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Environmental sustainability of agri-food supply chains in Italy: The case of the whole-peeled tomato production under life cycle assessment methodology

Pasquale Garofalo [a,*], Laura D'Andrea [a], Matteo Tomaiuolo [a], Accursio Venezia [b], Annamaria Castrignanò [a]

[a] *Consiglio per la Ricerca in Agricoltura e l'analisi dell'economia agraria (CREA), Unità di Ricerca per i Sistemi Colturali degli Ambienti caldo-aridi (CREA-SCA), Bari, Italy*

[b] *Consiglio per la Ricerca in Agricoltura e l'analisi dell'economia agraria (CREA), Centro di Ricerca per l'Orticoltura (CREA- ORT), Pontecagnano, SA, Italy*

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ABSTRACT

This life cycle assessment aimed to identify the impacts related to greenhouse gas emissions expressed as $kgCO_{2eq}$ 100- year Global Warming Potential (GWP100) in the whole peeled canned tomato production, considering all the supply chain steps. This study involved companies located in the Southern Italy who produce tinned tomatoes in 400 g tin cans. Tomato production throughout the field, processing, waste treatment, transport and post-consumers waste disposal phases were investigated. The analysis was conducted using a life-cycle approach, the related process flow chart and the relevant mass and energy flows for each production step were identified. Primary data were collected from farmers and processing companies located in the Capitanata plain (Southern Italy), whereas Ecoinvent (v 3.1) provided secondary data. The assessment was carried out by using the ILCD 2011 midpoint method. As regards greenhouse gas emissions, results showed that waste produced during the processing phase was the main contributor to the total environmental impact, followed by the packaging and cropping phase. Mineral fertilization especially nitrogen supply had the highest burdens for the growth phase. Sensitivity analysis was carried out to assess the overall benefit achievable from different mitigation options, highlighting as the composting process and the use of compost replacing the mineral fertilization improved greatly the environmental sustainability of tomato supply chain.

1. Introduction

The agri-food chain generates greenhouse gas (GHG) emissions at all stages from manufacturing and distribution of inputs used at farm level to food processing and preparation, distribution and waste disposal. Direct impacts of agriculture stand at about 10–12% of global GHG emissions, whereas the food sector accounts for more than 20% of the EU-25's total GHG impacts (Tukker and Jensen, 2006; Garnett, 2011). These figures are confirmed by EIPRO (Environmental Impact of Products, European Commission, 2006), and this study has shown that food products are responsible for 20–30% of environmental impacts of total consumption.

The tomato processing industry is one of the most important sectors in the agri-food industry and annually more than 40 million tons of tomatoes are somehow processed at global level (WPTC, 2015). Italy is the first producer in the Mediterranean area and the third largest producer of processing tomato in the world. The total production of processing tomato (*Lycopersicon esculentum* Mill.) in Italy is 5.5 million tons and Apulia region covers 33% of the total production (ISTAT, 2015).

Tomato production is based on a wide range of growing techniques associated with different cropping sites (greenhouse or open field), fertilizer inputs (mineral or organic) and energetic requirements (electricity and fossil fuels). At plant, energy and material inputs as well as waste generate during processing phase can largely vary as a function of the final product (paste, puree or canned tomato, Manfredi and Vignali, 2014; Karakaya and Ozilgen, 2011). In consequence, the environmental impact related to the tomato production can vary considerably between the different

* Corresponding author.
E-mail addresses: pasquale.garofalo@crea.gov.it, garofalopasquale@virgilio.it (P. Garofalo).

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supply chains. Thus, it is essential to implement tools and methodologies that allow producers to assess the environmental impact of their products along the entire supply chain to develop a sustainable tomato production.

Moreover, quantification of the environmental performance of agri-food production such as tomato also allows an increased competitiveness of companies in the food market, catching the attention of consumers towards environmentally friendly products (Laroche et al., 2001).

To assess accurately the environmental impact and the utilization of resources to search for more sustainable products, the entire life cycle should be evaluated. Life Cycle Assessment is a useful methodology for this purpose throughout the "cradle to grave" analysis (Roy et al., 2008). LCA has shown to be a helpful tool to evaluate and compare environmental impacts and economic costs of different agricultural production systems (Thomassen and de Boer, 2005) and support environmental decision-making (Notarnicola et al., 2012). With reference to ISO 14040:2006 and 14044:2006 (International Organisation for Standardization, ISO, 2006a, 2006b) which define the main stages to perform the analysis, LCA is a useful methodology for examining the product life-cycle identifying the environmental impacts from the compilation and analysis of both input and output flows (Rebitzer et al., 2004; Baldo et al., 2008). This methodology not only identifies the environmental burdens during the life cycle of a product, but it can also represent the basis to propose, simulate and validate alternative scenarios to mitigate the environmental impacts along the entire supply chain (Beccali et al., 2009).

LCA can include the assessment of a wide range of impacts (in the form of depletion of fossil fuel and minerals, land use, acidification, eutrophication, ecotoxicity, climate change, ozone layer depletion, carcinogenic substances, respiratory effects and ionising radiation), but agri-food industry consumes a significant amount of energy due to agricultural machinery operation, irrigation, chemical use, transport and processing. This energy consumption contributes to GHG emissions, mainly carbon dioxide (CO_2), methane (CH_4) and dinitrogen monoxide (N_2O) (Horne et al., 2009). Moreover, the agri-food chains and businesses are taking initiatives on the carbon footprint of their products, communicating the related environmental performance via carbon labels because of a more conscious demand from consumers (Sinden, 2009). Hence, there is a need to assess the global warming potential from this food sector to identify GHG mitigation measures.

As regards tomato, most life cycle studies are related to tomatoes grown in greenhouse (Antón et al., 2004, 2005; Muñoz et al., 2004; Boulard et al., 2011; Heuts et al., 2012; Torrellas et al., 2012; Theurl et al., 2014), whereas there are few studies related to open field cultivation (Page et al., 2012; Manfredi and Vignali, 2014). For tomatoes grown in greenhouse, infrastructure accounted for more than 40% of GWP, followed by fertilization with a percentage of 30% on GWP counting (Bojacá et al., 2014). For tomatoes grown in the open field, fertilization resulted in the main contributor to GHG emissions (Martinez-Blanco et al., 2011; Jones et al., 2012). In Italy only a small number of investigations were carried out on the environmental performance of tomato and focussed exclusively on plants grown in greenhouse (Cellura et al., 2012; Del Borghi et al., 2014). In addition, only two studies assessed the environmental impact of processing phase in tomato associated with production of paste, whole-peeled, diced tomato and tomato juice (Karakaya and Ozilgen, 2011) and specifically for tomato puree (Manfredi and Vignali, 2014), considering also the cultivation phase. In Italy, whole-peeled tomato represent about 23.3% of the different tomato derivatives and this share reaches 43% in central-southern Italy and approximately 89% of this product is packed in tin can (Torazza, 2009).

Thus, the present study aimed to investigate the environmental impact due to GHG emissions of whole-peeled tomato, converted into an appropriate equivalent indicator ($kgCO_{2eq}$ 100-year Global Warming Potential, GWP_{100}). GWP_{100} was estimated for the entire supply chain, starting from the production of tomatoes in open field, then processed into whole-peeled fruit, filled in steel can (480 g is the gross weight, 400 g is the net weight including 160 g of preserving juice) and delivered them to the point of sale, considering also the treatment of post-production and post-consuming waste. The study was carried out according to the ILCD Handbook and ISO 14040 guidelines (European Commission, 2012). The software SimaPro (v 8.03; PrèConsultat, 2014) was used for modelling the system under study and its environmental performance. A sensitivity analysis took place in this study to evaluate different and possible mitigation strategies to improve the sustainability along the entire tomato supply chain.

2. Methodology

As indicated by the ISO14040 guidelines, LCA was performed in four steps: goal and scope definition, inventory analysis, impact assessment and interpretation of the results.

Tomato supply chain, as for other agri-food products, consists of three macro-areas or processes. The first one, also called "upstream process" regards tomato management. In this step were involved the tractors and implements to carry out soil management (i.e. ploughing, disking, harrowing, transplanting), fertilization, irrigation, chemical and pesticide application and harvest. The environmental impact due to GHG emissions derived not only from the diesel burned in the tractor engine for soil tillage, fertilizer and chemical application, but also and essentially from the fossil fuel extraction and refining processes, from the input-at-field manufacturing and electricity for the irrigation. In the "core-stream process" tomato fruits were processed during the industrial phase and GHG emissions were related to the energy used for processing and packaging.

In the "downstream process" the analysis focussed on the different management of post-production waste and post-consuming waste (packaging disposal), according to the consumer behaviour.

2.1. Goal and scope definition

As aforementioned, there is scarce literature on environmental impact of the processing tomato supply chain in Southern Italy and even fewer studies focussed on the canned whole-peeled tomato.

Thus, the authors believed that a detailed knowledge of the environmental conditions of an important agri-food sector in Southern Italy, such as processing tomato industry, through reliable and as much as possible comprehensive clear data, was necessary to improve the environmental sustainability of this food sector. In the light of that, the purpose of this study was twofold: i) to evaluate the environmental impact due to GHG emissions (quantified by GWP_{100} index) of canned tomato at the different production steps in Apulia region (Southern Italy); ii) to define material and energy flows causing the highest environmental impact and identify potential mitigation strategies throughout this supply chain. The productivity data of tomatoes were collected from tomato growers at the end of the growing seasons from 2011 to 2014 and expresses as kg ha^{-1} y^{-1} by arithmetic averaging. The most representative crop and field management of the reality under study was obtained from face to face interviews with farmers to identify the energy and material flows on field. One of the biggest tomato industries in Apulia region provided data about the material and energy flows during the processing phase as well as the