



**Food Product
Environmental Footprint
Literature Summary:**

Tomatoes



State of Oregon
DEQ Department of Environmental Quality

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Executive Summary:

Tomatoes



Tomatoes are ubiquitous in the U.S. diet: in terms of per-capita consumption, they are the fourth most popular fresh-market vegetable, and the U.S. is second only to China in tomato production. But as any backyard gardener knows, not all tomatoes are created equal, and this holds true for their environmental footprint as well. How, when, and where tomatoes are grown, processed and distributed all affect the overall footprint. The purpose of this summary is to highlight what is known about the environmental impacts of tomato production, processing, distribution and consumption based on a review of publicly available life cycle assessment (LCA) studies. This summary does not provide information that is specific to Oregon tomato production, but nevertheless may be useful to both producers and users of tomatoes and tomato products in Oregon as well as other locations.

Fresh tomatoes



Processing tomatoes



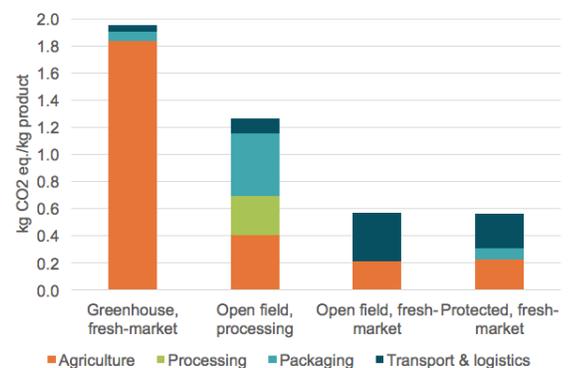
Tomatoes are produced in the U.S. for two distinctly different markets: fresh consumption and processing. The life cycle of the two tomato categories is depicted in the image above. Fresh-market tomato varieties are juicier and, in commercial production, often harvested prior to being ripe in order to tolerate shipping and extend shelf life. Processing varieties contain higher percentages of soluble solids, are vine ripened, and typically have a thicker skin in order to withstand mechanical harvesting and bulk transport. Processing tomatoes are converted to tomato pastes, sauces, juices and canned tomato products. The total U.S. production of fresh-market tomatoes in 2015 was 1.3 billion kilograms; 13.4 billion kilograms of processing tomatoes were also produced. California accounts for 96% of U.S. processing tomato output. Fresh-market tomatoes are produced in every state in the country, but two-thirds to three-fourths of commercial scale production occurs in California and Florida. Fresh-market tomatoes sold in Oregon that are not produced locally likely come from Mexico, California and British Columbia.

Key Findings

Four types of production methods were identified in the literature:

- **Greenhouse, fresh market tomatoes:** Enclosed structures with supplemental heating and/or lighting for off-season production in cold climate regions are common. Many use soilless media, hydroponics or other above-ground growing approaches, and may apply carbon dioxide (CO₂) enrichment to promote higher yields.
- **Open field, processing tomatoes:** They are often grown in open field conditions as seasonality and appearance are less of a concern. They are mechanically harvested, then undergo processing to make purée, sauce, paste, juice, etc.
- **Open field, fresh-market tomatoes:** This category includes in-ground production without overhead protection. Open field production is seasonal in nearly all locations in the U.S. Fertilization and irrigation methods can vary widely. Tomatoes grown for fresh market are typically hand-harvested.
- **Protected, fresh-market tomatoes:** Low- or high-tech “greenhouse,” shade-house or tunnel structures are used to as protection from weather and pests, but supplemental heat or light is not used. Production can be in the ground, in soilless media, or hydroponic. The added protection offers higher yield and more consistent quality than open field production.

Average greenhouse gas emissions by tomato production type



Agricultural Production

The life cycle phases that were consistently represented in the LCA literature include agriculture, processing, packaging, and transport and logistics. Retail, storage, consumption and waste handling after use were less frequently evaluated. Focusing only on the agricultural production of tomatoes, there is a distinct difference in carbon footprint per kilogram of tomatoes between heated greenhouse production and other production categories as depicted above. Often greenhouses are heated with natural gas or other fossil fuels.

The dominant contributions to the agricultural stage for protected, fresh market production are (on average) from agrochemicals – primarily fertilizer production – and subsequent field emissions (37%), and the greenhouse infrastructure (22%). One study in Florida of open field, fresh-market tomato production shows that pesticide production contributes 39% of agricultural related greenhouse gas emissions, followed by a 17% contribution from fertilizer production and 17% from field emissions, and an additional 7% from field machinery emissions. Irrigation in the same study contributed between 3 and 27% of agricultural production, depending on the irrigation method.

Different life cycle phases contribute to the different impact categories for processed tomato purée, as shown to the right. Packaging plays a dominant role.

Packaging Matters

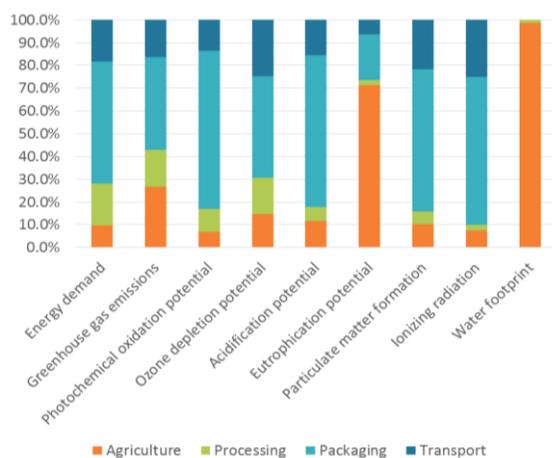
Across the 21 processing tomato studies reviewed, agricultural production and processing represent significant contributions to greenhouse gas emissions, but packaging format can also contribute significantly to the total. This is notable because greenhouse gas reductions can readily be achieved by considering alternative packaging formats. One study demonstrated that when steel cans were used, packaging represented 50% or more of the overall life cycle greenhouse gas emissions; with glass, packaging is 40-45%; with carton-based containers, packaging is around 5% of the total.

Conclusions

This summary of literature review of the life cycle of tomato production offers a number of valuable conclusions:

- Heating greenhouses for out-of-season tomato production adds a significant contribution to greenhouse gas emissions and other environmental impacts, and this contribution typically outweighs the impacts of long distance transport from warmer production regions. Local hot-house tomatoes grown in colder seasons may be more impactful than field-grown tomatoes shipped long distances.
- Agrichemicals - both fertilizer and pesticide production - and fertilizer-related field emissions are important contributors to the greenhouse gas emissions of open-field and protected tomato production. Insufficient data are available to determine whether organic production reduces greenhouse gas emissions per kilogram of tomato produced.
- Packaging is an important component of the life cycle impacts of processed tomato products, and efforts to reduce packaging impacts (lighter glass jars, paper carton containers, etc.) can significantly influence the overall life cycle performance.
- Growing fresh-market tomatoes under (unheated) protected structures appears to offer considerable benefit in terms of yield and quality without adding a notable environmental impact burden.
- Trade-offs between different environmental burdens can be an important consideration when comparing different systems.

Distribution of life cycle impacts of Italian tomato purée production





Overview

Tomatoes are ubiquitous in the U.S. diet: in terms of per-capita consumption, they are the fourth most popular fresh-market vegetable, and the U.S. is second only to China in tomato production¹. But as any backyard gardener knows, not all tomatoes are created equal, and this holds true for their environmental footprint as well. How, when, and where tomatoes are grown, processed and distributed all affect the overall footprint.

The purpose of this summary is to highlight what is known about the environmental impacts of tomato production, processing, distribution and consumption based on a review of publicly available life cycle assessment (LCA) studies. Such studies can identify those parts of the value chain with disproportionately high environmental burdens, allowing improvement efforts to focus where they are likely to have the most bearing. These LCA studies can also point to potential trade-offs between environmental indicators or abatement strategies. This summary does not provide information that is specific to Oregon tomato production, but nevertheless may be useful to both producers and users of tomatoes and tomato products in Oregon as well as other locations.

This literature summary is one of a series commissioned by the Oregon Department of Environmental Quality. For additional information on the background and objectives of these summaries, as well as on LCA methods and definitions of terms, please refer to the [Food Product Environmental Footprint](#)

Tomatoes are produced in the U.S. for two distinctly different markets: fresh- and processing. Fresh-market tomato varieties are juicier and, in commercial production, often harvested prior to being ripe in order to tolerate shipping and extend shelf life. Processing varieties contain higher percentages of soluble solids, are vine ripened, and typically have a thicker skin in order to withstand mechanical harvesting and bulk transport. Processing tomatoes are converted to tomato pastes, sauces, juices and canned tomato products. The total U.S. production of fresh-market tomatoes in 2015 was 1.3 billion kilograms, with 87 million kilograms of this grown under protective structures; 13.4 billion kilograms of processing tomatoes were also produced. California accounts for 96% of U.S. processing tomato output. Fresh-market tomatoes are produced in every state in the country, but two-thirds to three-fourths of commercial scale production occurs in California and Florida. Fresh-market tomatoes sold in Oregon that are not produced locally likely come from Mexico in the winter and California during the rest of the year, although hothouse tomatoes from British Columbia are also common.

¹ <http://www.ers.usda.gov/topics/crops/vegetables-pulses/tomatoes.aspx>

Available LCA Research

Tomatoes have been well studied in the life cycle assessment (LCA) literature; we identified 17 separate published reports, all from peer-reviewed journals. While we sought studies dating back to 2005, all identified tomato studies were published beginning in 2011. A given study will often consider different production practices or scenarios; 59 separate scenarios were identified across the 17 reports. U.S. based studies are limited to one considering processing tomatoes grown in California and one looking at open field production in Florida. The remaining studies consider production in Italy, Spain, France, Austria, Australia, UK, Switzerland, Iran and Morocco. The majority of studies focus on greenhouse gas emissions (GHGE) and energy use, with some consideration of water use. A handful of studies consider a broader spectrum of environmental impacts (eutrophication, acidification, human and eco-toxicity) but in general, it is far more difficult to draw broadly applicable conclusions as these impacts tend to carry high uncertainty and are much more localized and spatially dependent. Thus, conclusions in this summary focus on GHGE.



FIGURE 1. Generic life cycle of fresh-market and processing tomatoes.

Production Categories

For the purposes of reviewing environmental footprints, it is useful to divide tomato production methods into the following four categories:

- **Open field, processing** – Nearly all processing tomatoes are grown in open field conditions as seasonality and appearance are less of a concern. They are often mechanically harvested and undergo various degrees of processing to become purée, sauce, paste, juice, etc.
- **Open field, fresh-market** – This category includes in-ground production without overhead protection. Open field production is seasonal in nearly all locations in the U.S. Fertilization and irrigation methods can vary widely. Tomatoes grown for fresh market are typically hand-harvested.
- **Protected, fresh-market** – Protected production uses low- or high-tech “greenhouse,” shade-house or tunnel structures that provide protection from weather and pests, but do not involve supplemental heat or light. Production can be in the ground, in soilless media, or hydroponic. The added protection offers higher yield and more consistent quality than open field production. In milder climates, such protection is sufficient to permit growing in cooler seasons.
- **Greenhouse, fresh market** – In this summary, greenhouse specifies enclosed structures with supplemental heating and/or lighting for off-season production in cold climate regions. These systems typically use soilless media, hydroponics or other above-ground growing approaches. They may also involve carbon dioxide (CO₂) enrichment (increasing the in-house atmospheric concentration of CO₂) to promote higher yields.

Key Findings

Full Life Cycle Results

To summarize the results from identified studies, we divided the scenarios found in the literature into the four production categories previously listed, compiled reported GHGE values at major life cycle stages, and averaged values at life cycle stages (Figure 2). This meta-analysis is done with prudence as studies vary in methodological approaches, boundary conditions and scenario specifics. Still, general characterizing trends can be observed.

The following life cycle stages, represented in Figure 1, have been included in Figure 2:

- **Agriculture** includes all impacts up to farm gate, including the production of farm inputs (fertilizer, pesticides, greenhouses, tractor fuel) and (in most cases) field emissions of nitrous oxide, a potent greenhouse gas that can form when agricultural fields are fertilized. The agricultural stage is considered in more detail below.
- **Processing** is only expected to be an important stage for processing tomatoes as fresh-market tomatoes experience no processing. Insights are presented in the “Processing tomatoes” section below.
- **Packaging** should include all materials used to enclose and protect products from farm to consumer. Small amounts of packaging are used for fresh-market tomatoes, but this stage is far more important for processing tomatoes (see “Processing tomatoes” section below).
- **Transport & logistics** includes the movement of product from farm to processor to retail. Despite the focus on food miles in recent years, environmental impacts tend to depend more on transport mode (sea freight, rail, truck, air freight) than on distance traveled. Still, distance matters, and the studies presented in Figure 2 assume a wide range of travel distances, making it challenging to draw conclusions on the importance of transport. A few general observations, however, are worth noting: 1) as transport time is less important for already processed tomato products, more efficient transport modes (sea freight, rail) can be used, thus reducing the environmental impact, even over long distances; 2) an advantage of heated greenhouse production in off-seasons can be simplifying transport logistics and reducing distance.
- **Retail** stages in food LCAs typically include a product’s share of the overhead energy use (lighting, heating, air conditioning, refrigeration) in grocery stores. None of the tomato LCA studies included this stage. Given that tomatoes are typically not refrigerated at retail, the carbon footprint of this stage is expected to be minimal.
- **Consumption** stages can include personal vehicle transport from retail to home, refrigeration in home, and potentially cooking. The one tomato study that included consumption was based in Australia and interviewed 50 shoppers to give an indication of distance travelled to the supermarket, as well as how often tomatoes are stored in the refrigerator. While obviously a small sample for a stage with high variability, the result of this study (seen in open field, fresh-market and greenhouse, fresh-market categories in Figure 2) suggests that these consumption stage impacts can be notable. This is in agreement with other food LCA studies.
- **Waste management** typically includes the end-of-life impacts of disposing products or their associated packaging. None of the studies considered here explicitly reported values for waste management. This does not necessarily mean that such impacts were not considered in the study, but that they were not reported separately from other stages.

Next we explore a few life cycle stages in more detail: agricultural production, packaging and transportation.

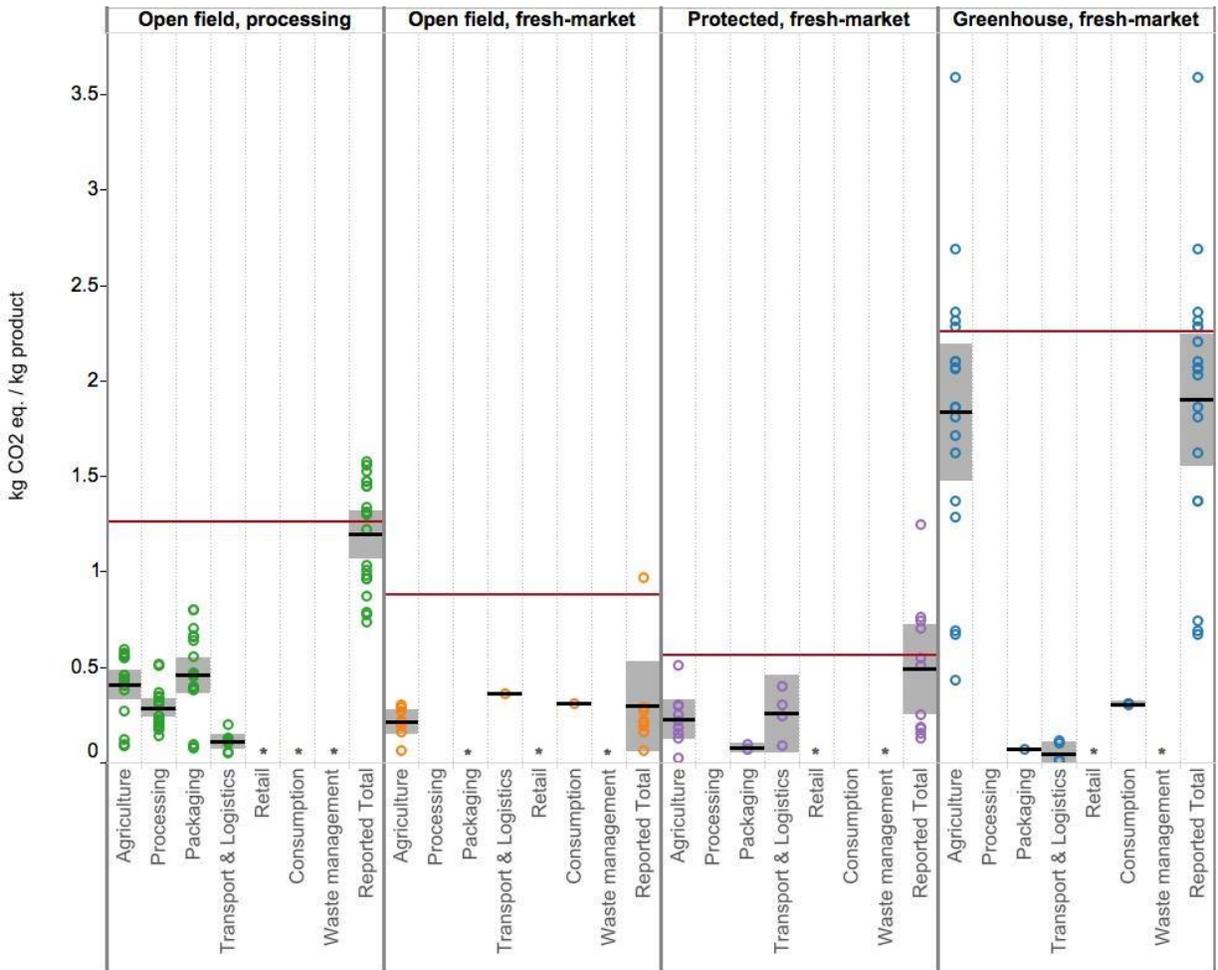


FIGURE 2. Life cycle greenhouse gas emission results from all studies reviewed, divided into production categories and displayed across life cycle stages.

Circles represent individual study results, offering a sense of the data spread or cluster. Horizontal black bars represent averages for each stage, and grey blocks are 95% confidence intervals around the averages. The “Reported Total” column shows totals from a given study, although it is important to recognize that not all studies include the full life cycle stages represented here. Stages marked with an asterisk (*) are those for which some environmental impacts are expected to occur, but no data were available in the identified studies. Red bars indicate the sum of the averages from each life cycle stage, for each production category.

Agricultural Production (*Greenhouses (usually) mean more GHGE*)

Focusing only on the agricultural production of tomatoes, there is a distinct difference in GHGE per kilogram of tomatoes between heated greenhouse production and other production categories (Figure 3). Manufacturing of the greenhouse infrastructure can contribute mildly to this, but it is largely due to supplemental heating required to operate such greenhouses out-of-season in cold climates. Greenhouse heating averages 64% of the agricultural stage (high = 77%, low=37%) across the six heated greenhouse scenarios that report sufficient detail to disaggregate contributions. Often greenhouses are heated with natural gas or other fossil fuels, but utilization of waste heat or integration with combined heat and power systems can lead to improvements in environmental performance. Production yields strongly influence environmental impacts per kilogram of product for all production systems, but especially for heated greenhouses, as it is the volume of the space that must be heated, and bigger yield means more kilogram per unit volume.

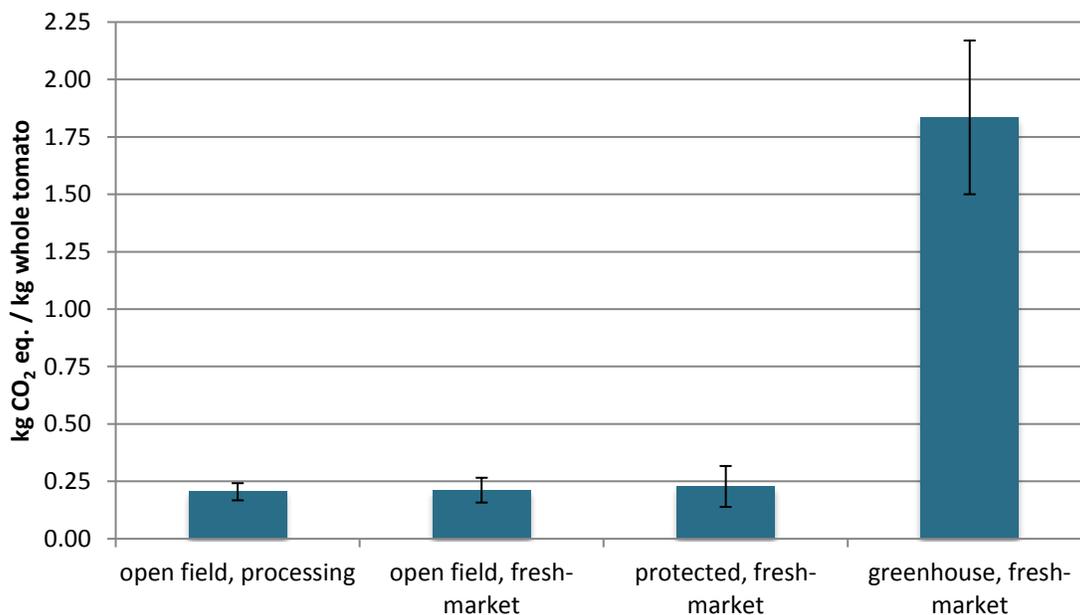


FIGURE 3. Agricultural stage (cradle to farm gate) greenhouse gas emissions averaged across identified literature for four distinct production categories.

The number of reported values included in each average are 21, 8, 11 and 19 for open field processing, open field fresh-market, protected fresh-market and heated greenhouse fresh-market, respectively. Error bars represent 95% confidence intervals. Note that the value for “open field, processing” appears lower here than in Figure 2 as it has been corrected here to basis of a kilogram of whole (farm gate) tomato, whereas the agriculture stage value in Figure 2 reflects the quantity of farm gate tomatoes needed per kg of processed product.



The dominant contributions to the agricultural stage for protected, fresh market production are (on average) from agrochemicals – primarily fertilizer production – and subsequent field emissions² (37%), and the greenhouse infrastructure (22%). Using a study from Florida (Jones et al. 2012) as a representative example of open field, fresh-market tomato production, pesticide production contributes 39% of agricultural related GHGs, followed by a 17% contribution from fertilizer production and 17% from field emissions, and an additional 7% from field machinery emissions. Irrigation in the Florida study is between 3 and 27% of agricultural production, depending on the irrigation method.

Processing Tomatoes (*Packaging matters*)

Across the 21 processing tomato entries considered, agricultural production averages 32% of the total life cycle GHGE, processing averages 23%, whereas packaging is an average 36% of the total. Thus, while, agricultural production and processing represent significant contributions to GHGE, packaging's large impacts are notable because reductions can readily be achieved.

One study looking at Italian grown and processed tomatoes considered varying degrees of processing (peeled, chopped, puréed) and packaging formats (Del Borghi *et al.* 2014). On a weight basis of packaged product, this study found very little difference between processing methods, but paper carton-based containers had considerably lower GHGE than glass or steel containers, and impacts decreased with larger format packaging. When steel cans were used, packaging represented 50% or more of the overall life cycle GHGE; with glass, packaging is 40-45% of the total life cycle; with carton-based containers, packaging is around 5% of the total.

Another study considers the environmental footprint of processed tomatoes grown in California (Brodt *et al.* 2013). According to this study, 1 kilogram of tomato paste requires 4.6 times the amount of raw tomatoes as 1 kilogram of diced tomatoes because of the concentration that occurs. Thus, on a basis of final product weight, the agricultural and processing stages for tomato paste have 4.5-5.5 times the impact in GHGE and energy demand as do diced tomatoes, but the impacts from consumer packaging are about the same. In fact, packaging diced tomatoes in typical 14.5 ounce steel cans represents more than half of the total life cycle energy demand and GHGE (when excluding transport). However, the typical serving size is much smaller for tomato paste, 33 grams compared to 122 grams for diced tomatoes. On a serving size basis, agricultural production and processing are comparable between paste and diced, but impacts of consumer packaging as well as transport per serving are 3.5 times greater for diced. This suggests that, if the serving size differences are representative *and* there aren't

² Field emissions: Nitrous oxide (N₂O), a greenhouse gas 265 times as powerful as CO₂, can be released from nitrifying and denitrifying activities in the soil when nitrogen fertilizers are added to agricultural soils.

notable differences in consumer-level preparation (cooking, for example), then some savings per serving can be realized by using paste over diced, merely because of reduced packaging volume and transport weight.

Figure 4 shows the distribution across life cycle stages of a number of environmental impacts for the production and delivery to retail of Italian tomato purée (Manfredi and Vignali 2014). For most environmental impacts, packaging is the single largest contributor. This study considered a few achievable scenarios aimed at reducing impacts: a 15% reduction in natural gas consumption (through energy optimization of processing equipment); replacing all grid electricity used in the system (production through distribution) with photovoltaic electricity; reducing the average distance from processor to retailer from 550 kilometers to 400 kilometers; and reducing the jar glass weight by 20%. All of these scenarios had minimal effects of a 2-3% reduction in cradle-to-distribution impacts on the first eight categories in Figure 4 (water footprint was not included) except reducing glass weight, which resulted in 7-12% reductions in all categories but eutrophication potential, where the reduction was around 3%. Again, this emphasizes the importance of packaging in the overall life cycle of processed tomato products.

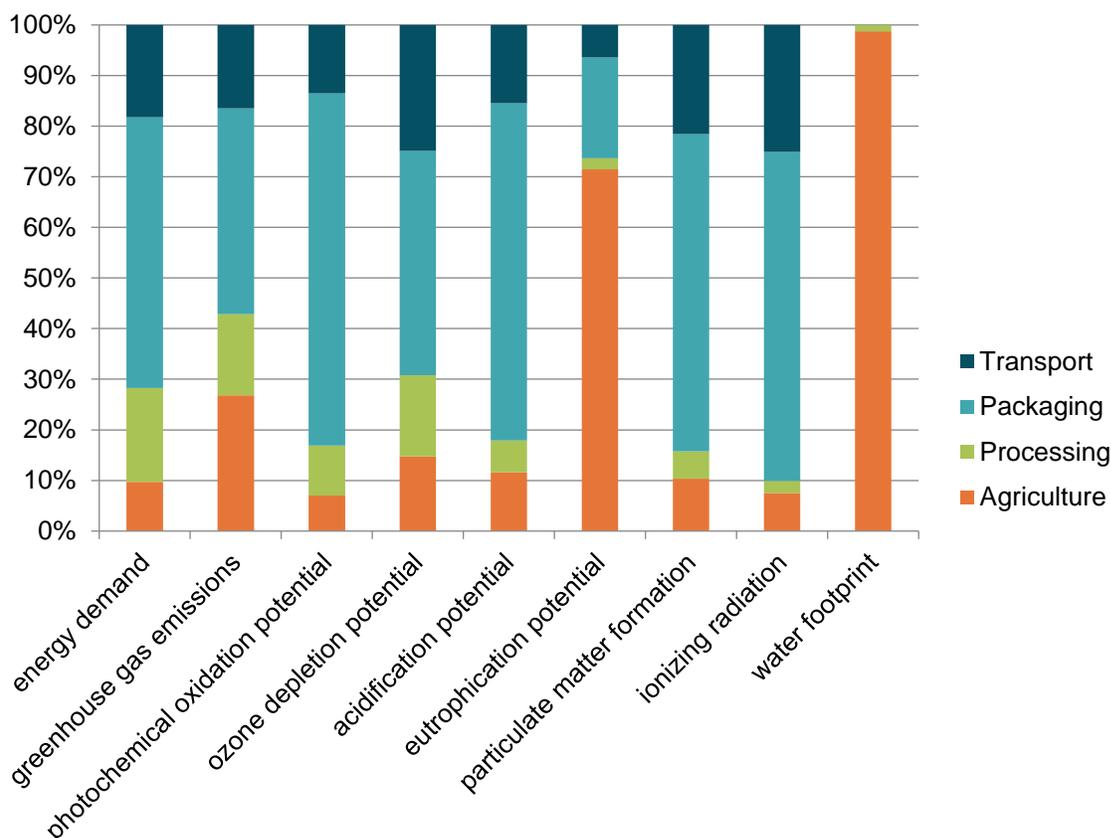


FIGURE 4. Distribution of environmental impacts across life cycle stages for the production and delivery to retail of Italian tomato purée. Adapted from Manfredi and Vignali 2014.

Production vs. Transport (*So what about food miles?*)

Heated greenhouses allow off-season local production in cold climates. But how does the environmental impact of heating compare with long distance transport from warmer regions? Studies comparing local, out-of-season production of fresh tomatoes in Northern Europe with imports from southern production regions offer potential parallels to a North American situation. All of the following examples show that it is environmentally preferable, in terms of GHGE, to ship tomatoes long distances than to heat a local greenhouse.

One study considers four options for tomatoes consumed in Vienna, Austria: in-season, fresh tomatoes grown organically under protection; out-of-season production in a heated Austrian greenhouse; out-of-season, fresh tomatoes grown in protected culture in Spain and shipped to Austria, and Italian canned tomatoes (Theurl *et al.* 2014). The in-season, local tomatoes contributed the lowest GHGE per kilogram of tomatoes. Out-of-season, fresh tomatoes shipped from Spain (grown in protected structures) have lower GHGE than canned tomatoes from Italy (grown in open field) or local, fresh tomatoes produced in heated greenhouses. In all cases, the manufacturing of greenhouse/hoop house structures contributes less than 10% to overall GHGE, so contributions from building the structures are minor. In the case of canned tomatoes from Italy, the processing and packaging contribute more than three times the GHGE as does the long distance transport (1600 kilometers) to Vienna.

A separate study found that production of fresh tomatoes in heated glass houses in the UK required four times the energy and resulted in three times the GHGE per kilogram delivered to a regional distribution center in the UK than protected culture production in Spain that is shipped 2300 kilometers via truck (Webb *et al.* 2013). This is despite tomato yield in the UK greenhouses being 2-3 times that in Spain. The transport energy in shipping tomatoes from Spain to the UK was about one third of the total for the Spanish case.

Another study compared tomato production under protected culture in Morocco and transported to France with local (French) off-season production in heated greenhouses, and found a similar trend (Payen *et al.* 2015). Local, off-season production has greater impact not only on climate change, but also non-renewable energy consumption and marine eutrophication. However, this study also evaluated water use impact – water deprivation – and water use for growing tomatoes in Morocco had nearly four times the impact as out of season production in France (see Figure 5). This result suggests that while it appears that long-distance transport is preferable to heating a greenhouse, there may be trade-offs depending on the distant production needs.

Research Gaps

While general analogies can be drawn from European studies, more North American studies are needed to truly understand the impacts of tomato production and distribution options available in the U.S. Analysis of tomato production in Mexico, especially, would be a valuable addition.

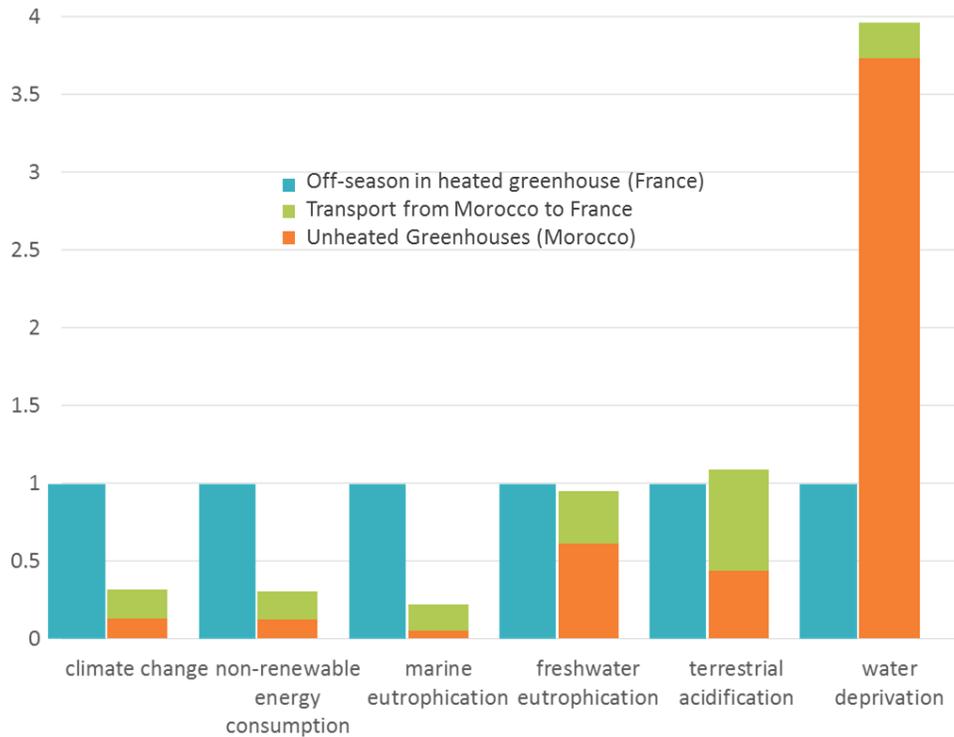


FIGURE 5. Comparison of off-season production in heated greenhouses in France with protected culture in Morocco (and transported to France) across various environmental impact categories. Note the relative impacts of production (orange) and transport (green) for the Morocco grown tomatoes. Values have been normalized in each impact category such that French production = 1. Adapted from Payen *et al.* 2015.

As is often true with food LCA studies, downstream stages of retail and consumption have not been included in most of the existing literature. These stages can have notable contributions, but they are challenging to model as situations and behaviors are highly variable.

Also absent is consideration of retail- and consumer-level food waste. Food waste represents a notable inefficiency in our food system that must be addressed; the environmental burden of producing food that is wasted is the same as food that is eaten. A better understanding of the role of tomato waste could be particularly relevant in making choices between fresh and processed tomatoes: fresh tomatoes are expected to have significantly more retail-level and consumer-level waste due to spoilage, and this may be significant enough to balance out the increased impacts of processing and packaging. Likewise, due to the high cosmetic standards for fresh-market tomatoes, culling rates can be significant. Some retailers are addressing this by selling “ugly” produce at slightly discounted prices.

A more thorough inclusion of environmental impact categories beyond GHGE would offer a more complete picture of tomato production and consumption. Of particular interest may be water use impacts and human and eco-toxicity, especially studies that focus on the impacts and trade-offs of pesticide use.

One interesting question that is not completely answered with the existing literature is the “fresh vs. processed” and/or “tomato sauce vs. tomato paste” question when the end-consumed item is a tomato sauce based food. To fully answer this question, at-home (or in industrial kitchen) cooking, waste and storage logistics, and sensitivity to transportation modes and distances all should be accounted.

Conclusions

Tomatoes are a common component of the U.S. diet, making consideration of the environmental impact of their production, processing, packaging, distribution and consumption a valuable case study. Results from the life cycle assessment literature suggest a few generally applicable conclusions:

- Heating greenhouses for out-of-season tomato production adds a significant contribution to greenhouse gas emissions and other environmental impacts, and this contribution typically outweighs the impacts of long distance transport from warmer production regions.
- Agrichemicals – both fertilizer and pesticide production – and fertilizer-related field emissions are important contributors to the greenhouse gas emissions of open-field and protected tomato production. Insufficient data are available to determine whether organic production reduces greenhouse gas emissions per kilogram of tomato produced.
- Packaging is an important component of the life cycle impacts of processed tomato products, and efforts to reduce packaging impacts (lighter glass jars, paper carton containers, etc.) can significantly influence the overall life cycle performance.
- Growing fresh-market tomatoes under (unheated) protected structures appears to offer considerable benefit in terms of yield and quality without adding a notable environmental impact burden.
- Trade-offs between different environmental burdens can be an important consideration when comparing different systems.

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