Life Cycle Analysis of Tomato Production

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Comparing British Columbia Greenhouse-Grown Tomatoes to Florida Field-Grown Tomatoes for use at the University of British Columbia

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1.0 Introduction

The University of British Columbia (UBC) Food Services department is the primary food provider on the Vancouver Campus. Currently, Food Services operates 31 businesses including cafeterias, franchise restaurants such as Tim Horton's, residence dining and catering. One of UBC Food Service's key values is a commitment to social, economic and environmental sustainability. Part of the department's commitment to sustainability includes procurement standards. Essentially, the goal of this standard is to ensure that UBC Food Services will favour local suppliers who follow sustainable production, packaging and transportation principals [1].

In 2009, UBC Food Services purchased 15552 lbs. of various types of tomatoes. 96% were imported from Florida or Mexico and only 4% purchased from local British Columbia farmers [2]. For this reason, the UBC Sustainability Department was asked by UBC Food Services to determine what source is the most sustainable option.

The purpose of this study is to apply the method of life cycle analysis (LCA) to the different methods of tomato production that the UBC Food Services utilizes throughout the year in order to determine which option is the most sustainable. Two options were looked at: locally greenhouse-grown tomatoes and imported field-grown tomatoes. Florida was used as a case study for the imported field-grown method and information from members of the BC Greenhouse Growers Association was used to model local tomato production.

In general, it is believed that field growing requires small amounts of energy and fuels for production, but a large amount of energy for transportation from Florida to UBC. On the other hand, greenhouses require large amounts of energy from fossil fuels for heating, but small energy for transportation. This study sought to quantify these energy inputs as well as those from other sources (fertilizer production, farm equipment usage, etc.) through the use of the life cycle analyses software.

Version 4 of GaBi Education life cycle analysis software was used to conduct the investigation. Using the LCA software GaBi a system with raw material inputs and energy requirements the two methods of tomato production were compared based on the global warming potential (GWP) and human toxicity potential (HTP) using CML 2007 calculation methods.

2.0 Literature Review

A study was done comparing the environmental and human health impacts of two sources of tomatoes for Vancouver, British Columbia: locally grown greenhouse tomatoes and field-grown tomatoes imported from California [3]. The study focused on three major components of tomato production: energy consumption during production, fertilizer use, and transportation to market. The impact categories studied were global warming potential, acid rain potential, smog formation potential, and human toxicity. The study found that field-grown tomatoes from California had lower impacts in all categories due to the low energy input requirements. Greenhouse tomatoes had a greater environmental impact due to the amount of fuel required to maintain growing temperatures and therefore were concluded to not be the most favourable option.

Another study comparing greenhouse to field grown tomatoes was conducted near the Mediterranean Coast [4]. This study only looked at the production impacts of growing tomatoes and did not include an analysis of transportation. Included parameters were greenhouse structure, irrigation equipment, fertilizers, pesticides, and cultural tasks. The study used CML 2001 impact categories to compare the two operations and found that overall, field-grown tomatoes had a greater environmental burden than greenhouse-grown tomatoes.

3.0 Goal & Scope

The goal of this study was to compare BC greenhouse grown tomatoes to Florida field grown tomatoes in terms of GWP and HTP and to compare relative contributions from each impact category. Not all aspects of tomato production and consumption could be easily analyzed in this manner. For this reason a qualitative discussion is provided on factors such as water usage, land erosion, and economic and social considerations.

The input categories are as follows; transportation from production region to UBC, fertilizer, agricultural equipment used, fuel requirements, pesticides/herbicides, disposal of agricultural byproduct (crop burning/composting), and greenhouse energy usage.

The conclusions will reassess the environmental, social, and economic effects of purchasing tomatoes from both sources in order to provide a recommendation to UBC Food Services.

4.0 System

The schematic representation of the system studied is shown in *Figure 1*. The inputs for the production of tomatoes include energy and chemicals such as fertilizer and pesticides. The study also considers the impacts of extraction, processing, and transportation of the raw materials to produce the intermediates required for tomato production. Though both processes require different amounts of each, the system model is consistent for both. Figures 2 and 3 show the model constructed with GaBi software to model the life cycle of Florida and BC tomatoes, respectively.

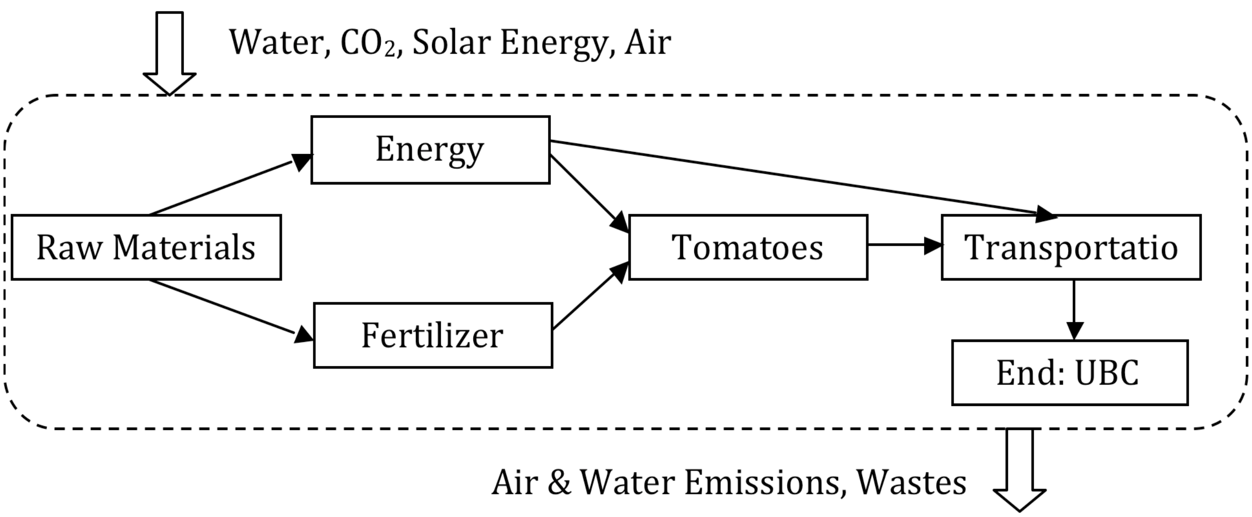

Figure 1. General flow diagram and system boundaries for the tomato life cycle analysis

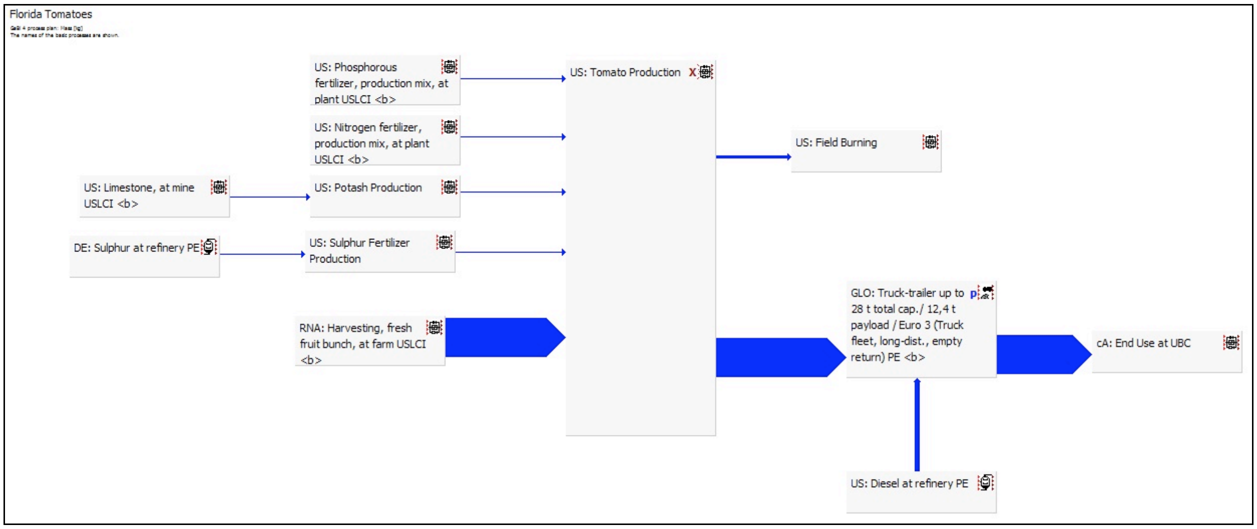

Figure 2. Detailed life cycle diagram from GaBi software for Florida field-grown tomatoes

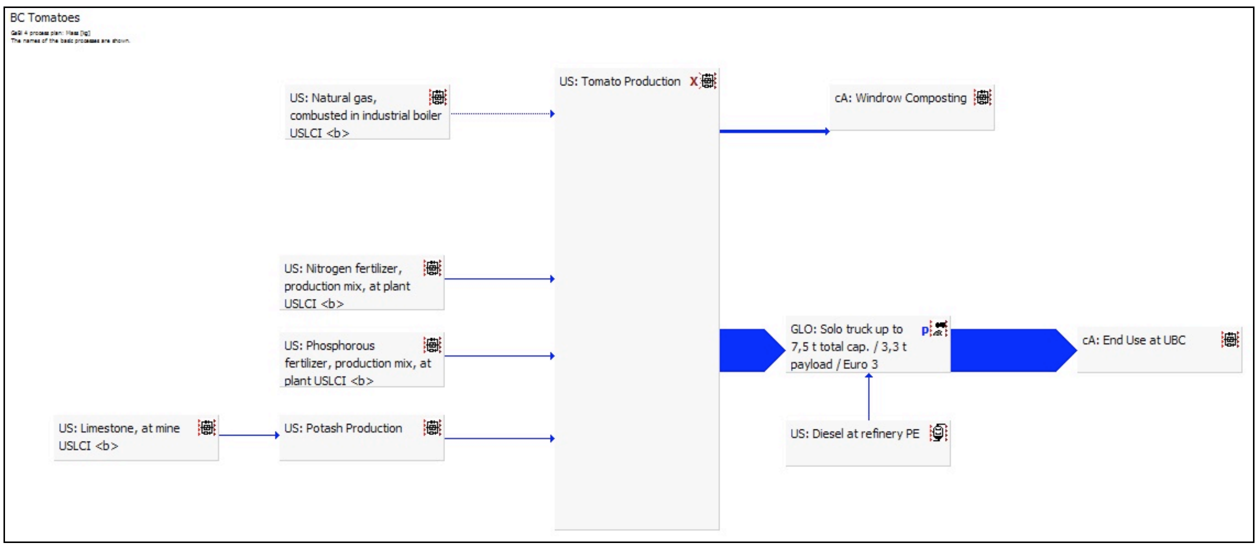

Figure 3. Detailed life cycle diagram from GaBi software for BC greenhouse-grown tomatoes

5.0 Functional Unit

All impact categories and data presented in this paper are based on the units of per kilogram of tomatoes produced.

6.0 Impact Categories

To further refine the study a few impact categories were selected including the global warming potential (GWP) based on CO_2 equivalent and the human Toxicity Potential based on Dichlorobenzene (DCB) equivalent which describes the danger to human health caused by emissions associated with various processes. These selections are not exhaustive. The GaBi LCA software is capable of comparing these and many other categories and sub-categories with its extensive database. The groups that have been included were chosen because they represent the most important considerations for people living in British Columbia.

7.0 Quantitative Life Cycle Analysis Inputs

Extensive research was conducted in order to find the most recent and accurate data possible for use in the life cycle analysis. In general, most data for Florida field-grown tomatoes was obtained from various United States government agencies. For BC greenhouse-grown tomatoes, the majority of data was collected from communications with members of the BC Greenhouse Growers Association and agricultural research papers. For a list of all processes and databases used to develop the tomato life cycle, refer to *Table 3* in *Appendix A*.

7.1 Energy

Table 1 displays the data input to the LCA for energy use for both Florida and BC tomatoes. Natural gas is currently the source of fuel for most greenhouse heating and is expected to continue to be in the foreseeable future due to low cost and ease of use [5]. In the past during periods of high natural gas prices, some greenhouses turned to burning wood pellets for heating. It was assumed that natural gas is the only fuel source for BC greenhouses. A considerable technological advantage of BC greenhouses is carbon dioxide recycling technology. In some greenhouses, emissions from the burning of natural gas for heating are captured and fed into the greenhouse to enrich the CO_2 content and improve growing conditions [5]. For this study, a worst-case scenario was assumed where this technology is not utilized and all natural gas emissions are released to the atmosphere.

Lighting, powered by hydro electricity, can be used in greenhouses in order to extend growing seasons and improve yield; however, BC greenhouses do not widely implement this technique [5]. The electrical energy required to power the small amount of instrumentation for the greenhouse was considered to be negligible and thus were not included in the analysis. In addition, planting, harvesting, and processing are all done by hand and were assumed not to require any energy input.

Parameter	BC Greenhouse [5]	Florida Field [6]
Yield density*	65 kg/m^2	17.8 kg/m^2
Principal Energy Source	Natural Gas	Diesel
Energy Use	.024615 GJ/kg	.001 L diesel/kg
Energy Used for	Heating	Equipment operation

Table 1. Summary of energy inputs

***Yield density is noted as energy values were originally obtained in terms of energy per unit area. It is important to note that should yield density change in future, this would also change final values obtained for energy used per kg of tomato production**

Field-grown tomatoes require little human-produced energy inputs; most energy for growth is sequestered from the environment [7]. The only significant energy input to field-grown tomatoes is fossil fuel for farm equipment for harvesting, field preparation before and after the growing season, and fertilizer and pesticide application. The harvesting process was obtained from the USLCI database and was used in the LCA to calculate the emissions due to farming activities for field-grown tomatoes in Florida. This process includes diesel fuel used to power the farm equipment and all associated emissions from production to final use of the fuel.

Energy use per kilogram of tomatoes varies can vary greatly for both Florida and BC tomatoes. For both sources, energy use per kg of tomatoes is highly dependent on yield; therefore, as growing techniques continue to improve, energy use per mass of tomatoes will decrease. For example, energy consumption has decreased by approximately 50% since 1994 for BC greenhouses [3]. In addition, energy use can vary with location of the greenhouse and seasonal conditions [5].

7.2 Fertilizer

Three types of fertilizers are used to grow tomatoes: nitrogen fertilizer (NH_4^+), phosphorous fertilizer (P_2O_5), and potash (K_2O). The same types of fertilizers are used in both BC and Florida; however, the application method and rate differ. BC greenhouse tomatoes are generally grown hydroponically and require all nutrients to be supplied through chemical addition. This is done efficiently using a computer controlled fertilizer recirculation system. The system recycles water and nutrients unused by one tomato plant to another such that nutrients are not wasted and there is little potential for loss of nutrients through seepage into groundwater [5]. Because exact data could not be obtained from the BC Greenhouse Growers Association, the fertilizer demand of BC greenhouse tomatoes was assumed to be equivalent to the nutrient uptake of hydroponic tomato plants based on a study on nutrient uptake by hydroponically grown greenhouse tomatoes [8].

Fertilizer Type	Active Ingredient	BC Greenhouse (kg fertilizer/kg tomatoes) [9]	Florida (kg fertilizer/kg tomatoes) [6]
Nitrogen	NH_4^+	0.011	0.048
Phosphorous	P_2O_5	0.0026	0.022
Potash	K_2O	0.011	0.09

Table 2. Fertilizer Inputs

The average fertilizer application per square meter for all tomato farms in Florida was calculated based on 2006 data from the United States National Agricultural Statistics Service [6]. Fertilizer is normally applied using spray tractor equipment or through the irrigation system in Florida. Unfortunately, the emission factors for releases to air, soil, and groundwater due to agricultural fertilizer application have not yet been determined by the US EPA [9]. For this reason, the emissions related to this activity were not included in the LCA.

7.3 Pesticides and Herbicides

In general, BC greenhouses do not use any chemical pesticides or herbicides; instead, they use biological methods to combat pests. Populations of carnivorous insects, such as ladybugs or wasps, are introduced into the greenhouses to control pest populations. Pesticides are only used as a last resort when biological methods are ineffective [5]. Also, herbicides are not used in BC greenhouses according to the BC Greenhouse Growers association.

The most commonly used fungicide for field-grown tomatoes Florida is sulphur. Sulphur fungicide is effective at preventing the growth of powdery mildew and mites. A commonly available sulphur-containing fungicide is called Kumulus ®, which contains 80% sulphur as the active ingredient [10]. This product was used to model the LCI of sulphur fungicide to be applied to field-grown tomatoes in Florida. It was assumed that the sulphur active ingredient is produced as a by-product from a refinery and that the additional production of Kumulus ® does not have any significant environmental emissions. The application rate of sulphur to Florida field-grown tomato crops in 2006 was 0.015kg sulphur per kg tomatoes, according from the US National Agricultural Statistics Service [6].

7.4 Packaging and Transportation

Following harvesting, tomatoes must be packaged for transport. In the case of this study, it was assumed that the environmental impacts of packaging are equal for Florida and BC tomatoes. For this reason, this process was not included in the LCA.

The average distance a tomato travels from a BC greenhouse to UBC was assumed to be 200km [11]. A 7-ton single unit truck was assumed to be 33% full of tomatoes [5]. The distance between central Florida and UBC is 5135km [11]. It was assumed that a large 28-ton capacity truck-trailer is used to transport tomatoes and other vegetables from Florida to UBC and that the trucks carry 40% of that capacity as tomatoes. The standard truck-trailer and single unit truck LCIs including diesel fuel production from the GaBi database were used.

7.5 Disposal of Agricultural End Products

For both field and greenhouse tomatoes, it was estimated that for every kilogram of tomatoes harvested, 0.1kg of plant matter was produced. In Florida, it is common practice for farmers to burn their fields following the tomato harvest and leave the ashes in place to replenish nutrients to the soil [18]. Emission factors from the USEPA for opening burning of green waste [13] were used to create a field burning process in the GaBi life cycle analysis. Most BC greenhouses compost the remaining plant matter after harvest in local windrow compost piles. Emission data for windrow composting of green waste was obtained from a study and a windrow composting [17] process was created in GaBi.

Both composting field burner were considered to be carbon-neutral because any carbon dioxide emitted through this process was originally sequestered from the atmosphere by the growth of the tomatoes. In other words, carbon dioxide emissions were not included in the created GaBi processes.

8.0 Qualitative Factors for the Life Cycle of Tomatoes

This section will qualitatively describe and discuss those factors that cannot be easily quantified in terms of contributions to environmental indices such as GWP and HTP The factors in this section were not used in the Life Cycle model developed with the GaBi software; however, they are important to include in a discussion of environmental, social and economic sustainability.

8.1 Water Usage

Irrigation water is an extremely important aspect of both field and greenhouse farming. Unfortunately, the databases available for GaBi software do not include any processes or emission factors for the operation of an irrigation system; however, this is an important factor to include for comparison of greenhouse and field grown tomatoes. Based on data from the US Geological Survey, Florida tomatoes require approximately 40 L/kg tomatoes [14]. According to the Ontario Ministry of Agriculture fact sheet on green house cultivation, the average green house tomato grower will require .4 m depth of water over the season. Based on greenhouse production rates this translates into 6.15 L/kg [15].

While the environmental impact of obtaining water in BC vs. Florida could not be computed by the Gabi software, it can be concluded that the significant difference in water usage will translate into lower environmental impacts of the BC tomatoes.

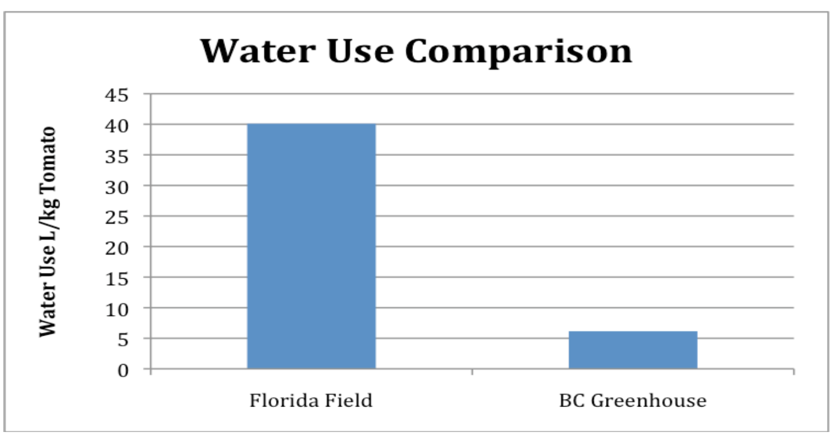

Figure 4. Water use comparison

8.2 Erosion, Groundwater Pollution and Eutrophication

Though not quantified in this study, potential for groundwater pollution, erosion and eutrophication associated with agriculture are important considerations. Cultivation of field crops causes exposure of soils to erosion. Fertilization and subsequent application of irrigation causes leaching of nutrients into groundwater and subsequent eutrophication [9]. This is not a point of concern for BC Green houses. As discussed in *section 7.2*, BC greenhouses are equipped with water and nutrient recirculation systems, using only that water which is necessary and not allowing for seepage of nutrients into soil [8]. For this reason, a qualitative comparison shows that BC Greenhouse tomatoes have zero environmental and human health impact in this category, whereas Florida field-grown tomatoes have an impact.

8.3 Economics and Society

In General, BC greenhouse tomatoes are more expensive than imported field-grown tomatoes due to the high fossil fuel input requirements and increased labour costs of greenhouse growing in British Columbia [16]. However, there are significant social and economic advantages to buying locally grown products instead of imported products.

Purchasing locally grown products ensures that the labour, environmental and economic legislations of British Columbia apply to production. This ensures that ethical labour practices are employed. Furthermore, it is advantageous for UBC to support local businesses that contribute to the local tax base and strengthen the local economy. Importing tomatoes from the United States also ensures social sustainability principals are employed; however, the labour practices of Mexico are not as stringent as those in the USA and Canada. For these reasons, it was qualitatively determined that BC tomatoes have the greatest contribution to the economic and social sustainability of UBC.

9.0 Results and Discussion

This section outlines the results obtained from the quantitative life cycle analysis carried out with the GaBi software. Global Warming Potential and Human Toxicity Potential were chosen as representative indices to study in detail, and a comparison between the field and greenhouse production methods is presented here. All values in this section are reported relative to the production of 1 kg of tomatoes.

Figure 5 shows the amounts of CO_2 equivalent that is generated from each process per kilogram of tomatoes. It also shows the impact of the impact of the production process without the transportation to the end user at UBC. This results suggest that the physical process of producing field-grown tomatoes in Florida has a lower global warming potential than the process to produce greenhouse-grown tomatoes in the Lower Mainland. However, with the transportation step included, greenhouse tomatoes have a lower overall global warming potential. The transportation from Florida adds over 0.5 kg CO_2 eq. per kg tomatoes and is the major hotspot in the process.

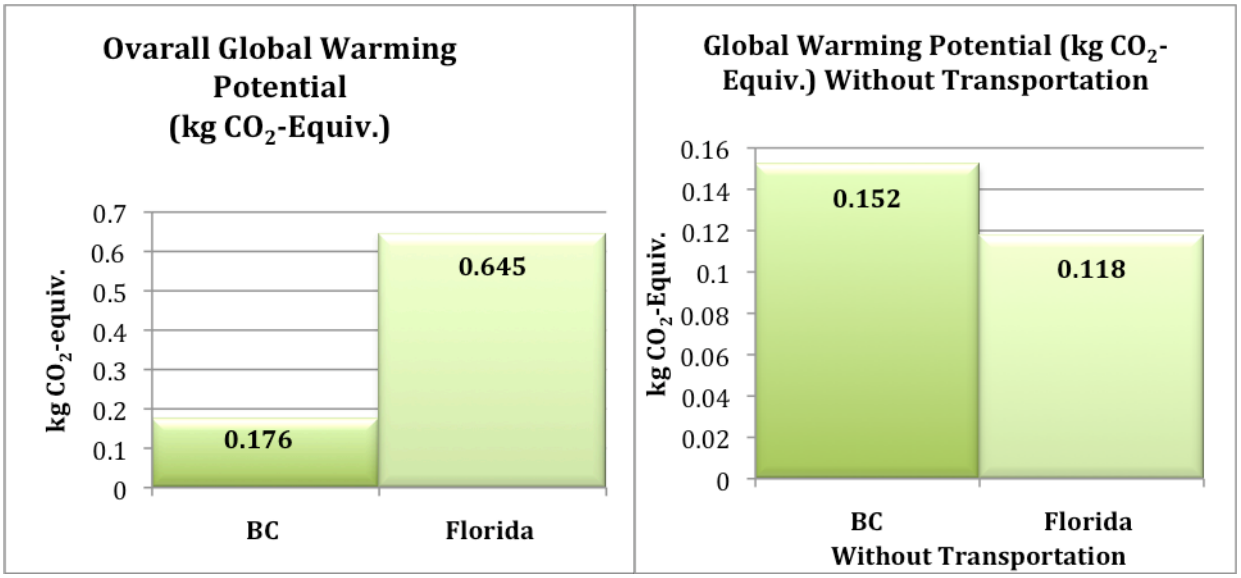

Figure 6. Comparison of global warming potential, with and without transportation

The results found using the human health toxicity potential index support the conclusions found in the global warming potential analysis. *Figure 6* shows the comparison of the BC and Florida tomatoes with and without transportation based on human toxicity. In both cases, BC greenhouse tomatoes have a lower impact on human health than Florida field-grown tomatoes. Transportation accounts for about 53% of the total toxicity index for field production. Also, it is clear that the transportation has a very small influence on the toxicity generated by the greenhouse method where the amount remains constant at 2.2 g DCB eq. because of the short travel distance from BC greenhouses to UBC. In summary, greenhouse tomatoes from BC have a lower impact on human health than Florida tomatoes mainly due to the emissions of the transportation phase of the Florida tomato LCA.

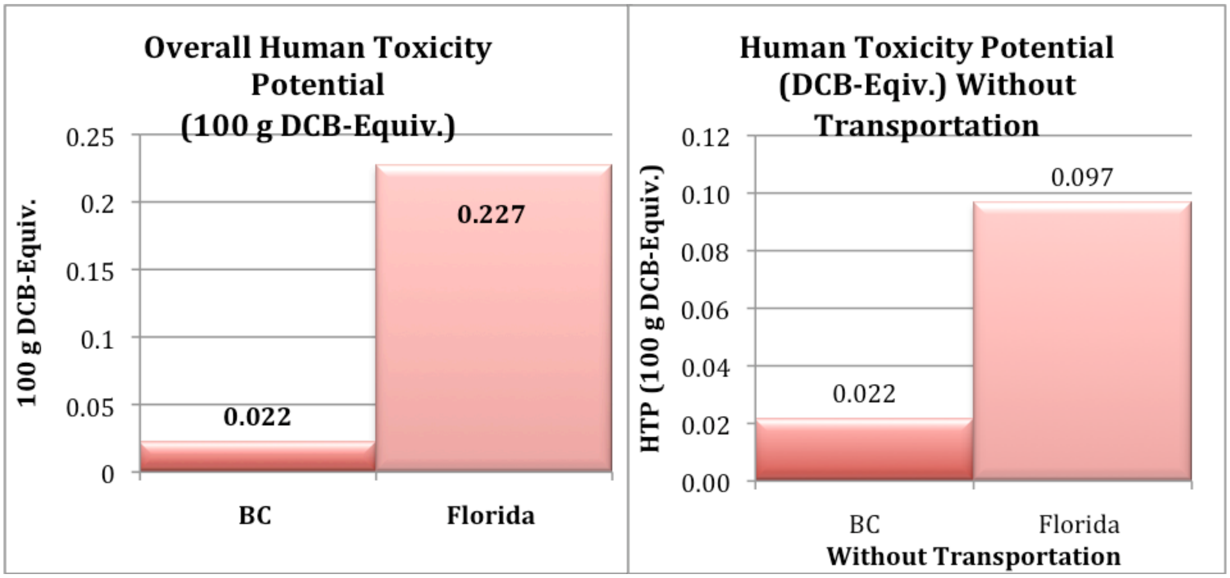

Figure 7. Comparison of human toxicity potential, with and without transportation

Though this comparison provides a fairly conclusive picture of the preferable choice for UBC Food Services, a more thorough analysis of each tomato production method can reveal more useful information on how to reduce the environmental and human health impacts of each. *Figure 7* shows a side-by-side comparison of the relative impact of each step in the life cycle of both tomato production processes. Both the field and greenhouse processes have a single item, or hot spot, that contributes the majority of the GWP. As mentioned above, transportation of the field tomatoes from Florida to UBC is the GWP hotspot, while the heating of the greenhouse through the combustion of natural gas is the GWP hotspot for greenhouse production. As discussed in *section 7.1*, BC greenhouses have decreased natural gas consumption by approximately 50% [3,5]. Despite the incredible reduction in the past 25 years, this remains the hotspot for the process and improved heating and insulation technologies should continue to be implemented and alternative fuel sources should be tested in order to reduce the impact of this process.

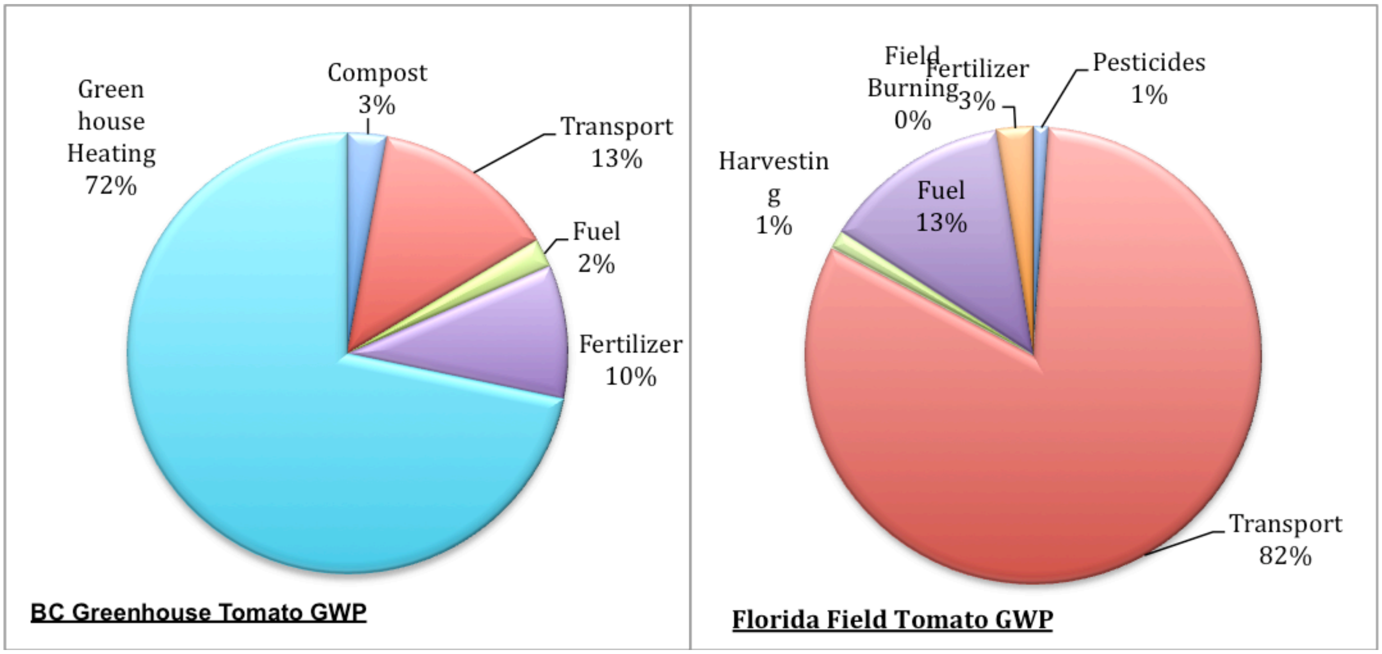

Figure 8. Piecewise contribution to global warming potential for Florida and BC tomatoes

The human toxicity index has similar results. Again, transportation for Florida tomatoes and heating for greenhouse tomatoes are the major contributors. *Figure 8* illustrates this trend and shows the relative contributions of other processes to the overall life cycle of both types of tomatoes. For BC greenhouse tomatoes, fertilizer production and consumption also accounts for a significant portion of the toxicity of this life cycle. In contrast, the Florida tomato toxicity impact is dominated by transportation and the production of fuel for transportation and the operation of farm equipment. This is another possible area of improvement for each process where the fuel could be replaced by some other lower impact energy source such as biodiesel. Interestingly, the disposal of agricultural end products, composting and burning, do not contribute significantly to the overall GWP of the products.

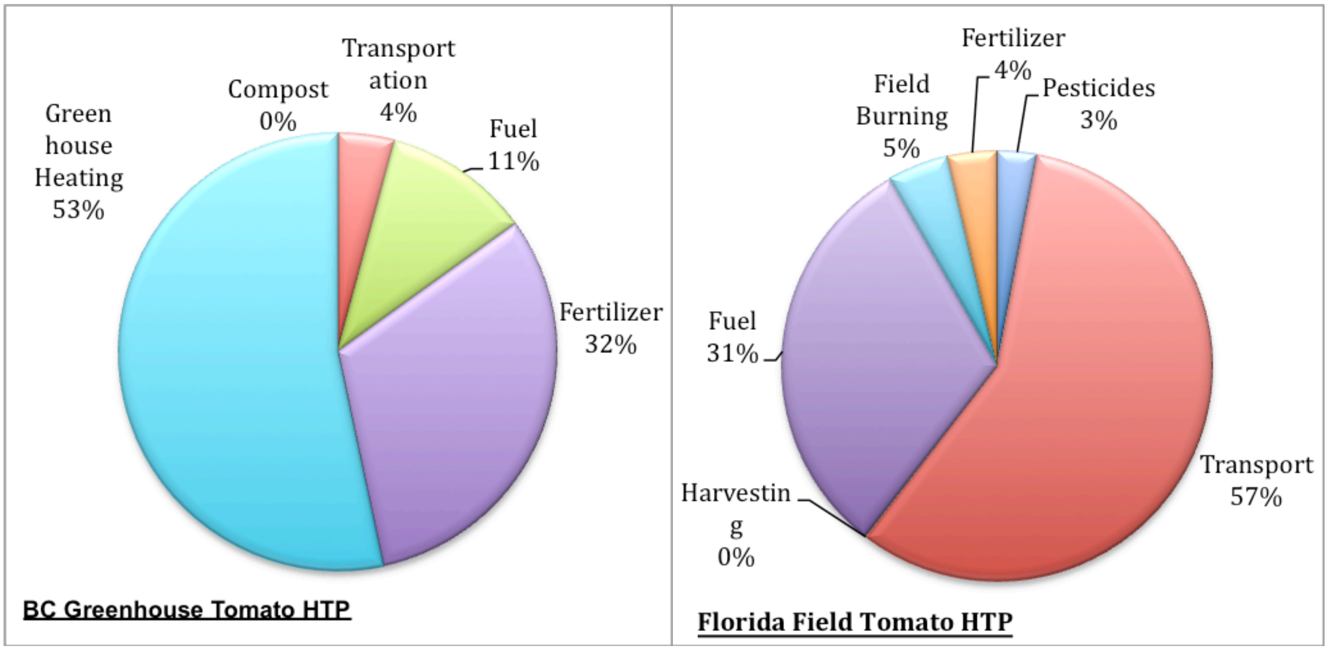

Figure 9. Piecewise contribution to human toxicity potential for BC and Florida tomatoes

It is important to keep in mind that *Figure 7* and *Figure 8* show relative contributions to each impact category, not direct comparisons between Florida and BC tomatoes; however, it is possible to further refine the comparison by including an overall qualitative comparison of the two processes. *Figures 9* and *10* directly compare the GWP and HTP of BC greenhouse tomatoes to Florida field tomatoes. *Figure 9* further illustrates the outcome that the impact of transporting the tomatoes from Florida to UBC is too great to compensate for the lower energy costs of production. The global warming potential for every aspect of the tomato life cycle is greater for Florida tomatoes, except for the heating costs associated with greenhouses. Overall, BC greenhouse tomatoes have the lowest global warming potential impact.

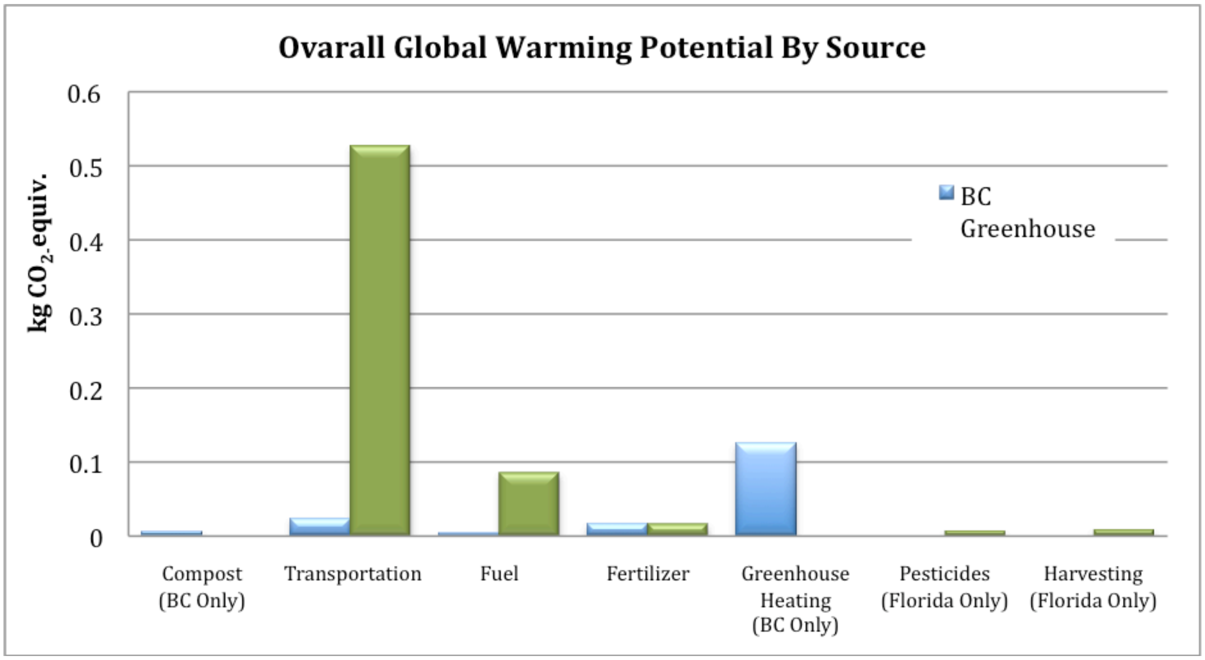

Figure 9. Global warming potential by source

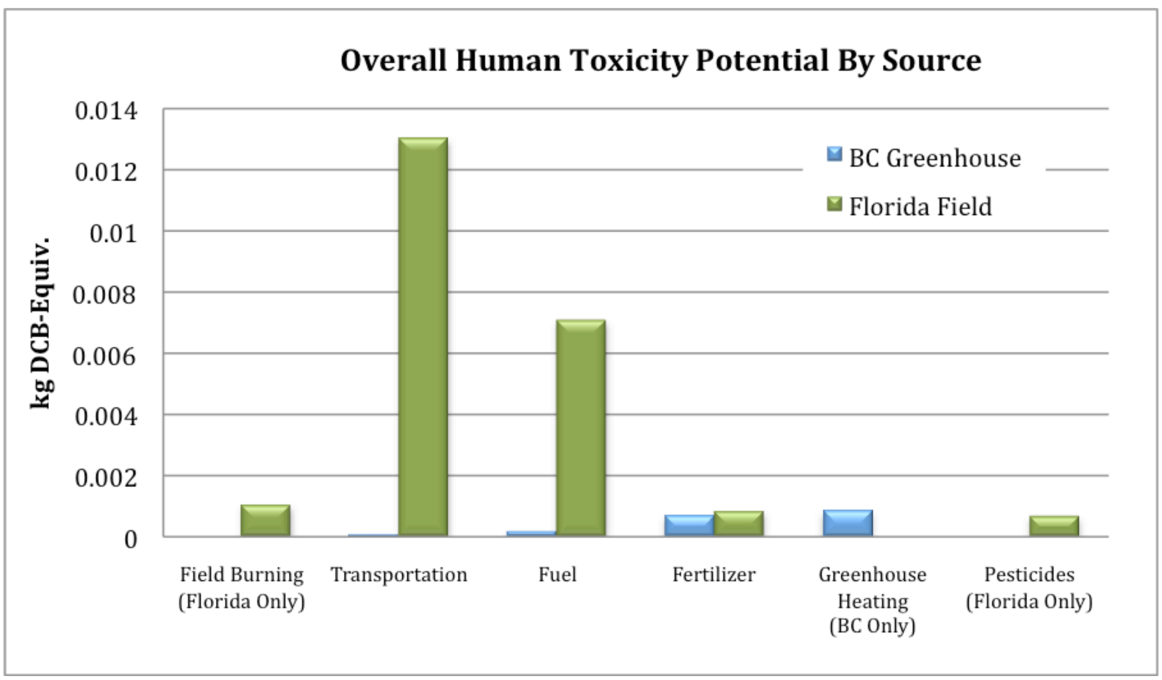

Figure 10. Human toxicity potential by source

Figure 10 further shows that BC greenhouse method has very minimal health impact. The transportation and fuel continue to be the largest sources of toxicity and once again, BC greenhouses have an equal or lesser human health impact than Florida tomatoes at each life cycle stage.

Finally, the qualitative aspects of both life cycles outlined in *section 8* can be analyzed. Firstly, BC greenhouse tomatoes use 85% less water for irrigation than field-grown tomatoes in Florida. Secondly, the use of water collection technology in greenhouses completely eliminates the effects of irrigation water pollution and soil erosion. Lastly, from the perspective of UBC Food Services, there is a great economic and social sustainability advantage to purchasing tomatoes from local growers.

In conclusion, the results of this life cycle analysis demonstrate that BC greenhouse-grown tomatoes are the most sustainable choice for UBC Food Services. The results and conclusions in this section also

extend to other impact categories that were not included in this discussion. For more information on the other impact categories a table of the calculated Gabi indices can be found in the *Tables 4* and *5* in *Appendix B*.

10.0 Conclusion

Having applied the LCA to tomatoes used by UBC Food Services using the GaBi Life Cycle software a conclusion can be drawn about the sustainability of each process and which should be utilized by UBC. Based on the factors considered in this study, BC tomatoes are the most sustainable option. It is important to note that the processes are more balanced once transportation is removed from the analysis; however, it is impossible to neglect this stage of the life cycle for tomatoes being used by UBC Food Services.

This study should not be considered a definitive result as the processes involved with tomato production are constantly changing and upgrading. Future studies should be conducted to reevaluate this conclusion, especially if there is a significant change in transportation methods from Florida that would possibly shift the advantage to the imported product. These future studies are required for definitive results that are current and up to date with present technology and processes.

For the most part, the results of this study are limited to the specific situation of UBC Food Services. The comparison of the two sources omitted some factors of the total life cycle, such as packaging, because the contribution of these factors was assumed to be equal for both sources. This is acceptable for comparison of the two products relative to one another; however, the results are not definitive for the absolute impact of tomato production.

The results obtained do support the conclusions from the study conducted in the Mediterranean [4]; however, contradict the study by Nicolas Daniel in 2009 [3]. In the case of the Daniel study, it is believed that the increased transportation distance between Florida and UBC versus California and UBC is the reason for the contradicting results; and thus, the results of this study generally do agree with previous research.

Because of the large contribution of transportation to the overall GWP and HTP of imported tomatoes, the results of this paper are also applicable to other vegetables with similar production and transportation requirements. Therefore, it is reasonable to suggest that vegetables grown in BC Greenhouses are a more sustainable alternative than vegetables grown anywhere a further distance away that the southern United States, including Mexico.

12.0 Recommendations

In conclusion, it is recommended that UBC Food Services attempt to purchase tomatoes from local BC greenhouses as much as possible. Unfortunately, local tomatoes are only available from April to November, so UBC Food Services will be forced to purchase imported tomatoes for the winter months. Currently, 96% of the tomatoes used by Food Services are imported from Florida or Mexico and only 4% are from local growers [2]. It is therefore recommended that local tomatoes should be purchased approximately 75% of the year, while they are available, and the balance should be imported as required during the winter. By following this purchasing distribution, UBC Food Services would reduce the carbon dioxide equivalent emissions due to tomato purchases by 54% or 2463 kg CO_2 equiv. per year.

13.0 References

[1] The Univesrity of British Columbia Food Services. UBC Food Services: About Us. 12 April 2010 <http://www.food.ubc.ca/about/index.html>.

[2] Domingo, Maria Cylena. "Personal Email Communications: SEEDS Project." 2 February 2010.

[3] Daniels, Nicolas. Steamlined LCA of Tomato Production: Locally Produced Greenhouse Tomatoes Vs Field Grown Imports from California. Vancouver: CEEN 523, 2009.

[4] Muñoz, P., et al. "COMPARING THE ENVIRONMENTAL IMPACTS OF GREENHOUSE VERSUS OPEN-FIELD TOMATO PRODUCTION IN THE MEDITERRANEAN REGION." ISHS Acta Horticulturae 801: International Symposium on High Technology for Greenhouse System Management (n.d.).

[5] Ball, Amandeep. Personal phone communications Tyler Wilkes and Andrea MacDonald. 7 April 2010.

[6] US National Agricultural Statistics Service. "U.S. tomatoes, fresh: Chemical Use by State, Percent of Acres Treated, and Total Applied, 2006." 2006. NASS - Florida Reports and Statistics. 24 March 2010 <http://www.nass.usda.gov/Statistics_by_State/Florida/index.asp#.html>.

[7] Florida Tomato Committee. "Tomato 101." Florida Tomatoes. 24 March 2010 <http://www.floridatomatoes.org/tomato%20101.pdf>.

[8] Gertsson, Ulla E. "Nutrient Uptake By Tomatoes Grown in Hydroponics." Acta Hort. 401 (1995): 351-356.

[9] United States Environmental Protection Agency. "Fertilizer Application." March 1999. US EPA Technology Transfer Network. 2 April 2010 <http://www.epa.gov/ttn/chief/ap42/ch09/draft/d09s0201.pdf>.

[10] Ag Solutions. East - Product Profile - Kumulus DF. 2010. 2 April 2010 <http://www.agsolutions.ca/basf/agprocan/agsolutions/WebASProd.nsf/WebProductProfile/PROD-CIRD-7W5VD3?OpenDocument>.

[12] Google. Google Maps. 2 April 2010 <http://maps.google.ca>.

[13] Technology Transfer Network - Factors Information Retrieval System (FIRE). 10 April 2010 <http://cfpub.epa.gov/webfire/>.

[14] United States Geological Survey (USGS). Estimated Water Use in the United States in 2000 - Table 7. 2000. 2 April 2010 <http://pubs.usgs.gov/circ/2004/circ1268/htdocs/table07.html>.

[15] LeBoeuf, Janice. Effects of Dry Conditions on the Tomato Plant. 2007. Ontario Ministry of Agriculture Food and Rural Affairs. 2 April 2010 <http://www.omafra.gov.on.ca/english/crops/facts/dry-tomato.htm>.

[16] Margaret, Mary Gay. Personal phone communciations Andrea Macdonald. 7 April 2010.

[17] Anderson, et. al. “Quantification of Greenhouse Gas Emissions from Windrow Composting of Garden Waste.” Journal of Environmental Quality. 39 (2010): 713-724.

[18] United States Environmental Protection Agency. Florida Tomato (Vegetable) MetaData – Pesticides – US EPA. 2 April 2010. <http://www.epa.gov/oppefed1/models/water/met_fl_tomato.htm>

Appendix A – Life Cycle Analysis Input Data

Process Title	Notes	Database/Source
US: Limestone, at mine	Used to represent potash mining, closest available process	US LCI
US: Potash Production	Created process, additional emissions from potash processing	US EPA emission factors
US: Phosphorus fertilizer, production mix, at plant	Phosphorous fertilizer production and transport	US LCI
US: Nitrogen fertilizer, production mix, at plant	Nitrogen fertilizer production and transport	US LCI
US: Natural gas, combusted in industrial boiler	Natural gas production, transport, and combustion in BC greenhouses	US LCI
US: Tomato Production	Created process to combine all inputs	n/a
CA: Windrow Composting	Created process	[17]
GLO: Solo truck up to 7.5t capacity	Transport of BC tomatoes	Ecoivent
US: Diesel at refinery	Diesel production in North America	US LCI
DE: Sulphur at refinery	Elemental sulphur production for fertilizer	Ecoivent
US: Sulphur herbicide production	Created process for additional production of sulphur herbicide	US EPA Emission Factors
RNA: Harvesting, fresh fruit bunch, at farm	Farming processes involved in growing and harvesting tomatoes	US LCI
US: Field Burning	Created process	US EPA Emission Factors
GLO: Trailer-truck up to 28t payload	Transportation of Florida tomatoes	Evoivent

Table 3. Processes used in GaBi software for life cycle analysis

Appendix B – Life Cycle Analysis Results

CML2001 - Dec. 07, Abiotic Depletion (ADP) [kg Sb-Equiv.]	0.000187
CML2001 - Dec. 07, Acidification Potential (AP) [kg SO2-Equiv.]	0.000589
CML2001 - Dec. 07, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	0.001556
CML2001 - Dec. 07, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	0.002215
CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	0.175782
CML2001 - Dec. 07, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	0.002229
CML2001 - Dec. 07, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	1.551282
CML2001 - Dec. 07, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	5.47E-11
CML2001 - Dec. 07, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	3.79E-05
CML2001 - Dec. 07, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	4.51E-05

Table 4. Complete list of impact indices for BC greenhouse tomatoes

CML2001 - Dec. 07, Abiotic Depletion (ADP) [kg Sb-Equiv.]	0.004361184
CML2001 - Dec. 07, Acidification Potential (AP) [kg SO2-Equiv.]	0.004058983
CML2001 - Dec. 07, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	0.002149291
CML2001 - Dec. 07, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	0.003766516
CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	0.644643324
CML2001 - Dec. 07, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	0.022680062
CML2001 - Dec. 07, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	13.57612638
CML2001 - Dec. 07, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1.35E-09
CML2001 - Dec. 07, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	0.000346808
CML2001 - Dec. 07, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	0.000503584

Table 5. Complete list of impact indices for Florida field tomatoes