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Life cycle assessment of tomato paste production: a case study

Salça üretiminin yaşam döngüsü değerlendirmesine dair bir vaka analizi

Fehmi Görkem ÜÇTUĞ[1*], Zehranur TEKİN[1], Zeynep DAYIOĞLUGİL[2], Ercan ULUSOY[2], Şule OKTAYLAR KEYİK[2]

[1]Department of Mechanical Engineering, Faculty of Engineering, Izmir University of Economics, İzmir, Turkey.
gorkem.uctug@yahoo.com, zehranur.gicir@ieu.edu.tr
[2]Tat Gıda Incorporated Company, Bursa, Turkey.
zeynep.dayioglugil@tat.com.tr, ercan.ulusoy@tat.com.tr, sule.keyik@tat.com.tr

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Abstract

This study involves the cradle-to-gate life cycle assessment of tomato paste production in Turkey. All the data was obtained from a large-scale production company located in north-west Turkey in 2020. CCaLC software with Ecoinvent2 database alongside CML2001 method was used for the analysis and the following impacts were taken into account: acidification potential, carbon footprint, eutrophication potential, human toxicity potential, ozone layer depletion potential, and photochemical smog potential. Functional unit was chosen as 1 kg of tomato paste sold in glass jars. The results show that the biggest contributor to environmental impacts was the raw material supply stage, mainly due to fungicide (for agriculture) and metal (for packaging) use. Energy required for agricultural and production processes were also found to have significant effects of the impacts. The results were found to be in very good consistency with earlier literature. Using photovoltaic panels for meeting 10% of the electricity demand of agricultural and production processes or utilizing tomato harvesting waste to produce biomethane were found to have almost no positive effects as far as impact reduction is concerned. These results show that switching to organic farming seems to be essential if environmental impacts of processed food products such as tomato paste are to be reduced.

Keywords: Carbon footprint, Environmental impact, Food products, Life cycle assessment, Tomato paste, Turkey.

Öz

Bu çalışma, Türkiye'de salça üretiminin beşikten kapıya yaşam döngüsü değerlendirmesini içermektedir. Tüm veriler 2020 yılında Türkiye'nin kuzeybatısında bulunan büyük ölçekli bir üretim şirketinden elde edilmiştir. Analiz için CML2001 yönteminin yanı sıra Ecoinvent2 veri tabanına sahip CCaLC yazılımı kullanılmış ve şu etkiler göz önüne alınmıştır: asidifikasyon potansiyeli, karbon ayak izi, ötrofikasyon potansiyeli, insan toksisite potansiyeli, ozon tabakasını inceltme potansiyeli ve fotokimyasal sis potansiyeli. Fonksiyonel birim cam kavanozda satılan 1 kg salça olarak seçilmiştir. Sonuçlar, çevresel etkilere en büyük katkının, esas olarak mantar ilacı (tarım için) ve metal (ambalaj için) kullanımı nedeniyle hammadde tedarik aşamasından geldiğini göstermektedir. Tarım ve üretim süreçleri için gerekli olan enerjinin de çevresel etkilerde önemli bir payı olduğu tespit edilmiştir. Sonuçların literatürdeki diğer yayınlarla tutarlılığının yüksek olduğu görülmüştür. Tarım ve üretim süreçlerinin elektrik talebinin %10'unu karşılamak için fotovoltaik panellerin kullanılması veya biyometan üretmek için domates hasat atığının kullanılmasının etki azaltma söz konusu olduğunda hemen hemen hiçbir olumlu etkiye sahip olmadığı saptanmıştır. Bu sonuçlar, salça gibi işlenmiş gıda ürünlerinin çevresel etkilerinin azaltılması için organik tarıma geçişin gerekli olduğunu göstermektedir.

Anahtar kelimeler: Karbon ayak izi, Çevresel etki, Gıda ürünleri, Yaşam döngüsü analizi, Domates salçası, Türkiye.

1 Introduction

With ever-increasing world population and slowly but steadily changing climate, food supply security has gained further importance. Located in a subtropical climate zone, Turkey has significant advantages in agricultural production diversity and vegetable agriculture due to its favorable climatic conditions. However, whether the final product will be of high quality depends on how the process from field to table is [1]. According to the 2021 data of the Turkish Statistical Institute (TSI), the most grown vegetable in Turkey is tomato, with an annual production of 13.1 million tons [2]. While they can be consumed fresh, tomatoes are usually processed industrially to obtain several different final products. Amongst these products, concentrated tomato products form the biggest category. Concentrated tomato products can be classified into three groups according to the amount of unsalted dry matter dissolved in water [3]:

Tomato puree: It is a product that is produced by processing the pulp of tomato (*Lycopersicum esculentum P. Mill*) and has a brix (dry matter ratio) of minimum 7% and maximum 20%, excluding additional salt.

Double Concentrated Tomato Paste: It is a product produced by processing tomato pulp and has a brix of at least 28%, excluding added salt, and is made durable by physical means.

Triple Concentrated Paste: It is a product produced by processing tomato pulp and has a brix of at least 36%, excluding added salt, and made durable by physical means.

The largest industry in which industrial tomatoes are used in Turkey is the tomato paste industry, where approximately 85% of the tomatoes produced are utilized [4]. Turkish Food Codex defines tomato paste as a product obtained by thickening the tomato pulp, which is obtained by separating the ripe, solid, red-colored and fresh fruits of the tomato plant from parts such as peel, seed and fiber, and thickening it to at least 28% brix, excluding additional salt, and made durable by physical means

*Corresponding author/Yazışılan Yazar

[3]. While the amount of tomatoes produced to make tomato paste in 2005 was around 2.9 million tons per year, this figure exceeded 4.5 million tons in 2021 [2]. Various studies conducted in Turkey show that the consumption of industrial tomato paste is between 1.5-2 kg/person year [5]. Turkey is also a major exporter of tomato paste, with an approximate worth of $161 million in 2019 [6]. Turkey is currently the fourth largest producer of processed tomato products in the world, with a share of 12% of the global market.

Increasing world population and climate change makes people, companies and governments concerned about the environmental impacts of raw material utilization and energy consumption. In that regard, food industry has a significant contribution to both resource use and consequent environmental impacts [7]. Many food supply activities lead to emission of greenhouse gases (GHGs) and other climate changing factors, such as aerosols and changes in albedo [8]. Agricultural output produces 9,800–16,900 megatons of carbon dioxide equivalent (CO_2 eq.) every year, accounting for 19-29% of global GHG emissions [9]. Many companies focus on improving their energy usage efficiency and make their products more sustainable. While sustainability analyses usually focus on calculating the carbon footprint of the products in many cases, it is essential to investigate the process thoroughly by taking different stages such as raw material supply, on-site production, transportation, storage (if applicable), and end-of-life-treatment into account. Such an approach would require a life cycle assessment, or shortly LCA, of the process [10],[11]. All industrial activities, including food production, contribute considerably to resource consumption and have major environmental implications that should be examined using a life cycle approach [12],[13].

Using various different keywords such as "tomato paste LCA" "tomato paste carbon footprint," "tomato paste environmental impact" a detailed literature search on the LCA of tomato paste in multiple scientific databases was carried out. While several studies concerning the environmental impact analysis of tomato cultivation were found [14],[21], studies on the LCA of tomato products were scarce. Although tomato puree and tomato paste are similar products in terms of production techniques and flavor, studies on the LCA of tomato puree production [23]-[25] were not analyzed in detail. As far as studies that focus on the LCA of tomato paste production are concerned, tomato paste produced in Italy was analyzed in an industrial project [26]; Behzadian et al. calculated the water, energy and carbon footprints of tomato paste produced in the United Kingdom [27] whereas Parajuli et al. performed the cradle-to-grave LCA of several potato and tomato products in the USA, including tomato paste [28]; and Winans et al. carried out the life cycle assessment of diced tomato and tomato paste production in California, USA [29]. As far as studies that involve the environmental impact analysis of tomato paste produced in Turkey are concerned, Karakaya and Özilgen calculated the energy utilization and carbon footprint of several tomato products, including tomato paste, produced in Turkey [30]. They found out that the CO_2 emissions increased twofold in the case of peeled or diced-tomatoes, and increased threefold when juiced compared to fresh tomato. Chemical fertilizers and transportation were found to make the highest contribution to energy utilization and CO_2 emissions. In the most relevant study that was found, Palma et al. compared the environmental impacts of tomato paste produced in Turkey and in France [31]. They calculated GHG emissions, human toxicity potential and eutrophication potential of both products by considering raw material supply, production processes, logistics and post-consumption treatment of the packaging materials. Their results showed that packaging, energy used and steam production are the main hotspots, with the French tomato paste having slightly lower impacts than its Turkish counterpart.

To the best of the authors' knowledge, this particular study is considered to be the most comprehensive life cycle assessment study that involves the analysis of tomato paste produced in Turkey. While the study by Palma et al. has a similar scope to this one in terms of system boundaries, this paper distinguishes itself from the earlier literature in the following regard:

- The impact coverage of this study is greater than the study by Palma et al., covering six impacts instead of three.
- This study provides a detailed life cycle inventory of tomato paste production, enabling the readers to compare different processes for identical/similar products.
- This study not only report the environmental impacts of tomato paste produced in Turkey, but also investigates the effects of implementing potentially impact-reducing actions.

Since Turkey is a major producer and exporter of tomato paste, as indicated above, LCA of tomato paste produced in Turkey must be documented so that the environmental impacts of this material-and-energy-intensive process can be fully understood and corrective actions for agricultural and production processes can be taken. For the reasons described in detail above, this particular paper is regarded as a novel and significant contribution to the existing literature on the LCA of processed food products. To that end, this study involves the LCA of tomato paste produced in Turkey by using real-life data from a major industrial food production company. Information of previous studies conducted on the LCA of the production of tomato paste is presented in section 2 whereas the details of the LCA methodology can be found in section 3.

2 Methodology

2.1 Scope and goal definition

LCA is an internationally accepted approach for calculating the environmental impact of goods and services over their entire lifetime [32]. LCA is conducted according to ISO14040 and ISO14044 standards [33],[34] and other guidelines may be used provided they meet the minimum requirements of these ISO standards. The technical guide in the Reference Life Cycle Data System [35] data system handbook is also an important reference. According to all these standards, an iterative process with four types of activities should be followed when conducting an LCA study [36]:

i) Defining the scope and purpose of the study,

ii) Collecting life cycle inventory (LCI) on the inputs and outputs of the relevant process,

iii) Examining the sources used for the preparation of the LCI in terms of certain data quality parameters and calculating the environmental impacts,

iv) Evaluation and interpretation of findings together with sensitivity and uncertainty analyses.

The inputs and outputs are transformed to various environmental affects in the impact characterization process. Global warming (or climate change) potential is one of the most frequently calculated environmental impacts examined in the literature, although other environmental consequences are also significant depending on the food product, such as potential influence on freshwater or terrestrial eutrophication, human toxicity, or ozone layer depletion [12]. All phases of the food product's life cycle contribute to environmental consequences. According to various research, the most important stages are primary manufacturing, packing, and usage phase [37],[38].

The functional unit was decided to be one 1-kg jar of tomato paste (gross-weight) consumed by the final consumer. There are two reasons for choosing this particular functional unit: First, the 1-kg jar has the highest share in the market as far as tomato-paste products are concerned. Secondly, many other studies focusing on the LCA similar products have used the same functional unit, making comparison easier. The following stages have been modelled in a cradle-to-grave approach:

i) Raw material supply,
ii) Tomato paste production,
iii) Transportation,
iv) Use,
v) End-of-life treatment.

2.2 Life cycle inventory preparation

In CCaLC2 software, life cycle modelling can be implemented by creating five main stages, which are raw material supply; production (which then can be categorized into further sub-stages to simulate the production processes in real life as accurately as possible); storage; use; and waste management (referred to as "end-of-life treatment"). Moreover, the transportation of raw materials and final products from the point of the production to the point of use as well as the transportation of waste from the point of generation to the point of treatment can be modelled in CCALC2 software. In this particular study, the storage stage has been left out as tomato paste does not need any special storage (such as cold storage) at any point during its life cycle. All the remaining stages have been considered as depicted in Figure 1.

Table 1 provides a pedigree matrix that contains information on the data quality indicators, while Table 2 presents detailed energy and material flows associated with each stage. The data quality indicators in Table 1 were used to evaluate the data in Table 2.

All the data was obtained from a real-life tomato paste production company located in northwest Turkey. This particular company has an annual tomato processing capacity of 550,000 tons, which corresponds to approximately 20% of the tomatoes produced industrially in Turkey in one year. The company does not only produce processed foods, it is also one of the biggest cultivators in the country, with a total agricultural cultivation area of almost 2,500 acres. Since almost all the data regarding the production of tomato paste has been acquired directly from the producing company, only a few assumptions needed to be made in this work, as listed below:

- The study from which the environmental impact values of Turkish grid electricity was adopted [40] has been published in 2016. It was assumed that the contributions of different resources within Turkey's grid electricity have remained more or less the same since then (this study was conducted in 2020). The contribution of different resources to the grid electricity were taken as follows: natural gas (32%), imported coal (18%), hydroelectricity (dam-type: 18%), lignite (14%), hydroelectricity (run-of-the-river type: 7%), wind (6%), anthracite (1%), asphaltite (1%), biomass (1%), others (2%). These values are in reasonable consistency with those reported for 2020, when this particular study was conducted. While it is clear that the environmental impacts of Turkish electricity in 2020 would have been slightly different than those in 2016, it is assumed that this difference could be ignored,

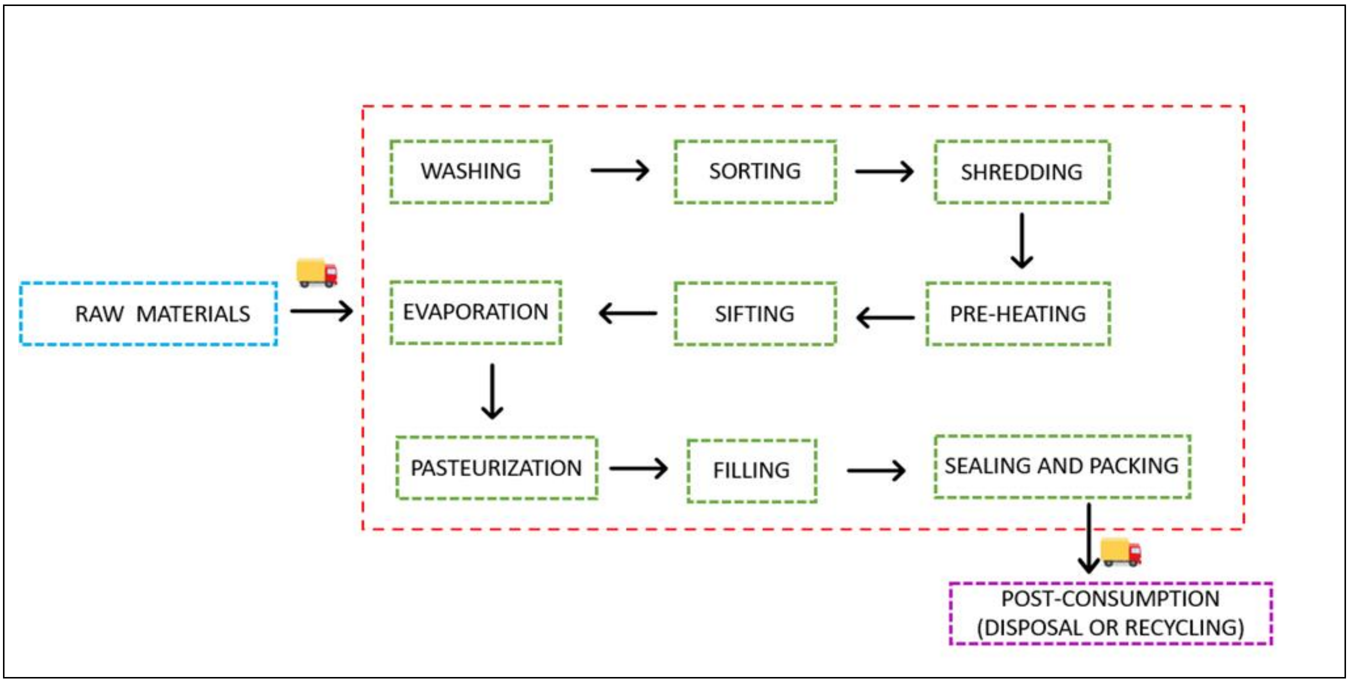

Figure 1. System Boundaries.

Table 1. Pedigree matrix with data quality indicators.

Indicator score	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non verified data partly based on assumptions	Qualified estimate	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (50% of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from	Unknown or ≥15 years of difference
Temporal correlation	≤3 years of difference to year of study	3 to 6 years difference	5 to 10 years difference	10 to 15 years of difference	Unknown or ≥15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Table 2. Inventory data for tomato paste production per functional unit.

Stage	Inputs	Amount	Ecoinvent Dataset	Data Quality [(*)]
Tomato cultivation and harvesting	Calcium anhydrite	0.02 g	Calcium anhydrite	(1, 4, 2, 1, 1)
	Fuel for machinery	0.02 g	diesel, at refinery, global	(1, 4, 2, 1, 1)
	Manure	0.09 g	digested matter, application in agriculture	(1, 4, 2, 1, 1)
	Water	0.38 kg	drinking water, from ground water	(1, 4, 2, 1, 1)
	Fertilizer, N	0.29 kg	Fertilizer, N	(1, 4, 2, 1, 1)
	Fertilizer, K	0.018 kg	Fertilizer, K	(1, 4, 2, 1, 1)
	Fertilizer, P	0.018 kg	Fertilizer, P	(1, 4, 2, 1, 1)
	Fungicide	2.15 g	Fungicide, at regional storehouse, Europe	(1, 4, 2, 1, 1)
	Herbicide	0.05 g	Herbicide, at regional storehouse, Europe	(1, 4, 2, 1, 1)
	Insecticide	0.11 g	Insecticide, at regional storehouse, Europe	(1, 4, 2, 1, 1)
	Magnesium	0.21 g	Magnesium, at plant	(1, 4, 2, 1, 1)
	Protein	0.40 g	Protein concentrate, from whey, at fermentation	(1, 4, 2, 1, 1)
	Sulfur	5.9 g	Sulphur	(1, 4, 2, 1, 1)
	Zinc	0.44 g	Zinc – high grade	(1, 4, 2, 1, 1)
	Electricity	0.54 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
Washing	Water	1.64 kg	drinking water, from ground water	(1, 4, 1, 1, 1)
	Electricity	0.028 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
	Wastewater treatment [(b)]	1.64 kg	wastewater treatment, industrial, 2	(1, 4, 1, 1, 1)

Table 2. Continued.

Stage	**Inputs**	**Amount**	**Ecoinvent Dataset**	**Data Quality [(*)]**
Sorting	Electricity	0.0085 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
Shredding	Electricity	0.015 MJ	Turkish grid electricity [a]	
Pre-heating	Heat	0.5 MJ	heat, natural gas, at industrial furnace > 100 kW	(1, 4, 1, 1, 1)
	Electricity	0.73 kJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
Sifting	Electricity	0.047 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
Evaporation	Electricity	0.17 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
	Water	0.012 kg	drinking water, from ground water	(1, 4, 1, 1, 1)
	Heat	1.31 MJ	heat, natural gas, at industrial furnace > 100 kW	(1, 4, 1, 1, 1)
	Caustic	0.25 g	Sodium hydroxide (caustic soda, 49% conc.)	(1, 4, 1, 1, 1)
Pasteurization	Electricity	0.03 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
	Water	0.23 kg	drinking water, from ground water	(1, 4, 1, 1, 1)
	Heat	0.20 MJ	heat, natural gas, at industrial furnace > 100 kW	(1, 4, 1, 1, 1)
Filling	Glass jar	0.3 kg	Glass bottle (virgin)	
	Jar lids	0.03 kg	Tin plate (virgin)	
	Nitric Acid	0.05 g	Nitric acid, 50% in H_2O, at plant	(1, 4, 1, 1, 1)
	Caustic	0.14 g	Sodium hydroxide (caustic soda, 49% conc.)	(1, 4, 1, 1, 1)
	Electricity	0.013 MJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
Sealing & Packing	Adhesive Tape Plastic wrap	0.04 g 0.012 kg	adhesive mortar, at plant Polyethylene film (LDPE)	(1, 4, 1, 1, 1)
	Boxes	6.4 g	tin plate, virgin	(1, 4, 1, 1, 1)
	Cardboard	8.54 g	packaging, corrugated board, mixed fiber, single wall, at plant	(1, 4, 1, 1, 1)
	Electricity	0.031 kJ	Turkish grid electricity [a]	(1, 4, 2, 1, 1)
Transportation	Final product transportation to the end user	500 km	Transport, lorry (> 16 ft), fleet average	(1, 4, 1, 1, 1)
End-of-life treatment	Disposal of the glass jar	0.12 kg	Disposal, glass, 0%, water, to inert material landfill	(1, 4, 1, 1, 1)
	Disposal of the jar lid	0.0135 kg	Disposal, tin sheet, 0% water, to sanitary landfill	(1, 4, 1, 1, 1)
	Glass recycling	0.18 kg	Treatment of waste glass	(1, 4, 1, 1, 1)
	Jar recycling	00.0165 kg	Disposal, steel, to recycling [(c)]	(1, 4, 1, 1, 1)

[(*)]: Based on the data quality indicators in the order that they appear Table 1.
[a]: Added into CCALC2 database as a user-defined process, original data has been obtained from [40].
[b]: Not an input but a waste stream.
[c]: No data regarding tin recycling was found in Ecoinvent database, thus data for steel recycling had to be used.

- The following recycling percentages were assumed for each type of raw material, based on Turkish statistics [41]: glass (60%), metals (55%),
- There is no specific need for storage, ambient temperature is sufficient to ensure product quality,
- The transportation of the raw materials were neglected as the transportation distances are all less than 50 km. However, the transportation of the final product to the end-user was taken into account as this particular product is consumed across the entire country. An average distance of 500 km was considered.

2.3 Life cycle impact assessment

In this work, CCaLC2 LCA software alongside Ecoinvent2 database was used for life cycle modelling and estimating the following midpoint impacts in accordance with CML 2001 method: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP), ozone layer depletion potential (ODP), and photochemical smog potential (PSP). Midpoint impacts were preferred since the characterization procedure that is needed for the transition from midpoint to endpoint impact calculation can cause problems regarding the certainty of the results [39]. Estimating any other midpoint impact was not an option as CCaLC2 can only calculate the impacts listed above.

According to the data quality analysis, the average scores for each criteria were as follows:

- Reliability: 1 (as all the data is based on actual measurements from a real-life company),
- Completeness: 4 (as the data is collected from a single company)^,

- Temporal correlation: 1 (as all the data, with the exception of the emission factors of grid electricity, was collected within the last 3 years; while the electricity emission factors were obtained from a paper published 6 years before this particular study was realized),
- Geographical correlation: 1 (all the data reflects the actual situation in Turkey).

Further technological correlation: 1 (all the data was obtained from relevant enterprises).

3 Result and discussion

3.1 Impact assessment results

The impact scores and the contributions of different stages are displayed in Figure 2. On average, raw material supply was found to be the biggest contributor to the impacts with an average contribution of 45.3%. Production processes had an average contribution of 41.5%, followed by transportation with an average contribution of 14.3%. Storage and use stages were found to have almost no effect on the impact scores, with these two stages combined accounting for less than 0.5% of the impacts on average. For AP and ODP, the stage with the largest contribution to the impacts was the production processes, whereas for all the other four impacts the main contributor was the raw material supply stage.

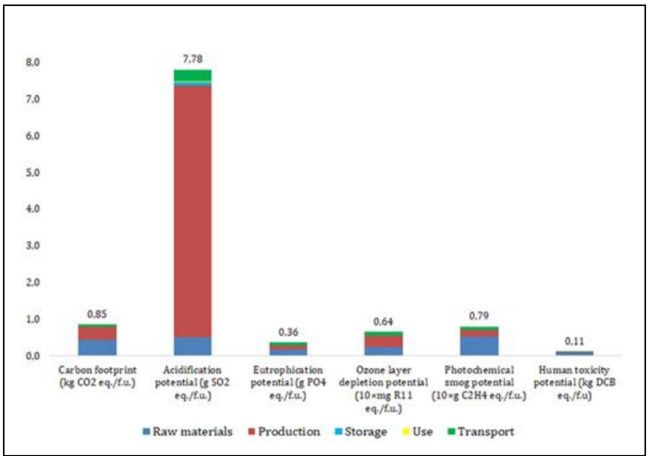

Figure 2. Impact scores and contributions of stages.

Table 3 below presents the main hotspots for each of the impacts that account for approximately 50% of each impact.

Table 3. Hot spot analysis for each impact.

Impact Type	Main Hotspots
CF	N-fertilizer (23%), evaporation energy (13.9%), tin packaging (10.8%)
AP	electricity for tomato cultivation (53.6%), evaporation energy (18.2%)
EP	transportation (23.7%), fungicide (21.8%), electricity for tomato cultivation (9.6%),
ODP	evaporation energy (24.1%), fungicide (19.1%), transportation (14.8%)
PSP	tin packaging (34.5%), transportation (12.2%), fungicide (10.6%)
HTP	fungicide (44.0%), transportation (13.9%), evaporation energy (12.1%)

These results show that the biggest individual contributors to the impact are fungicide use, tin packaging, transportation (by truck), energy used in the evaporation step, and finally the electricity used for the tomato cultivation process.

3.2 Comparison with the literature

The comparison of the carbon footprints of tomato paste analyzed in this study against tomato paste analyzed in other studies and two other generic tomato products can be found in Figure 3 below. At this point it should be mentioned that not all the studies mentioned earlier in the literature review (section 2) could be included in this figure because of the differences in functional units. Hence, only studies with functional units identical to the one selected in this study were taken into consideration for the comparison.

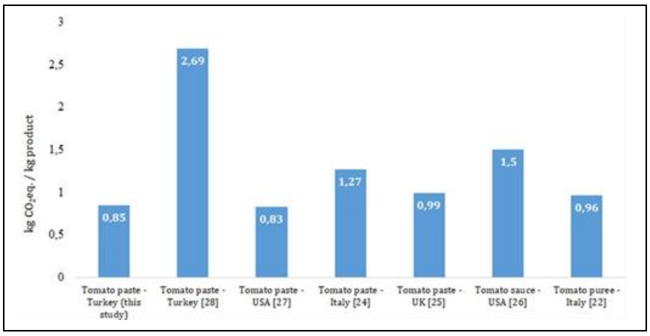

Figure 3. Comparison of carbon footprints of tomato paste produced in different locations as well as tomato sauce and tomato puree.

Results displayed in Figure 3 show that the findings of this study are in good agreement with the results reported earlier. Interestingly, the study by Palma et al. [31] which also investigated tomato paste production in Turkey revealed much higher impact scores compared to this study. This difference could be attributed to the production scale of the companies, and also the timing of the study. This particular study was conducted in 2021 by using data from 2020 whereas the study by Palma et al. was published in 2015. The energy mix of Turkey at the beginning of 2010s relied on fossil fuels at a much higher extent than what it became towards the end of the decade [42]; thus, producing the same product in early 2010s and early 2020s would have significantly different environmental impact scores, including carbon footprint. Other possible factors that could lead to differences in the GWP (or any other environmental impact, for that matter) of the same product in different locations are transportation distances, agricultural practices, waste management regulations, etc.

3.3 Effectiveness of impact mitigation strategies

There are several possible actions that could reduce the environmental impacts of a processed food product. These actions include but are not limited to using renewable energy for agricultural and/or production processes, changing packaging material type, improving the energy efficiency of the process, changing the means of transportation of the raw materials and/or the final product, and waste utilization. In this particular study, two of the above-mentioned methods, that are, renewable energy use and waste utilization have been investigated in terms of their impact-reducing potential.

As far as renewable energy use is concerned, it was assumed that a reasonable 10% of the energy required for agricultural processes and tomato paste production would be obtained from photovoltaic (PV) panels, as Turkey has a very high potential for electricity generation via PV technology [43].

According to the data collected from the company, the annual electricity consumption of the factory is approximately 1250 MWh. 10% of this amount corresponds to 125 MWh. With an assumed solar radiation of 1.2 MWh/m^2.year for northwest Turkey [44], meeting 10% of the factory's electricity demand from PV panels would require allocation of approximately 100 m^2 of area. While a techno-economic analysis is outside the scope of this particular study, it seems feasible for the company in question to consider using PV technology for the purposes of energy cost reduction and environmental impact mitigation.

Waste utilization was incorporated into the model by assuming the utilization of the fresh waste obtained prior to the pasteurization stage. This waste can be used to produce biomethane via anaerobic digestion as described elsewhere [45],[46]. The energy obtained from the combustion of this biomethane would normally be obtained via a fossil fuel such as coal or natural gas. Thus, utilizing biomethane would reduce fossil combustion by the amount that would provide the same energy output that the biomethane stock would provide. As far as the technical feasibility of the process is concerned, there is sufficient amount of fresh waste generated for the production of significant amounts of biogas thanks to the high tomato processing capacity of the company. There are two main reasons why biomethane produced via anaerobic digestion was preferred over other waste management strategies for tomato waste. Firstly and most importantly, there is significant amounts of natural gas consumption during the production of tomato paste, mainly for evaporation and pasteurization stages, as evident from the data presented in Table 2. Producing biomethane, therefore, not only provides an environmental benefit but also an economic one. Secondly, presence of chicken farms nearby make it practical to produce biomethane as chicken manure is often used as a starter culture for anaerobic digestion [46]. The results of the analyses of the two above-mentioned impact reduction strategies are presented in Table 4 below.

Table 4. Effects of impact-reducing actions on the environmental impacts of tomato paste production.

Impact Type	Impact reduction % via PV panel use	Impact reduction % via biogas production
CF	1.41	0.41
AP	7.74	0.10
EP	0.97	0.60
ODP	1.20	0.17
PSP	0.44	0.68
HTP	-0.86	0.76

4 Conclusion

Cradle-to-grave life cycle assessment of tomato paste production in Turkey was realized in this work. The results show that the biggest individual contributors to the impact are fungicide use, tin packaging, transportation (by truck), energy used in the evaporation step, and finally the electricity used for the tomato cultivation process. The carbon footprint, which is globally the most frequently calculated environmental impact, was found to be 0.85 $kgCO_2eq./1$ kg glass jar, which is consistent with the existing literature. On average, raw material supply was found to be responsible for 45.3%, followed by production processes and transportation with shares of 41.3% and 12.6%, respectively. Storage and end-of-life-treatment stages were found to have negligible contributions to the impacts.

Two impact reduction strategies, which are meeting 10% of the electricity demand of the agricultural and production processes via photovoltaic panels and utilizing the waste of the harvesting step to produce biomethane via anaerobic digestion, were investigated. Both methods were found to have minimal benefits as far as impact reduction is concerned. Switching to organic farming, although not analyzed in detail as it would not have been practical in this particular case, could be an effective method towards reducing the environmental impacts of tomato paste.

Considering that Turkey is one of the major tomato paste producers and exporters in the world, various incentive mechanisms that would favor organic farming such as tax reductions or exemptions or cheaper energy and/or fuel supply could help the processed food industry, tomato paste being an example, reduce their environmental impacts and therefore help Turkey achieve green transition.

Future work in this field should focus on investigating the environmental impacts of achieving large-scale tomato production via organic farming. However, such an analysis should also have a wider impact coverage by including impacts like land use or water footprint to get a clearer idea about the relative environmental impacts of conventional and organic farming.

5 Ethics committee approval and conflict of interest statement

There is no need for any permission from ethics committee for the article prepared.

The authors declare that they have no conflict of interest for the article prepared.

6 Author contribution statement

In this work, Fehmi Görkem ÜÇTUĞ was responsible from conceptualization, analysis, editing and supervision; Zehranur TEKİN was responsible from writing and editing; Zeynep DAYIOĞLUGİL was responsible from data collection and discussion of the results; Ercan ULUSOY was responsible from data collection and discussion of the results; Şule OKTAYLAR KEYİK was responsible from data collection and discussion of the results.

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