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Environmental Analysis of a Mashed Tomato Production: an Italian Case Study

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The agri-food sector is one of the most impactful from the environmental point of view, due to resources depletion, land degradation and air emissions. Considering that, in the last years, consumers' interest towards eco-friendly products is increasing, food industries aspire to reach more sustainable productions. In Italy, among vegetable crops that are processed and transformed in different derivatives, tomato ones are amongst the most commercialized. Mashed tomato represents about 50 % of packaged tomato marked volumes and, therefore, an environmental analysis of the emissions related to this production is a very timely topic.

Therefore, the aim of this study is the analysis of the environmental performances of mashed tomato produced by a Southern Italy company using a Life Cycle Assessment (LCA) approach, in order to select the most impacting phases and propose process changes to minimize the related emissions. The system boundaries were set from tomatoes' transportation to the company up to mashed tomato packaging; therefore, they covered the industrial life-cycle stages, following a "from gate to gate" approach.

Primary data were provided by the Italian company, whilst Ecoinvent database was used as source of secondary data; all data were, then, analysed using SimaPro 8.0.5 software, according to ISO 14040-14044, which is the reference standard for LCA. All the quantities related to materials, energy consumption and emissions to air, soil and water were reported to 500 g mashed tomato packaged in Tetra Pak as a reference product. The IMPACT 2002+ method was adopted to evaluate the effect of mashed tomato production on midpoint and endpoint categories.

1. Introduction

In the last years, different research's branches show interest in attainment of natural and environment friendly productions. Moreover, also consumers, knowing that their choices have an impact on ecological problems, tend to address their selections towards ecologically compatible products (Laroche et al., 2001). These considerations have to be made especially in sectors like the food one, which is among the most impactful for the environment (Guinée et al., 2006), due to production, preservation and distribution steps, which consume a considerable amount of energy (Roy et al., 2009). It is, thus, essential to evaluate the environmental impact and the utilization of resources in food production and distribution systems for sustainable consumption.

Life cycle assessment (LCA) is a tool for evaluating, in a quantitative way, environmental effects of a product, process, or activity throughout its life cycle or lifetime, which is known as a 'from cradle to grave' analysis (Reap et al., 2008). In order to perform deep analyses of a specific production, it is also possible to analyse part of the process, using a "from cradle to gate" (Andræ et al., 2004), "from gate to gate" (De Marco et al., 2015a) or "from gate to grave" (Rossi et al., 2015) approach. Different papers based on LCA analyses were published in different areas, such as, for example, energy (González-García et al., 2014), drug delivery systems (De Marco et al., 2016a), food products (De Marco et al., 2016b) and wines productions (Iannone et al., 2014).

Among the products of the food industry, a great interest has been shown by Italian regions, which boast different harvested food products. For example, Pizzigallo et al. (2008) studied the life cycle of a wine farm in Tuscany, De Marco et al. (2016c) studied the life cycle of ale and lager beer productions in Southern Italy, Beccali et al. (2010) looked at the impact of citrus-based products in Sicily, Cellura et al. (2012) applied LCA methodology to evaluate the energy consumption and environmental burdens associated with the production of protected crops in Sicily, De Marco et al. (2015b) studied apple powders production in Campania, De Marco and Iannone (2017) evaluated the LCA of production, packaging and preservation of Southern Italy semi-finished apricots.

Among food products, tomatoes and their derivatives are amongst the most studied one. Many papers were published on LCA of the agricultural stages of tomato production. For example, Torrellas et al. (2012) assessed the environmental impacts of a tomato crop in a multi-tunnel greenhouse on the coast of Almeria (Spain), Antón et al. (2014) proposed a method with the inclusion of new impact categories for agricultural LCA, Payen et al. (2015) compared from an LCA point of view local and imported tomatoes, Dias et al. (2017) proposed life cycle perspectives on the sustainability of Ontario (Canada) greenhouse tomato production. On the other hand, some papers focused their attention to the industrial stages tomato derivatives productions. Among them, Karakaya and Özilgen M. (2011) calculated energy utilization and carbon dioxide emissions during the production of different tomato products, such as fresh, peeled, diced, and juiced tomatoes; Del Borghi et al. (2014) performed a “from cradle to grave” LCA analysis on different tomato products, such as tomato purée, chopped and peeled tomatoes; Manfredi and Vignali (2014) performed an in-depth analysis on tomato puree packaged in a glass jar produced in northern Italy. Considering that the majority of papers focused their attention to the impacts associated to the agricultural phases, whereas the number of studies available on processed tomatoes is lower, in this paper, an LCA analysis of the industrial stages of mashed tomato produced by a Southern Italy company was performed. It is also important to consider another problem raised in many studies, which is related to the consideration of the industrial process as a “black box”, without taking into account the single unit operations, constituting the process (Sanjuán et al., 2014). As a result, the performed researches are not reproducible and aggregated data did not allow to perform LCA studies on similar products, since the contribution of the emissions of each unit operation to the overall emissions of the process is not known. For this reason, an in-depth analysis of the industrial stages of mashed tomato production was performed in this paper. Moreover, the typical allocation problem in LCA, which refers to criteria for determining how input or output flows of a product or process and their associated environmental burdens should be allocated or partitioned for a product or process that has different co-products, has to be considered. In cases involving multiple products, the first choice is avoiding allocation; this can be done by dividing the unit process to be allocated into two or more sub-processes. In this paper, allocation was avoided and the data considered in the life cycle inventory were not estimated but directly measured from the single unit operations constituting the process.

Therefore, the purpose of this study is the evaluation of the impacts due to mashed tomato production and packaging, choosing as functional unit 500 g of mashed tomatoes packaged in Tetra Pak.

2. Methodology

LCA analysis allows to correlate a broad set of data regarding the life-cycle of a product or a process in order to individuate the phases of the process that are critical from an environmental point of view. The main step of an LCA analysis are presented in the following sub-sections.

2.1 Goal definition, functional unit and system boundaries

Goal definition is one of the most important phases of the LCA methodology, because the choices made at this stage influence the entire study. The goal of this study is to evaluate the environmental impacts through an in-depth analysis of the production of mashed tomato, produced and packaged by a Southern Italy company.

The definition of the functional unit (FU) in the case of food products is frequently based on the mass of the product under analysis, and, in any case, is the reference to which all the inputs and outputs have to be related. In this study, the chosen FU is 500 g of mashed tomato produced and packaged in Tetra Pak. The boundaries of the system include all the industrial stages, from tomatoes arrival to the factory to packaging, as it is possible to observe in the flow sheet reported in Figure 1. The agricultural stages and the distribution of the products were not included in the system boundaries, whereas the management of wastewater and organic wastes was taken into account.

2.2 Data collection and life cycle inventory

In Table 1, the main activities of the observed process are reported. The life cycle inventory (LCI) is one of the most effort-consuming step and consists on the activities related to the search, the collection, and interpretation of the data necessary for the environmental assessment of the observed system. The tomatoes are unloaded from 25 tons trucks, and washed with a flow of water. Then, they are manually sorted and collected in boxes. After a mechanical grinding, they are blanched using saturated steam to avoid enzymatic reactions and to reach the right consistency of the final product. Steam is produced using an oil-fired boiler. In the refining operation, the tomato pulp and juice (at 60–70 °C) are separated from skins, which are composted.

Table 1: Process details and assumptions

Process	Characteristics and details
Tomatoes supply to facility	Transport by truck, 25 t
Energy supply to facility	Italian energy mix low voltage
Washing and sorting	Energy and water supply
Grinding	Energy supply
Blanching	T=66 °C; energy, water and fuel oil supply
Refining	Energy supply
Concentration	Double effect; from 5 to 8 °Bx; energy, water and fuel oil supply
Pasteurization	T=115 °C; t=4 min; Energy, water and fuel oil supply
Cooling	T=40 °C; water supply
Packaging	Energy supply, supporting materials and components supply

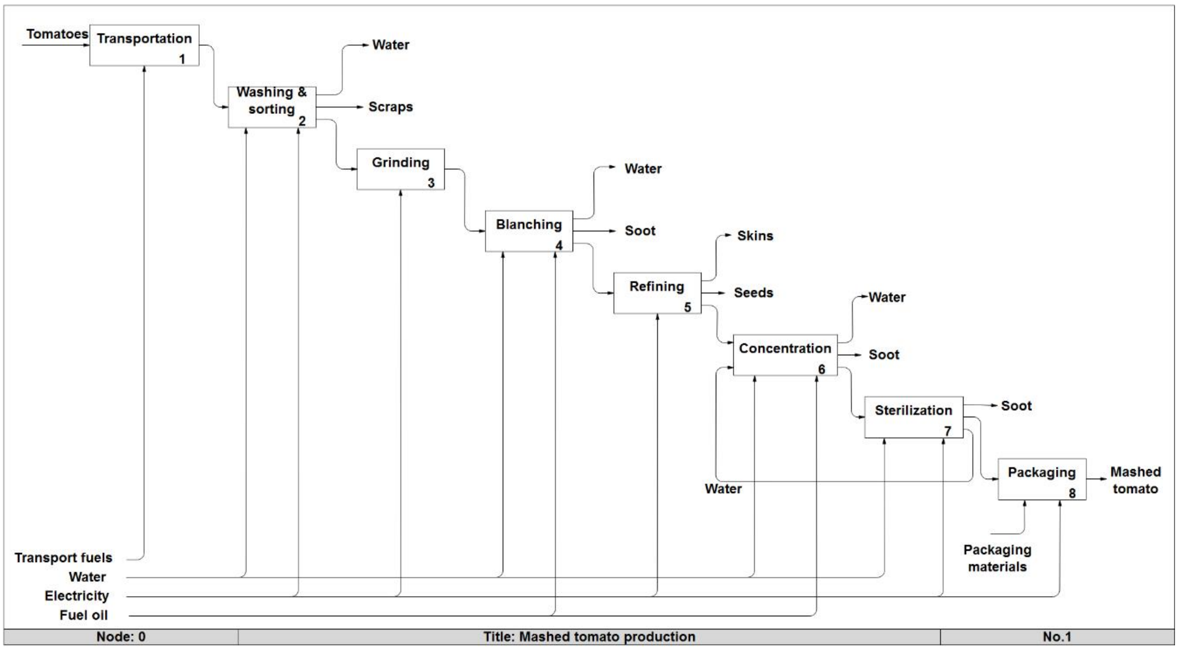

Figure 1: Mashed tomato production: scheme of the process.

The concentration from 5 °Bx to 7 °Bx occurs in double effect evaporators, where water is separated from tomato pulp using saturated steam at 121 °C. The tomato puree is sent to tubular heat exchangers where it is pasteurized at about 115 °C. Once reached that temperature, the puree is kept at that temperature for 4 minutes and, then, it is cooled at 40 °C using water at 20 °C. 500 g of product, then, are aseptically filled in Tetra Pak, which constitutes the primary packaging. 24 Tetra Pak bricks are charged in cardboard boxes that constitutes the secondary packaging and transported to the final storage warehouse through the usage of pallets (tertiary packaging).

Considering that each industrial production is specific and depends on the know-how of a particular industry, only primary data regarding the industrial stages of the process under analysis were recovered. In particular, these primary data, regarding materials and energy consumptions (measured with a wattmeter) for each stage of the process, were supplied by a Southern Italy industry through questionnaires and personal interviews, whereas background data regarding, for example, packaging materials production and inputs and outputs associated with the production of 1 kWh of electricity were retrieved by Ecoinvent 3.1 database. The LCA study was conducted using the LCA software SimaPro 8.0.5 (PRé Consultants, 2014) in agreement with the reference standard for LCA (i.e. ISO 14040-14044). For each unit process within the system boundary, input data, such as energy, water, natural sources and output data in terms of emission to air, water and soil were collected.

3. Results and discussion

The aim of this study is the interpretation of the data collected through the LCI phase and the evaluation and comparison of the impacts related to mashed tomato production. First of all, the results were interpreted using the midpoint categories defined by the IMPACT 2002+ life cycle impact assessment method: carcinogens (C), non-carcinogens (NC), respiratory inorganics (RI), ionizing radiations (IR), ozone layer depletion (OLD), respiratory organics (RO), aquatic ecotoxicity (AET), terrestrial ecotoxicity (TET), terrestrial acidification/nitrification (TAN), land occupation (LO), aquatic acidification (AA), aquatic eutrophication (AE), global warming potential (GWP), non-renewable energy consumption (NRE) and mineral extraction (ME).

Then, the environmental emissions were linked to four damage categories: human health, ecosystem quality, climate change and resources. The emissions related to the mashed tomato process in terms of midpoint categories are reported in Table 2. A detailed step-by-step analysis was performed, in order to understand which are the stages mainly affecting the emissions; the results are reported in Table 3. In order to visualize the different contributions, the stages of transportation, washing and sorting, grinding, blanching and refining were put together and considered as “preliminary phases”; their contribute was graphically compared with concentration, pasteurization and packaging stages, as it is possible to observe in Figure 2. It is clear that the packaging step is the one mainly affecting the emissions of the process; indeed, the emissions due to packaging materials are higher than 50 % in terms of C, NC, RI, IR, AET, TET, TAN, LO, NRE and ME. Preliminary phases have an appreciable contribute (higher than 20 %) on RI, OLD, RO, TET, AA, AET, GWP, NRE. The contribute of concentration is higher than 10 % on IR, OLD and NRE, whereas the contribute of pasteurization is appreciable only on OLD.

Table 2: IMPACT 2002+ global impacts at midpoint level.

Impact category		Unit	Total
Carcinogens	C	kg C_2H_3Cl eq	3.05E-03
Non-carcinogens	NC	kg C_2H_3Cl eq	2.51E-03
Respiratory inorganics	RI	kg PM2.5 eq	1.13E-04
Ionizing radiation	IR	Bq C-14 eq	1.58E+00
Ozone layer depletion	OLD	kg CFC-11 eq	2.24E-08
Respiratory organics	RO	kg C_2H_4 eq	7.19E-05
Aquatic ecotoxicity	AET	kg TEG water	1.29E+01
Terrestrial ecotoxicity	TET	kg TEG soil	4.65E+00
Terrestrial acid/nutri	TAN	kg SO_2 eq	2.19E-03
Land occupation	LO	m^{2}org.arable	5.47E-03
Aquatic acidification	AA	kg SO_2 eq	9.15E-04
Aquatic eutrophication	AET	kg PO_4 P-lim	3.99E-04
Global warming	GWP	kg CO_2 eq	1.72E-01
Non-renewable energy	NRE	MJ primary	2.50E+00
Mineral extraction	ME	MJ surplus	6.49E-03

Table 3: IMPACT 2002+ impacts at midpoint level for each step of the process.

Impact	Transportat	Washing & sorting	Grinding	Blanching	Refining	Concentrat	Pasteuriz	Packaging
C	6.07E-06	1.67E-05	1.57E-05	1.55E-04	3.05E-05	1.67E-04	3.38E-05	2.62E-03
NC	3.05E-05	1.79E-05	4.41E-06	1.50E-04	4.42E-05	1.61E-04	3.37E-05	2.07E-03
RI	3.66E-06	3.66E-06	4.21E-07	6.65E-06	1.14E-05	7.68E-06	3.23E-06	7.62E-05
IR	3.47E-02	2.59E-02	1.14E-02	1.55E-01	8.39E-02	1.90E-01	9.41E-02	9.84E-01
OLD	3.23E-09	2.41E-10	9.23E-11	3.72E-09	7.51E-10	4.63E-09	2.40E-09	7.35E-09
RO	5.55E-06	4.69E-06	1.35E-07	4.40E-06	1.95E-05	5.51E-06	3.81E-06	2.83E-05
AET	9.22E-01	3.79E-02	3.43E-02	7.01E-01	8.54E-02	8.70E-01	4.37E-01	9.79E+00
TET	9.79E-02	1.86E-01	8.91E-03	1.59E-01	7.71E-01	1.96E-01	1.33E-01	3.10E+00
TAN	1.16E-04	1.22E-04	8.15E-06	1.09E-04	3.88E-04	1.28E-04	6.94E-05	1.25E-03
LO	1.41E-04	5.48E-06	6.92E-06	5.41E-05	6.92E-06	6.19E-05	2.00E-05	5.18E-03
AA	1.92E-05	7.11E-05	2.75E-06	3.89E-05	2.74E-04	4.60E-05	3.19E-05	4.31E-04
AET	2.20E-08	6.89E-05	6.79E-08	1.60E-06	2.91E-04	1.97E-06	1.53E-05	1.98E-05
GWP	2.15E-03	1.78E-02	6.19E-04	4.44E-03	6.55E-02	5.15E-03	5.01E-03	7.17E-02
NRE	3.51E-02	6.88E-02	1.04E-02	2.93E-01	2.44E-01	3.69E-01	2.09E-01	1.27E+00
ME	3.67E-05	2.03E-05	2.11E-05	1.58E-04	3.72E-05	1.74E-04	4.25E-05	6.00E-03

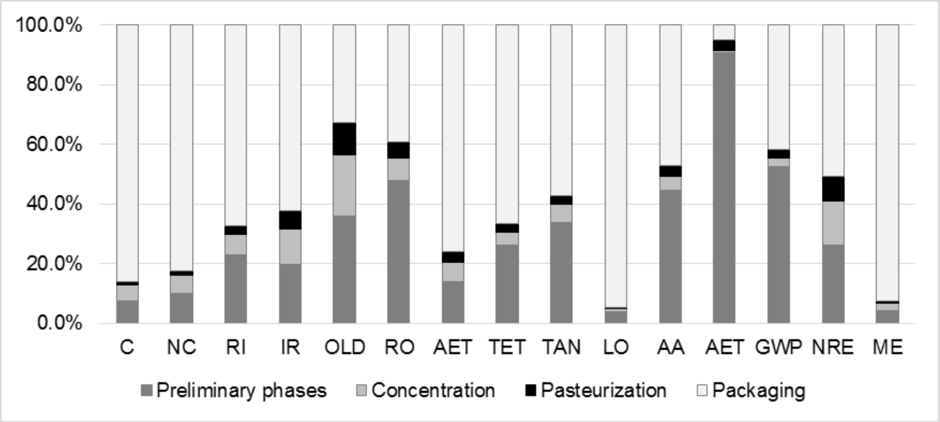

Figure 2: In depth analysis for mashed tomato production.

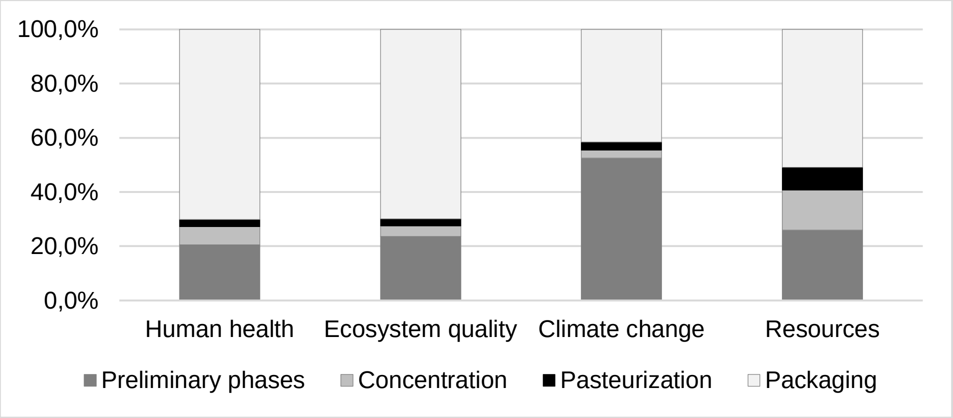

Figure 3: Global damage related to mashed tomato production.

The environmental impacts were then grouped, according to IMPACT 2002+ method, considering the damage on the endpoint categories. Figure 3 shows the emissions due to preliminary phases, concentration, pasteurization and packaging in terms of the damage categories. The human health and the ecosystem quality are mainly affected by the packaging step (70.2 and 69.9 %, respectively), whereas the emissions on climate change are due both to preliminary phases (52.5 %) and to packaging (41.6 %). On all these three categories the effect of concentration and pasteurization is lower than 7 %. The effect on resources is mainly due to packaging (50.9 %); preliminary phases' contribute is 26 %, whereas pasteurization and concentration contributes are equal to 14.7 and 8.3 %, respectively. Considering that all the processes are energy intensive, a remarkable reduction of the emissions can be obtained, adopting electricity produced in sustainable way (Fera et al., 2014).

4. Conclusions

In this work, an in-depth quantitative LCA analysis on mashed tomato production was performed, following a "from gate to gate" approach. Packaging is the main contributor to most of the impact categories, whereas the impact due to the processing phases is relevant (in particular on climate change), because of the electricity and fuel oil used in blanching, pasteurization and concentration stages. A further step will be the modification of primary and secondary packaging materials, in order to lower the emissions related to this very impacting stage.

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