³ 1.34E-05
Transport, freight, lorry 16–32 metric ton, EURO4 {GLO} market for Alloc Def, U	6.36E-04	Lebanon	1.43E-07	m ³ 7.25E-06
Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.33E-01	Italy	4.42E-06	m ³ 7.37E-05
Transport, freight, lorry 16–32 metric ton, EURO4 {GLO} market for Alloc Def, U	3.49E-03	Lebanon	7.84E-07	m ³ 3.97E-05
Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	4.87E+00	Brazil	9.23E-05	m ³ 1.75E-04
Transport, freight, lorry > 32 metric ton, EURO4 {GLO} market for Alloc Def, U	2.50E-02	Lebanon	3.50E-06	m ³ 1.77E-04
Transport, tractor and trailer, agricultural {GLO} market for Alloc Def, U	2.57E-02	Russia	3.70E-05	m ³ 1.36E-04
Sub-total			2.75E-01	m ³ 1.96E+01

Table 12 Amount of water consumed and water scarcity impacts for the milk production life cycle stage. First row indicates direct water consumption

Ecoinvent process	Quantity per FU	Aware factor (m ³ world eq /m ³)	Amount of water consumed per FU	Water scarcity (m ³ world eq)
Water	4.10E-02 L	Lebanon	4.10E-05 m ³	2.08E-03
Pesticide unspecified, production, RoW	4.46E-05 kg/year	Spain	1.11E-05 m ³	3.47E-04
Butyrolactone, market for, GLO	2.86E-06 kg/year	Spain	8.08E-07 m ³	2.54E-05
Chemical, inorganic, production, GLO	1.13E-02 kg	Brazil	5.39E-04 m ³	1.02E-03
Electricity, medium voltage, LB	3.10E-02 kWh/year	Lebanon	1.80E-04 m ³	9.12E-03
Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	2.39E-04 tkm	Spain	4.53E-09 m ³	1.42E-07
Transport, tractor, and trailer, agricultural {GLO} market for Alloc Def, U	2.62E-06 tkm	Lebanon	3.78E-09 m ³	1.92E-07
Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	1.22E-01 tkm	Brazil	2.31E-06 m ³	4.38E-06
Transport, tractor, and trailer, agricultural {GLO} market for Alloc Def, U	6.24E-04 tkm	Lebanon	9.01E-07 m ³	4.57E-05
Sub-total			7.75E-04 m ³	1.27E-02

Table 13 Amount of water consumed and water scarcity impacts for the yogurt production life cycle stage. First row indicates direct water consumption

Ecoinvent process	Quantity per FU	Aware factor (m ³ world eq /m ³)	Amount of water consumed per FU	Water scarcity (m ³ world eq)
Water	7.13E-03 m ³	Lebanon	7.13E-03 m ³	3.62E-01
Chlorine liquid, production, GLO	7.75E-03 kg/year	Germany	2.89E-04 m ³	3.23E-04
Soda Ash, market for, GLO	6.69E-04 kg/year	Germany	1.59E-05 m ³	1.77E-05
Nitric acid, without water, in 50% solution state, GLO	6.69E-04 kg/year	Germany	1.18E-05 m ³	1.31E-05
Yeast paste, from whey, at fermentation/CH S	2.67E-06 kg/year	Denmark	1.49E-07 m ³	3.03E-07
Electricity, medium voltage, LB	1.55E-01 kWh/year	Lebanon	8.99E-04 m ³	4.56E-02
Transport, freight, sea, transoceanic ship (GLO) market for Alloc Def, U	6.95E-02 tkm	Germany	1.32E-06 m ³	1.47E-06
Transport, freight, lorry 7.5–16 metric ton, EURO4 (GLO) market for Alloc Def, U	5.01E-04 tkm	Lebanon	1.54E-07 m ³	7.81E-06
Transport, freight, sea, transoceanic ship (GLO) market for Alloc Def, U	2.18E-05 tkm	Denmark	4.13E-10 m ³	8.21E-10
Transport, freight, lorry 7.5–16 metric ton, EURO4 (GLO) market for Alloc Def, U	1.47E-07 tkm	Lebanon	4.53E-11 m ³	2.30E-09
Sub-total			8.35E-03 m ³	4.08E-01

Table 14 Amount of water consumed and water scarcity impacts for the packaging, distribution, use, and end-of-life life cycle stages

Ecoinvent process	Quantity per FU	Aware factor (m ³ world eq /m ³)	Amount of water consumed per FU	Water scarcity (m ³ world eq)
High-density polyethylene resin, at plant/RNA	5.50E+01 g	Lebanon	6.33E-04 m ³	3.21E-02
Polypropylene granulate, market for, GLO	2.00E+00 g	Lebanon	3.20E-05 m ³	1.61E-03
Transport, freight, sea, transoceanic ship {GLO} market for Alloc Def, U	1.19E-01 tkm	Qatar	2.27E-06 m ³	1.36E-04
Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO4, R134a refrigerant, cooling {GLO} market for Alloc Def, U	2.56E-01 tkm	Lebanon	9.20E-05 m ³	4.66E-03
Transport, freight, lorry > 32 metric ton, EURO4 {GLO} market for Alloc Def, U	2.74E-03 tkm	Lebanon	3.84E-07 m ³	1.95E-05
Sub-total			7.60E-04 m ³	3.85E-02
Total			2.85E-01 m ³	2.00E+01

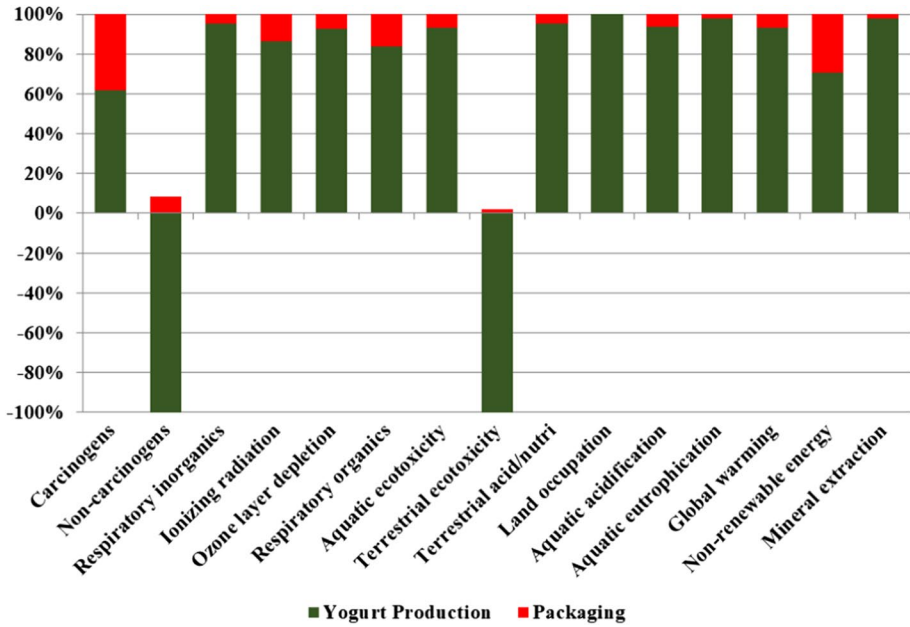


Fig. 4 Characterization results for the packaged yogurt production

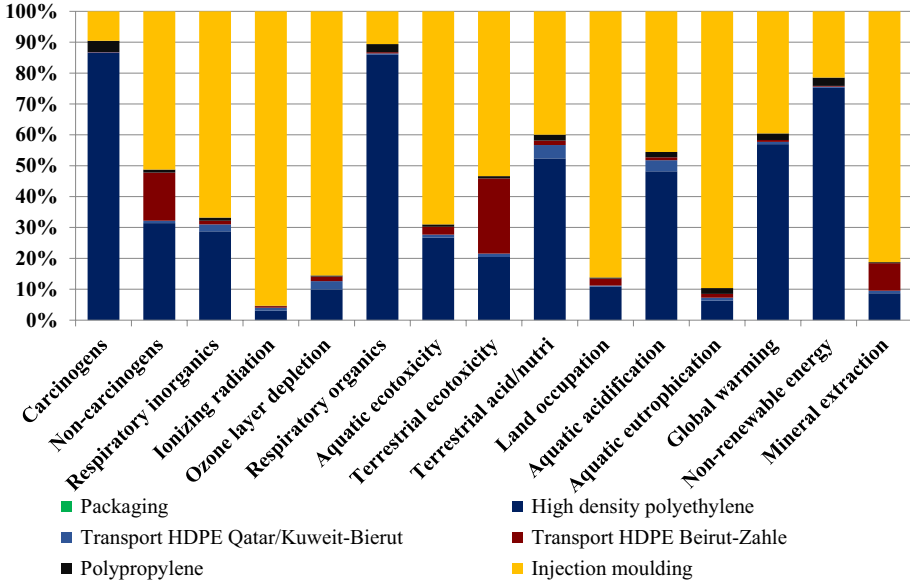


Fig. 5 Characterization results for the packaging stage

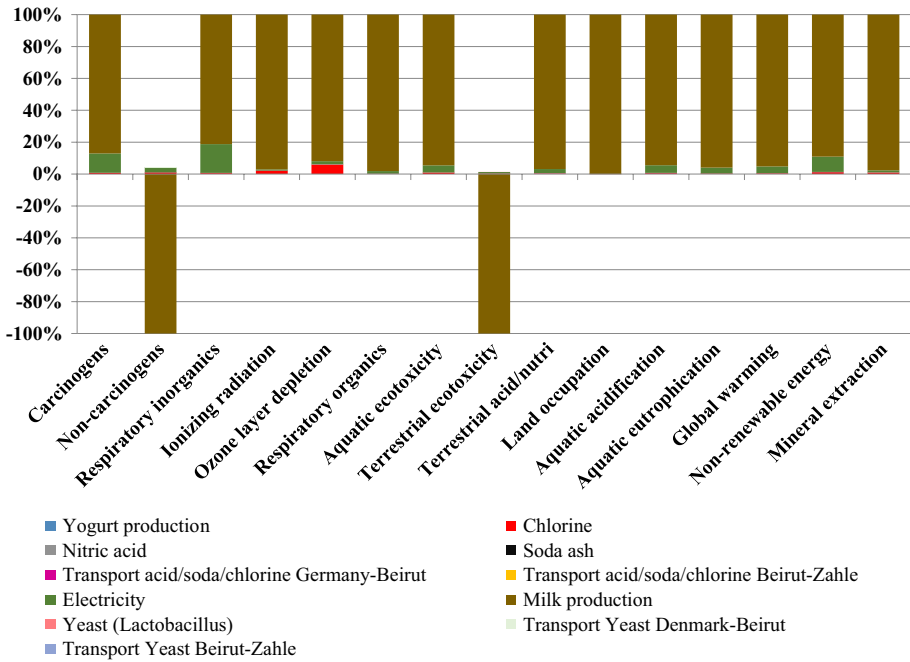


Fig. 6 Characterization results of the yogurt production stage

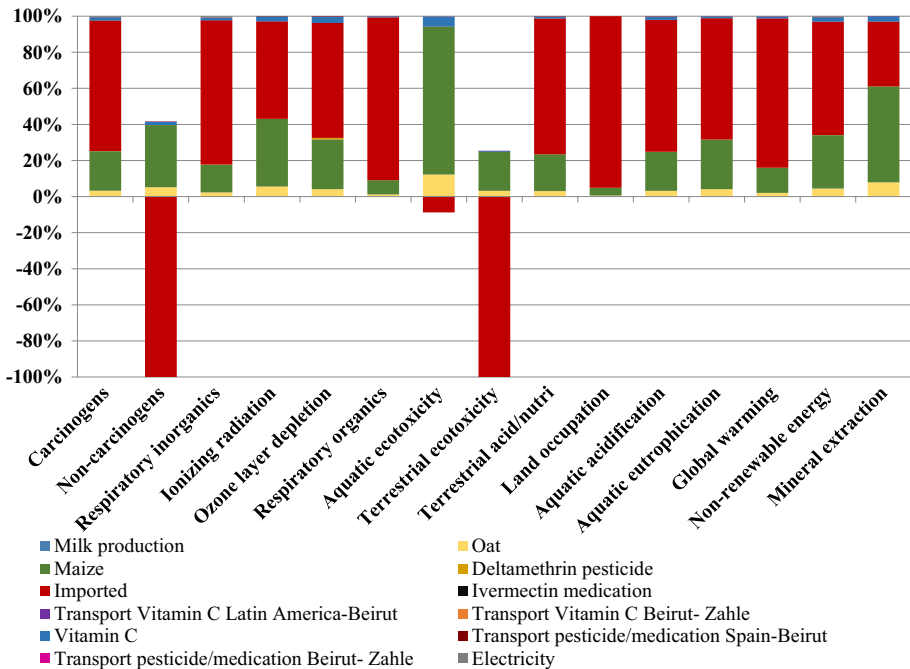


Fig. 7 Characterization results of the milk production stage

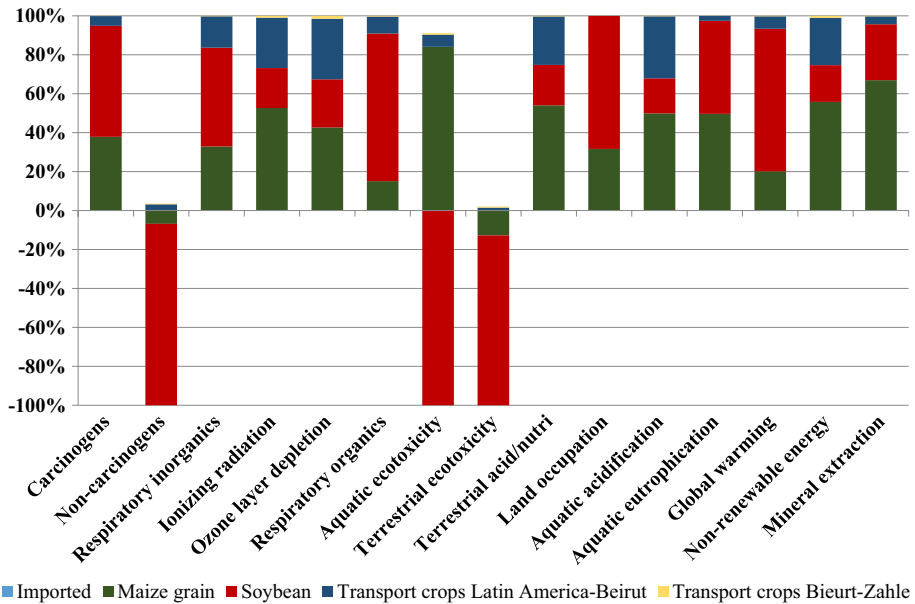


Fig. 8 Characterization results for the imported seeds

production phase has a high contribution in a LCA study for milk (Berlin, 2002; Eide, 2002; González-García et al., 2013a, 2013b).

As shown in Fig. 8, imported seeds have negative and positive environmental contributions for impact categories. Positive environmental contribution for soybean and maize grains is seen for non-carcinogens and aquatic/terrestrial ecotoxicity impact categories. A positive contribution (negative value on chart) means that the process has a positive benefit to the environment. The negative values are seen for non-carcinogens impact category: -93% for soybean, -7% for maize grain, and for terrestrial ecotoxicity impact category: -87% for soybean and -13% for maize grain. For aquatic ecotoxicity impact category, -100% of impact results from the soybean production. The reason for this is the use of both inorganic and organic fertilizers in the production of maize and soybean. Organic fertilizers contain only animal and plants-based materials such as leaves having low toxic releases to the soil comparing to inorganic fertilizers. Knowing that contaminated soil can result in many human health risks, by using organic based fertilizers a lower oral absorption can be observed, as well as a reduction in skin contact and particle inhalation (Saleem et al., 2014). Furthermore, organic fertilizers enrich the soil instead of damaging it; therefore, toxic leakages to the water and soil are avoided.

It can be seen that, regarding the major environmental contribution for the imported seeds stage, non-carcinogens, respiratory organics, and inorganics impact categories show significant impacts, especially for the soybean process selected. Acenaphthene, benzene, and dioxin are emitted in this stage into air and water by various amounts.

In addition, crops transport from Latin America to Beirut is showing a load especially for the respiratory inorganics, ozone layer depletion, ionizing radiation, aquatic acidification, and non-renewable energy impact categories. This is mainly due to GHG emissions and fuel consumption.

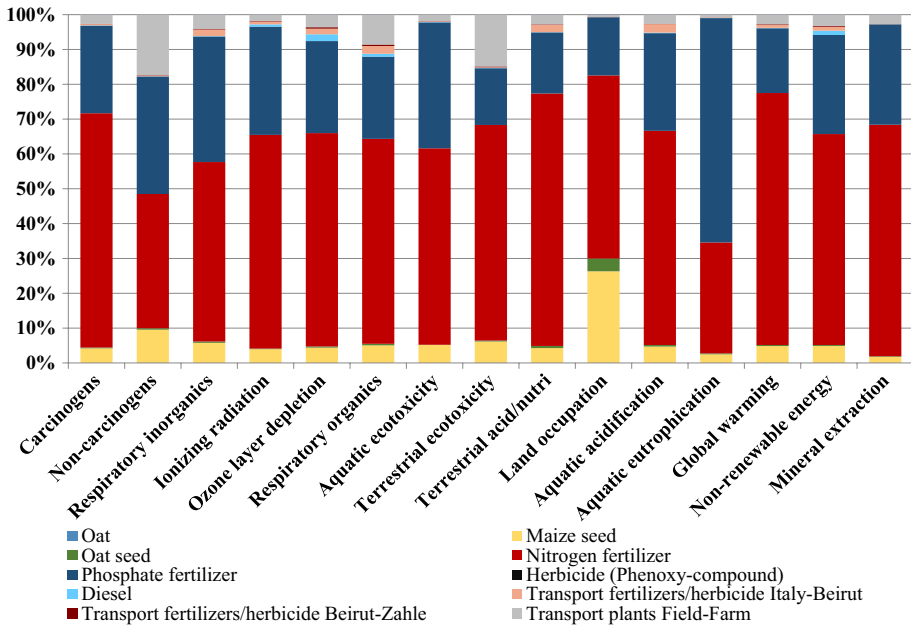


Fig. 9 Characterization results for the maize production stage

Figure 9 represents the characterization results for the maize production cultivation stage. The major environmental contributors for all impact categories are nitrogen and phosphate fertilizers. Nitrogen fertilizers major contribution is for the global warming (72.3%) and terrestrial acidification/nutrication (72.5%) impact categories, whereas phosphate fertilizers major contribution is for the aquatic eutrophication (64.4%) impact category. The reason is that the use of nitrogen fertilizers results in the emission of nitrogenous substances such as nitrogen oxide and ammonia, which are considered as acidification contributors leading to acid rainfalls. Furthermore, nitrogen oxides generate particulate matters considered as GHGs, thus leading to global warming (Hodan and Barnard, 2004). Phosphate fertilizers contain heavy metals, which are considered a limiting nutrient and therefore can lead to algae blooming, thus eutrophication.

4.2 Comparison with literature

In the study of Üçtuğ et al. (2019), the two stages having the highest contribution to the six impact categories studied were raw material supply and production stages, with the latter being the main contributor for 4 out of 6 impact categories. In our study, the main contribution to the life cycle impacts is the packaged yogurt production. In particular, the highest contributors are the animal crops, whether imported or cultivated. The electricity during the production process of the yogurt does not show a major contribution during the yogurt life cycle as is the case for the Turkish study. In addition to modelling the data using different impact assessment methods and LCA software, the difference in the results could be explained by the lack of proper detailed modelling of the farming stage according to the authors (Üçtuğ et al., 2019). Our results are in agreement with the ones

obtained by González-García et al. (2013a, 2013b) and Djekic et al. (2014) who confirmed that raw milk production at the dairy farm has a significant contribution due to the activities performed in the farm that lead to the emissions of ammonia, nitrate, and methane. To improve yogurt production, efforts should be made at the industry level since milk production shows the highest contribution (Wang et al., 2016).

In terms of global warming potential, our result of 3.03 kg CO₂eq per kg of yogurt for the life cycle is in the same order of magnitude as for Turkey (4.21 kg CO₂eq) (Üçtuğ et al., 2019), Spain (2.92 kg CO₂eq for Greek-style natural yogurt) (Vasilaki et al., 2016), Serbia (1.42–2.63 kg CO₂eq) (Djekic et al., 2014), and Portugal (1.78 kg CO₂eq) (González-García et al., 2013a, 2013b). Differences can be attributed to the different production processes and regions considered.

For the water scarcity, similar outcomes were found in Bai et al. (2018) where cow breeding showed the largest contribution to the water consumed. Also, Vasilaki et al. (2016) determined that the water consumed for 1 kg of yogurt is 326 L, which is in agreement with our result of 285 L. Although Owusu-Sekyere et al. (2017) studied the water footprint for several dairy products, no clear comparison can be established since the authors used a different method to evaluate the scarcity footprint.

4.3 Sensitivity analyses

Sensitivity analysis is a significant tool used in a life cycle assessment study to identify which stages or assumptions have a major impact on the final results (Maurice et al., 2000). Since the most contributing stages in the yogurt life cycle are the imported seeds and the maize production stages, three sensitivity analyses are performed accordingly.

Skaffarm seeds are imported from Latin America by transoceanic freight ship for a distance of 10,758 km to Beirut. In this analysis, imported seeds are assumed to be imported from Russia in order to decrease the distance to 5673 km and to verify whether this will alter the results. The reason why Russia is selected is that its agriculture accounts for more than 50% of grain cultivation, and therefore, it could be a potential for seeds importation. A comparison between seeds imported from Russia versus Latin America from an environmental perspective is represented in Fig. 10, in which seeds imported from Russia show a slight decrease in environmental impacts for most impact categories.

Another sensitivity analysis is performed on the packaging stage in order to check the impacts of HDPE bottles used for packaging in the industry in comparison with other packaging types such as polyethylene terephthalate (PET), polyvinyl chloride (PVC), and low-density polyethylene (LDPE). Figure 11 shows that LDPE and HDPE have similar environmental impacts for almost all impact categories, whereas PET and PVC show much higher impacts. For example for the non-carcinogens impact category, HDPE and LDPE result in the emission of 0.02 kg C₂H₃Cl_{eq} in comparison to 0.03 kg C₂H₃Cl_{eq} for PET, and 7.15 kg C₂H₃Cl_{eq} for PVC.

Due to the high contribution observed by nitrogen and phosphate fertilizers in the maize production stage, the third sensitivity analysis is modelled by changing the nitrogen fertilizer to urea since they both have similar compositions. Figure 12 shows a comparison at the level of the whole life cycle when nitrogen fertilizer is replaced with urea.

Figure 13 summarizes the three sensitivity analyses adopted in this study. Sensitivity analysis 1 (SA1) represents the importation of seeds from Russia instead of Latin America, SA2 represents the scenario in which nitrogen fertilizer is replaced with urea, and SA3 represents the scenario in which HDPE is replaced by LDPE. A variation regarding each

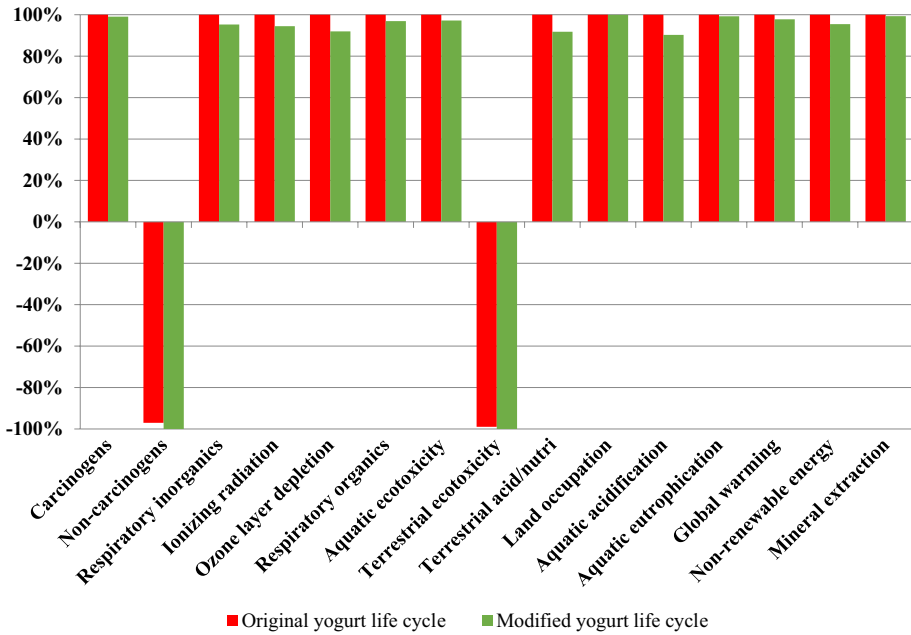


Fig. 10 Comparison results between seeds imported from Latin America versus Russia at the level of life cycle

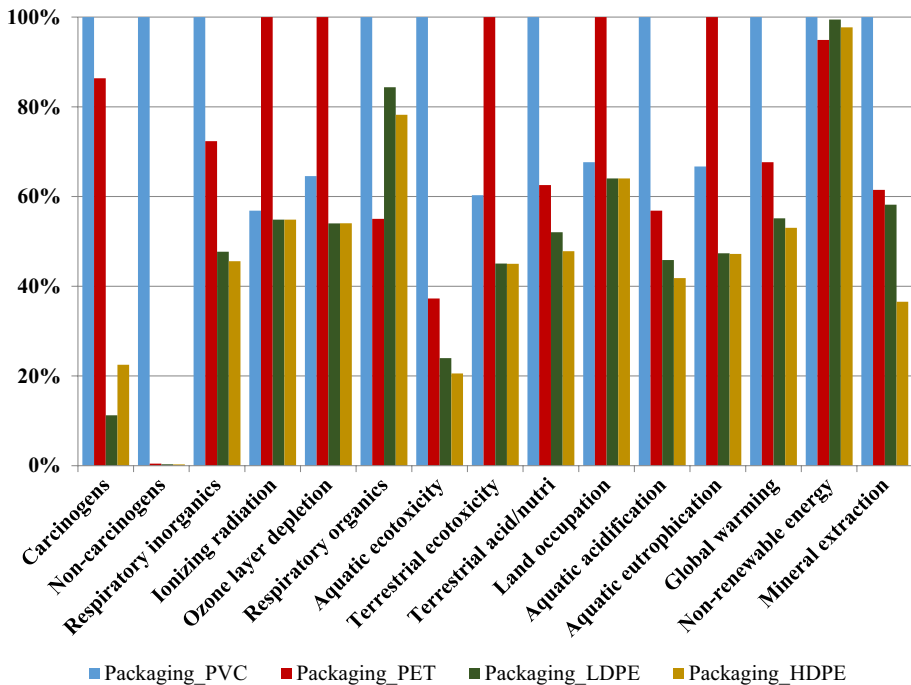


Fig. 11 Comparison between different packaging scenarios

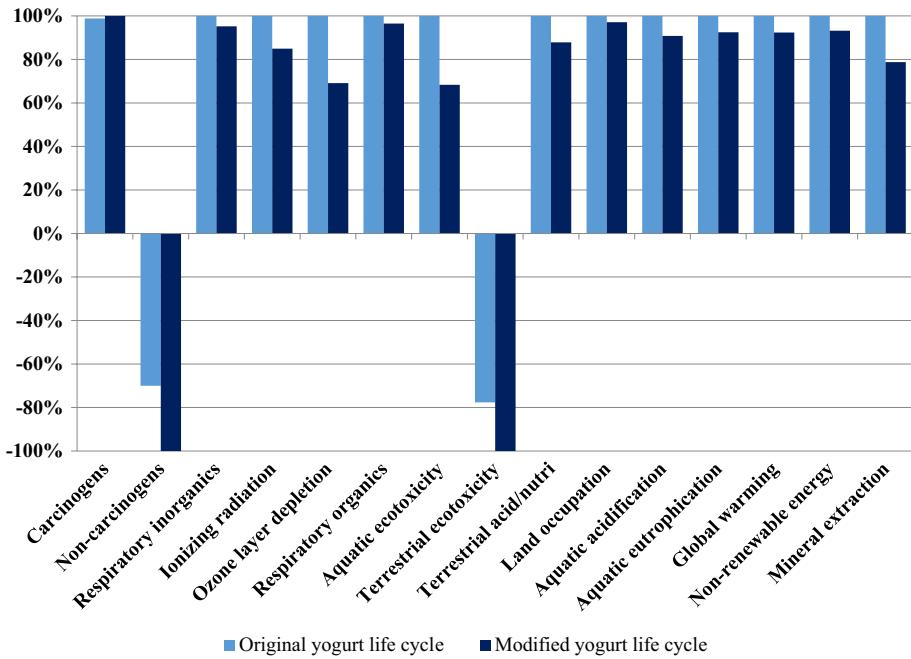


Fig. 12 Comparative characterization between original and modified fertilizers at the level of life cycle

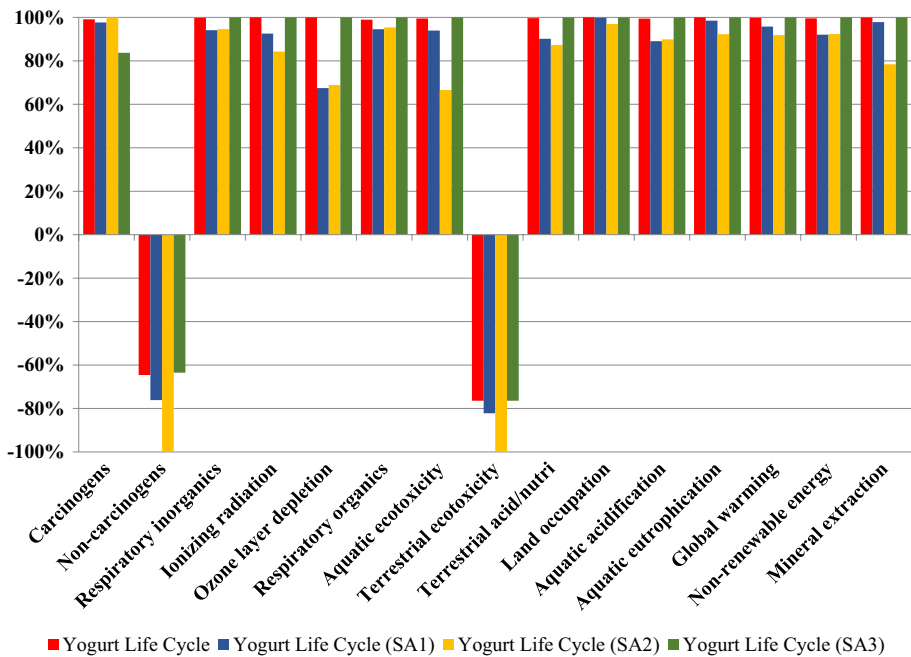


Fig. 13 Comparison between all sensitivity analysis scenarios and original yogurt life cycle

impact category can be seen in which some scenarios show an improvement in the environmental impacts over the original life cycle and some show the opposite. For example, importing the seeds from Russia can reduce 0.1 kg CO₂eq emissions, replacing nitrogen fertilizer by urea can reduce 0.2 kg CO₂eq emissions, and switching to LDPE does not cause any reduction in CO₂ emissions. Hence, in terms of global warming, switching to urea fertilizer seems to offer the optimum environmental choice.

4.4 Uncertainty analysis

In a life cycle assessment study, uncertainties may arise due to incomplete or inaccurate data. Uncertainty analysis is done to check the robustness of the results by quantifying data variability (Björklund, 2002). Monte Carlo analysis is a mathematical simulation applied for quantitative analysis to account for any kind of risk. It is used to recalculate the results by a random selection of values and concluding a probability distribution curve. In this study, 10,000 iterations are used with a stop factor of 0.005 and a confidence interval of 95%. Figure 14 shows the uncertainty analysis results for the yogurt life cycle at the characterization level for all impact categories. It can be seen that the standard deviation varies for each impact category.

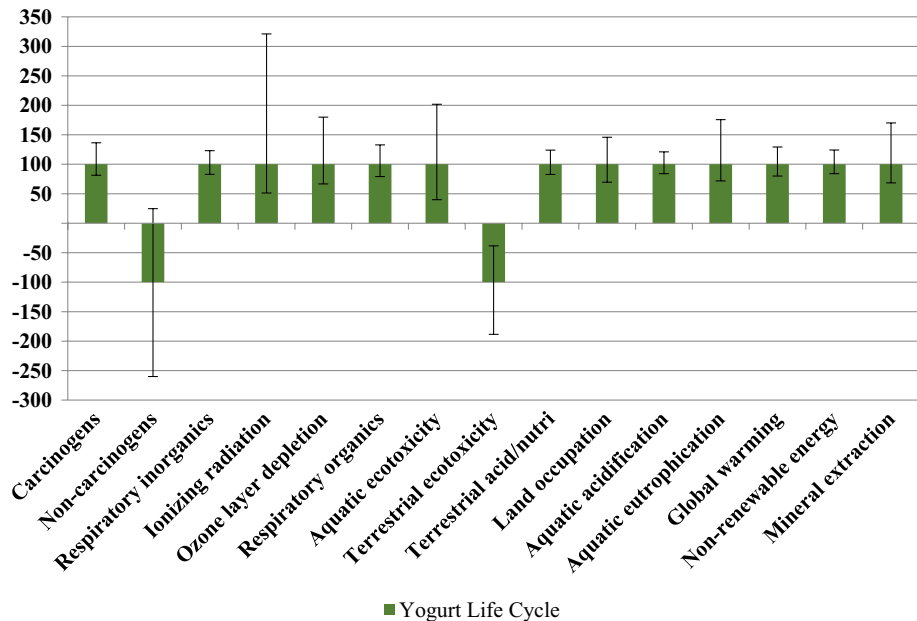


Fig. 14 Uncertainty analysis for the yogurt life cycle

5 Conclusion

In this study, life cycle assessment and water scarcity analyses of 1 kg of packaged yogurt produced by Skaffarm industry and consumed in Lebanon are conducted. In particular, this is performed to determine which stage in the cradle-to-grave analysis shows the highest contribution to the environmental impacts.

This study confirms previous researches that the largest contributor to the environmental profile is raw milk production at dairy farms. The results show that the stages accounting for the highest environmental load are the seeds importation, crops growing at farm, and milk production stages. In the seeds importation phase, the reasons are the use of organic fertilizers and the transportation from Latin America to Zahle. In the crop-growing phase at Skaffarm, nitrogen and phosphate fertilizers are causing the major environmental load. In the milk production stage, maize produced in the farm and the seeds imported from Latin America are the most contributing inputs. Concerning both water consumption and scarcity, the main contributor is the feed production stage.

Although most of the obtained data are in line with existing literature, there is space for improvement and reduction of the environmental impacts of dairy industries in Lebanon. Some measures can be considered to try to reduce the environmental impacts imposed by the agro-food industries in general, and the industry considered in this paper in particular. Several approaches can be adopted such as changing the origin of imported seeds, the type of packaging of the finished product, and the fertilizers used for the local cultivation in the farm. These three ways represent a promising solution to reduce the environmental impacts for some impact categories. Furthermore, another approach would be to import all of the seeds required for cows feed and neglect the local cultivation since it represents one of the major contributors. However, this needs to be further investigated through an economic feasibility study. To reduce the water footprint scarcity of yogurt, one possible way is to use a more efficient irrigation system, in addition to raising awareness at the level of the Lebanese country to implement changes and new policies towards lowering its AWARE factor.

Limitations of this study are derived from the fact that data is used from a single dairy plant since results and calculations are directly linked to raw data obtained from the industry considered. Hence, other studies are essential in determining if similar results would be derived across other dairies in Lebanon.

In order to implement LCA for dairy products and for the food chain in general in Lebanon, it is essential to start spreading the awareness on the necessity of a change regarding the environment, especially in a country that lacks clear sustainability plans. This study can represent a potential for implementing LCA applications at an industrial level in Lebanon since it is a pioneer study for the agro-food sector. Future work can be done to study a similar dairy product such as Ayran (Yogurt beverage) or flavoured yogurt.

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