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Uncertainty of input parameters and sensitivity analysis in life cycle assessment: An Italian processed tomato product

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ABSTRACT

In the last years, food industries have sought to achieve more sustainable productions to meet the consumers' needs and limit the damages to the environment. The agri-food sector is one of the most impactful on the environment, due to resources depletion, land degradation and emissions. In Italy, one of the most important sectors in the agri-food industry is the tomato processing. Indeed, Italy is one of the world leading processed tomato producers, representing approximately 13% of the global production and 48% of European production. According to the latest data released by the National Association of the Canned Vegetables Industry (Anicav), Italy's processed tomato production totalled 5.1 million metric tons (MMT) in 2016. Among them, mashed tomato ("passata") represents about 50% of packaged tomato volumes in Italy. The aim of this work is to use a Life Cycle Assessment (LCA) approach to make a "from cradle to grave" analysis of this Italian processed product. In particular, the environmental performances of 500 g mashed tomato packaged in Tetra Pak®, produced by a Southern Italy company, are studied. The uncertainty of the input parameters is taken into account and a Monte Carlo simulation is performed. All data are analyzed using SimaPro 8.4.0 software, adopting ReCiPe 1.12 method at midpoint and endpoint level.

It is clear that both agricultural steps, processing steps and packaging materials' production generate relevant contributions to impact categories at midpoint and endpoint level. In particular, cultivation is the main contributor to the majority of midpoint categories. In order to identify, among the processing steps, the most affecting ones, an in-depth analysis is proposed. Among them, blanching, concentration and pasteurization steps are the main contributors to the emissions. A sensitivity analysis, considering the effect of the substitution of the energy sources, is conducted. Two improved scenarios are proposed to minimize the emissions at endpoint level, and it can be observed that the most promising solution, from the environmental point of view, would lead to a global reduction of 33.3% of the emissions affecting human health, ecosystem diversity and resource bioavailability.

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1. Introduction

The food industry is among the world's largest industrial sectors and food productions significantly contribute to the environmental impact, mainly because of the high energy consumption (Guinée et al., 2006; Roy et al., 2009; Smith et al., 2008). Indeed, all the steps of food productions generate high emissions: agricultural steps require fertilizers, pesticides, energy and water; equipment used during production consumes electric power, natural gas or fuel oil; eventually, packaging materials require high quantity of energy for their production. In a recent study, it was estimated that in Europe the food contribution to the final consumption of goods is about 27% (Tukker et al., 2011). Therefore, nowadays, one of the major challenges of the food processing industries, in terms of process optimization and innovation, is the necessity of decreasing the environmental impact of food productions (Valsasina et al., 2017).

In order to address a production towards a higher sustainability, the environmental impact and the resources' utilization have to be accurately determined through the life cycle of the product. Life cycle assessment (LCA) is a helpful tool, which allows the quantitative evaluation of the environmental impacts of a product, process, or activity throughout its life cycle or lifetime, through a "from cradle to grave" analysis (Reap et al., 2008). In some cases, in order to perform detailed analyses of specific productions, the system boundaries covered only part of the process, using "from cradle to

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gate" (Andræ et al., 2004), "from gate to gate" (De Marco et al., 2015; Jiménez-González et al., 2000) or "from gate to grave" (Rossi et al., 2015) approaches. Different papers based on LCA analyses were published in different areas, such as, for example, food and beverages (Berlin, 2002; Berlin et al., 2007; Biswas and Naude, 2016; De Marco and Iannone, 2017; De Marco et al., 2016; De Marco et al., 2018; Prosapio et al., 2017; Roy et al., 2009), wines' production (Gazulla et al., 2010; Iannone et al., 2016) and wastewater treatments (Al-Salem et al., 2014; Lassaux et al., 2007; Tillman et al., 1998).

An important sector in the agri-food industry is the tomato processing; 41 million tons of tomatoes are processed annually at global level (WPTC, 2016). Italy is one of the world leading processed tomato producers, being the first one in the Mediterranean area and the third one worldwide (after California and China). Many papers were published on LCA of the agricultural steps of tomato production, considering greenhouse or open field cultivations (Antón et al., 2014; Cellura et al., 2012a, 2012b; Dias et al., 2017; Ntinas et al., 2017; Payen et al., 2015; Roy et al., 2009; Torrellas et al., 2012, 2013). For example, Torrellas et al. assessed the environmental impacts of a tomato crop in a multi-tunnel greenhouse on the coast of Almeria (Spain) (Torrellas et al., 2012), with the aim of suggesting alternative cleaner productions in greenhouse areas. Antón et al. included new impact categories linked to water consumption, land use, and pesticides and fertilizers' use, which are important for agricultural LCA (Antón et al., 2014). Payen et al. compared from an LCA point of view local and imported tomatoes (Payen et al., 2015), Dias et al. proposed life cycle perspectives on the sustainability of Ontario (Canada) greenhouse tomato production (Dias et al., 2017).

In addition, only few papers focused their attention on the processing steps of tomato derivatives' productions. Among them, Karakaya and Özilgen calculated energy utilization and carbon dioxide emissions during the production of some tomato products, such as fresh, peeled, diced, and juiced tomatoes (Karakaya and Özilgen, 2011); from their analysis, it can be noticed that the highest energy consumer and the most important source of carbon dioxide emissions is the product transportation to the distribution centers. Del Borghi et al. performed a "from cradle to grave" LCA analysis of different tomato products, such as tomato purée, chopped and peeled tomatoes (Del Borghi et al., 2014); they identified cultivation and packaging subsystems as the most impactful steps on different categories. Manfredi and Vignali performed an in-depth analysis on glass jar packaged tomato puree produced in Northern Italy (Manfredi and Vignali, 2014); packaging, constituted by the glass jar, was the main contributor to most impacts, followed by cultivation and processing steps. Garofalo et al. studied the effect of different steps throughout peeled canned tomato production in Southern Italy on the global warming potential (Garofalo et al., 2017); the most impactful step was landfill disposal, followed by packaging, processing and cultivation steps. De Marco et al. performed a "from gate to gate" study, considering processing and packaging steps in mashed tomato production (De Marco et al., 2017); packaging was the main contributor to the majority of impact categories.

The small number of papers concerning the industrial steps of tomato productions underlines that limited attention was devoted to these steps. Moreover, the uncertainty of the input parameters, which generates a variability in the analysis (Guo and Murphy, 2012), was considered in few papers (Bojacá et al., 2012; Ntinas et al., 2017; Romero-Gámez et al., 2017). Indeed, in LCA studies on food products, it is particularly important to take into account the uncertainty of data, because agricultural inputs are variable with climate variations (Meneses et al., 2016). In the case of tomato production (as in the other cases of agricultural products), the uncertainty of data is mainly due to the variability in local management practices and to the climate changes (Bojacá et al., 2012; Romero-Gámez et al., 2017).

It is also important to mention that in most studies, the industrial process was considered as a "black box", without exploiting the detailed operations constituting the whole process (Sanjuán et al., 2014). As a result, it is difficult to reproduce these studies on similar products because data are aggregated, and the contribution of each unit operation to the overall emissions is not known. For this reason, the aim of this paper is to make a step forward with respect to the existing literature providing an in-depth analysis of all the steps of mashed tomato (or Italian "passata") production, considering the uncertainty of the input parameters.

Moreover, a typical problem in LCA studies is the resources' allocation, which refers to criteria for quantifying the energy consumption of each step. In this paper, resource allocation was avoided and data considered in the life cycle inventory were directly calculated through mass and energy balances on the single unit operations constituting the process.

To sum up, the purpose of this study is an in-depth from cradle to grave LCA analysis of an Italian mashed tomato production (Italian "passata"), taking into account the influence of the uncertainty of the process inputs into the production.

2. System description

In Table 1, the main activities of the process under investigation are reported.

2.1. Cultivation

The Italian territory, due to its mild climate and terrain, presents areas particularly suited for tomato cultivation. The analyzed cultivation area is localized in Apulia region (Southern Italy). The preliminary operations are related to the soil tillage, which needs to be ploughed, disked and harrowed to prepare the transplant bedding some months before (in the previous autumn). Nutrients are provided to the soil through mineral fertilizers (nitrogen, phosphorous and potassium); nitrogen supply is divided into two doses, one before and one after transplanting, which takes place from April to May. In order to protect tomatoes, pesticides, herbicides and insecticides are supplied. Tomatoes have to be irrigated in abundance and with regularity. In spring, they are irrigated 2–3 times a week, but in the warmer months of summer, it is necessary to water them daily. Tomatoes reach the full maturity a couple of months after transplanting, and, therefore, are harvested in August and September and delivered to the processing company through 25 tons trucks after a first sorting of fruits on the field, in order to discard the unsuitable fruits.

Data regarding cultivation steps were supplied by fifty Apulia farmers and ratified by already published data (Garofalo et al., 2017).

2.2. Processing

Fresh tomatoes are unloaded from 25 tons trucks, discharged into a collecting channel and washed with a flow of water, pumped at a flow rate 5 times higher than the downloaded amount of tomato. This water stream delivers the tomatoes to the roller elevator, which carries the product to the sorting station, where it is manually sorted. Green, damaged and discolored tomatoes are discharged and transferred to a local company, which handles the organic wastes coming from all the companies of the area. Water used for washing is considered as "slightly contaminated by

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