

LCA OF LOCAL BIO-CHP FUELLED GREENHOUSES VERSUS MEDITERRANEAN OPEN FIELD TOMATOES FOR CONSUMPTION IN NORTHERN SCANDINAVIA

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ABSTRACT

Tomatoes are a commonly used product in the Scandinavian countries, where locally grown tomatoes generally have to be cultivated in greenhouses, heated for most part of the year. Tomatoes imported from the Mediterranean area will not need heated greenhouses, but are transported a longer distance. Earlier studies have shown imported tomatoes over long distances are environmentally preferable when compared to tomatoes produced in greenhouses. In this study, tomatoes for the Trøndelag market in Norway locally grown in greenhouses with heat from biofuelled CHP generation have been studied using life cycle assessment (LCA). An LCA model for the biofuel heated greenhouse tomatoes was created and compared to a model of field grown tomatoes in Spain. In a sensitivity analysis a fossil energy scenario for the greenhouse tomatoes was studied. The biofuelled greenhouse tomatoes was found to be better in all studied life cycle impact categories compared to the long-distance transported field grown tomatoes. The scenario with fossil energy to the greenhouse give much higher impacts compared to the long distance transported tomatoes in most categories studied. A shift towards more renewable energy systems is one important task for a more sustainable agriculture.

KEYWORDS

Bioenergy, Life Cycle Assessment, greenhouse, food, environmental impact

<https://doi.org/10.15626/Eco-Tech.2010.051>

1 INTRODUCTION

There is a growing demand for food that has been produced without large adverse environmental impacts. While we at least in theory can manage without many of the services and products that are available to us, the consumption of food is indispensable. This makes all actions that minimize the environmental impacts related to food production important [1]. As the greenhouse sector is among the more energy-consuming sectors within agriculture [2], it is of interest to study the environmental impacts of greenhouse grown vegetables and to investigate possible improvements. In this study life cycle assessment (LCA) is used to evaluate the environmental performance of producing tomatoes in Norwegian (Sør-Trøndelag) greenhouses heated with a micro-scale bio-fuelled gasification CHP and this system will be compared to conventional open-field tomatoes grown and shipped from southern Europe (Mediterranean Spain) to Northern Scandinavia (Trondheim, Norway).

Compared to imported tomatoes grown in open systems, locally produced tomatoes from greenhouses heated by fossil fuels such as oil and natural gas are a poor choice for the environment when it comes to primary energy consumption and carbon dioxide equivalents emissions [3]. Figures from an earlier process based LCA indicated that the primary energy consumption during the life-cycle of greenhouse tomatoes in Sweden are roughly twelve times that of tomatoes grown in fields in southern Europe and transported to Sweden [4]. Similarly, nine to twenty-one times more energy for heated greenhouses rather than open-air systems was found in a Belgium study [5]. The results can be assumed to be valid also for Norwegian conditions, and would indicate that a substitution of imports is not desirable. Although energy demand may be higher for greenhouse systems, if it comes from a renewable source, the environmental performance may be superior to long distance food imports from open-field systems.

Therefore, the aim of this study is to explore the environmental performance of bio-fuelled CHP heated greenhouses in the Trøndelag region for local production, in contrast to shipping tomatoes from open Spanish fields over long distances. The analysis is limited to a conventional open system (tomatoes grown in fields) in the Mediterranean region and a closed system (tomatoes grown in a greenhouse) heated by a biomass fuelled CHP plant using gasification technology in the mid-Norway region of Trøndelag. This study also considers three electricity mix scenarios.

2 METHODOLOGY AND CASE DESCRIPTION

LCA is a prevailing tool when analyzing renewable energy systems for environmental impacts [6] and it has its principles, framework and requirements defined and explained in the recently refined ISO standards, ISO 14040:2006 and ISO 14044:2006.

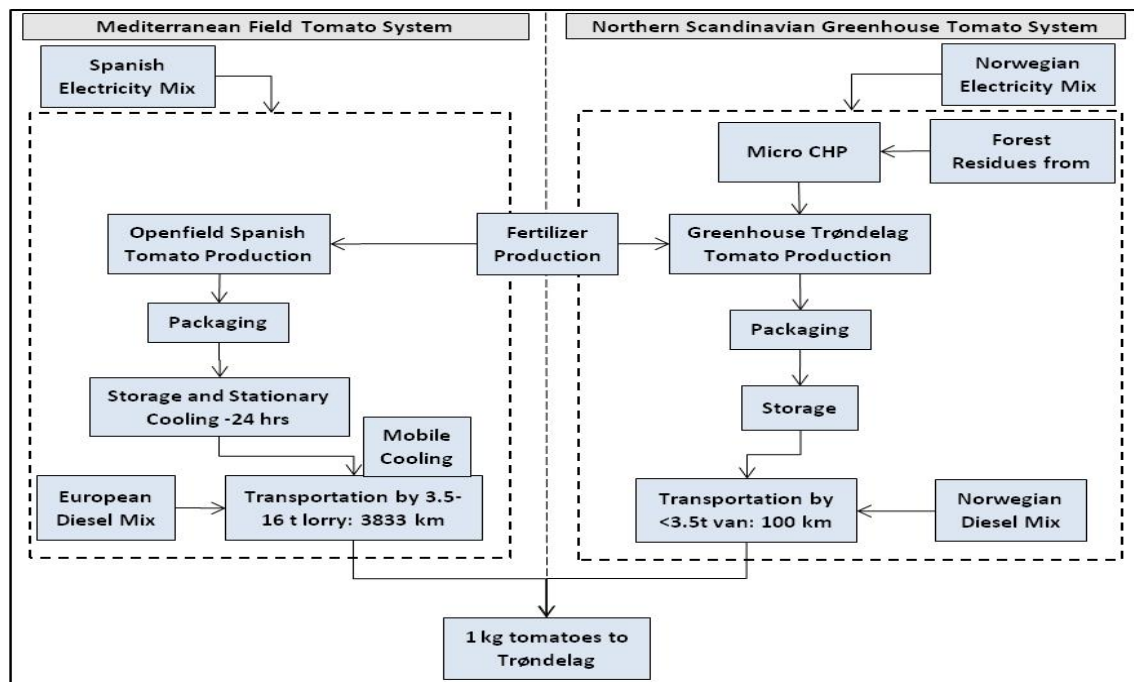
2.1 Goal and Scope

In this study LCA will be used to analyze and compare the environmental impacts in the case of producing greenhouse tomatoes in Trøndelag heated by a micro CHP (down-draft gasification) plant fuelled by forest residues from the Mid-Norway region versus the presently more conventional case of imported tomatoes from an open-field system in the South of Spain. The goal and scope of this study is to do a unit based analysis with the functional unit

being one kilogram of tomato production delivered to the market gate which is assumed to be the city of Trondheim. The use phase is assumed to be the same disregarding origin of the tomatoes, and is not included in this study.

Figure 1 illustrates a simplified model of the life-cycle process flow diagram focusing on the major foreground processes considered. The construction, operation and decommissioning phases are all considered for the life-cycle processes. Major processes that have significant differences between the two systems include average tomato procurement distance (3850 km for the Spanish tomato versus 100 km for the Trøndelag one), foreground electricity mixes (cleaner generation for the Trøndelag tomato) and energy input per unit of tomato production (higher energy intensity for greenhouse tomatoes). Unit process based factors stemming from empirical and simulation data are used. The ecoinvent v2.0 database [7] is used for the majority of the foreground and all of the background processes.

The software used for this process unit based LCA was SimaPro 7.1.8 and Matlab (R2007a). The SimaPro package has an easy to use interface and already has the ecoinvent v2.0 database and several environmental impact methodologies built into it making it a good program to use for this study. The problem-oriented CML 2 Baseline 2000 impact assessment method [8] is used to assess these impacts. The categories illustrated in this study include the potential impacts of global warming, acidification, eutrophication, abiotic depletion and ozone layer depletion.



2.2 System Description

Figure 1. Comparison of LCA System

2.2.1 Mediterranean Field Tomato System

Open-field tomato farming

The tomato yield for open-field tomato farm production in Spain was 106,500 kg/ha/yr [4]. Farming activities included are irrigation, mulching, fertilizing by broadcaster, and combine harvesting [9]. Nitrate and phosphate emissions to groundwater and dinitrogen monoxide (N₂O) emissions to air due to fertilizers were considered [10].

Fertilizer requirements considered were 19 g N (nitrogen), 7.7 g P (phosphorus) and 21 g K (potassium) per kg of tomato production [4]. The macro nutrients were assumed to come from ammonium nitrate, single superphosphate (P₂O₅) and potassium sulphate (K₂SO₄). Fertilizer production inventory data was based on a European production mix [9].

Tomato Cooling and Storage

Once tomatoes are harvested they are packaged into folding box board containers. A conventional European cardboard mix was assumed [11]. The amount of packaging needed was estimated to be 0.06 kg cardboard box per kg tomato. For stationary cooling, a 10 kW electric heat pump is assumed to be used with an average tomato residence time of 24 hours. One day stationary storage duration was thought to be reasonable since [4] estimated tomato durability to be fourteen days and with an optimum storage temperature of 12-14 °C. Also, in interviews farmers stated that the average on-farm storage time to be 1-1.5 days [5]. LCI data for the heat pump is based on [12]. Mobile cooling (while being shipped by lorry) was assumed to last a duration of five days and use 8.14E-3 kg diesel per kg tomato [4]. The cooling process was simplified to just consider diesel consumption. The diesel fuel required is assumed to be a European diesel mix [12].

Tomato Transportation

Norwegian statistics stated for 2009 that 87% of tomato imports from Spain to Norway arrived via lorry [26]. Therefore we assume all imported tomatoes in this system arrive by a 3.5-16 tonne lorry with LCI data based on European fleet average values [13]. The points of departure and arrival were assumed to be Murcia, Spain and Trondheim, Norway which spans a road way distance of 3,833 km [14]. Diesel consumed for transportation was assumed to be a European mix [12].

2.2.1 Sør-Trøndelag Tomato Production System

Greenhouse Tomato Production

The greenhouses considered have a metal frame, plastic windows and is based on a concrete foundation. The greenhouse life span is at least ten years and can be extended further by changing the plastics [15]. Here we assume a plastics lifetime of ten years and a greenhouse frame lifetime of twenty years. The amount of material needed for one hectare of greenhouse is 6.2 m³ of plastics, 12.3 m³ of aluminium and 1750 m³ of concrete [15]. The transparent plastic material was assumed to be polycarbonate (bispheno A polycarbonate) and inventory data for its production came from [11]. For the greenhouse frame the only metals considered are aluminium from a bar extrusion process with LCI data from [16] where a Norwegian electricity mix to produce the aluminium is assumed.

A temperature range between 18-25 ° C is needed to grow tomatoes in greenhouses [15]. For our heat requirement calculations we use company design coefficients from [17] and we

assume a constant temperature of 20 ° C inside the greenhouse. The average ambient temperature in Sør-Trøndelag is based on the average of a past ten year dataset with daily resolution from the Norwegian Meteorological institute [18]. The weather station where the data was collected is located in central Trøndelag at Trondheim Lufthavn Værnes (i.e. Trondheim Airport). Using design equations [23] the heat required for the tomato season (January 15-October 15 [17]) was calculated to be an average 10.95 kWh per kg of tomato production. The average electricity requirements for tomato production in Norwegian greenhouses was based on data from Statistics Norway on a per m² basis and for the region of Sør-Trøndelag: 280 kWh per m² or 7.0 kWh/kg tomato per year.

A tomato yield factor of 40 kg tomatoes per m² and year is based on email exchange with a greenhouse tomato producer in the Sør-Trøndelag region [17]. Water consumption is based on a greenhouse tomato production process where a water recirculation scheme was assumed [10]. Fertilizer requirements are based on [4]'s values on a per kg tomato production basis: 5 g N, 0.9 g P, and 6.5 g K. The same sources as for the Spanish tomato production were assumed.

Micro-CHP—Biofuelled Gasification

For the gas production to supply the micro scale CHP, a fixed-bed down-draft gasifier was considered [19, 20]. This allows for dry gas as opposed to wet gas cleaning since the concentration of tars in the producer gas is relatively low. A low tar concentration going to the internal combustion engine is important due to the gas cooling from 550 °C to 60 °C and thus condensed tar entrainment in the engine would be problematic. Dry gas cleaning significantly reduces the waste water stream needed to be treated. One such technology has been successfully demonstrated by a Danish Company, Biosynergi, and technical data from it is utilized for this micro-scale CHP. An appropriately sized internal combustion engine integrated with a generator is then assumed for the power production. Localized biomass procurement from both forest residues and saw mills is assumed [20].

The micro CHP unit is assumed to provide all of the heating requirements and a portion of the electricity demand for the greenhouse scenario. The electricity to heating ratio for this micro scale CHP is 0.45 and therefore the CHP when covering the 10.95 kWh heat load can provide 4.75 kWh of the required 7.0 kWh electricity per kg of tomato (accounting for parasitic load [19]). The remaining 2.26 kWh of power per kg tomato is assumed to come from the grid (see 2.2.3).

Tomato storage and Transportation

The same packaging assumptions were assumed as for the Mediterranean field tomato system. No cooling requirements are assumed necessary for local Scandinavian tomato storage before market [4, 5]. Transportation distance of tomatoes from greenhouse to market is assumed to be 100 km and the use of a van was assumed (>3.5 tonne) [13]. The diesel consumed for transportation is assumed to come from Norwegian sources [12].

2.2.3 Electricity Mix Scenarios

Three types of electricity mixes, see table 1, were considered in different scenarios [12]:

Table 1. Electricity Mix Scenarios

	Greenhouse Tomatoes	Spanish Open Field Tomatoes
Five-year Annual Average with import/ exports	Norway: 91.8%; Sweden: 5.62%; Denmark: 2.42%; Finland: 0.116%.	Spain: 96.3%; Portugal: 3.27%; France: 0.398%.
Regional Mix: NORDEL and Mediterranean MIX (MEDEL)	Norway: 29.0%; Sweden: 39.2%; Finland: 21.6%; Denmark: 10.2%.	Spain: 24.3%; France: 46.5%; Italy: 24.3%; Portugal: 3.845%
Marginal mix	100% Natural Gas IGCC	not applicable

- Country five-year annual average accounting for trade;
- Regional electricity mix amongst target and neighbouring countries;
- Marginal electricity mix (natural gas power plant) for the greenhouse system since it is the consequential system in this study [12].

In addition to the already described bio-heated greenhouse systems, an alternative local heating process was used where instead of the biomass CHP a micro-scale light fuel oil boiler was assumed [12] together with the NORDEL mix.

3 RESULTS

Figure 2 illustrates a contribution analysis of four cradle-to-gate cases: open-field vs greenhouse, with two electricity mix scenarios and a fossil energy scenario for the greenhouse production. The difference between the electricity mix scenarios for the open-field Spanish case was negligible and therefore only one case is illustrated. The x-axis represents the fraction of environmental impact as normalized by the tomato producing system that is contributing the most to the given impact category. Four impact categories were considered: Global Warming Potential 100 (GWP); Acidification Potential (AP); Eutrophication Potential (EP); and Abiotic Depletion Potential (ADP). The labelled scenarios are as follows: TS_AVE (Spanish grown tomatoes using the average Spanish electricity mix); TG_OIL_NORDEL (Greenhouse tomatoes using oil boiler with NORDEL electricity mix); TG_MRG (greenhouse tomatoes using the marginal electricity mix); and TG_AVE (greenhouse tomatoes using the average Norwegian electricity mix).

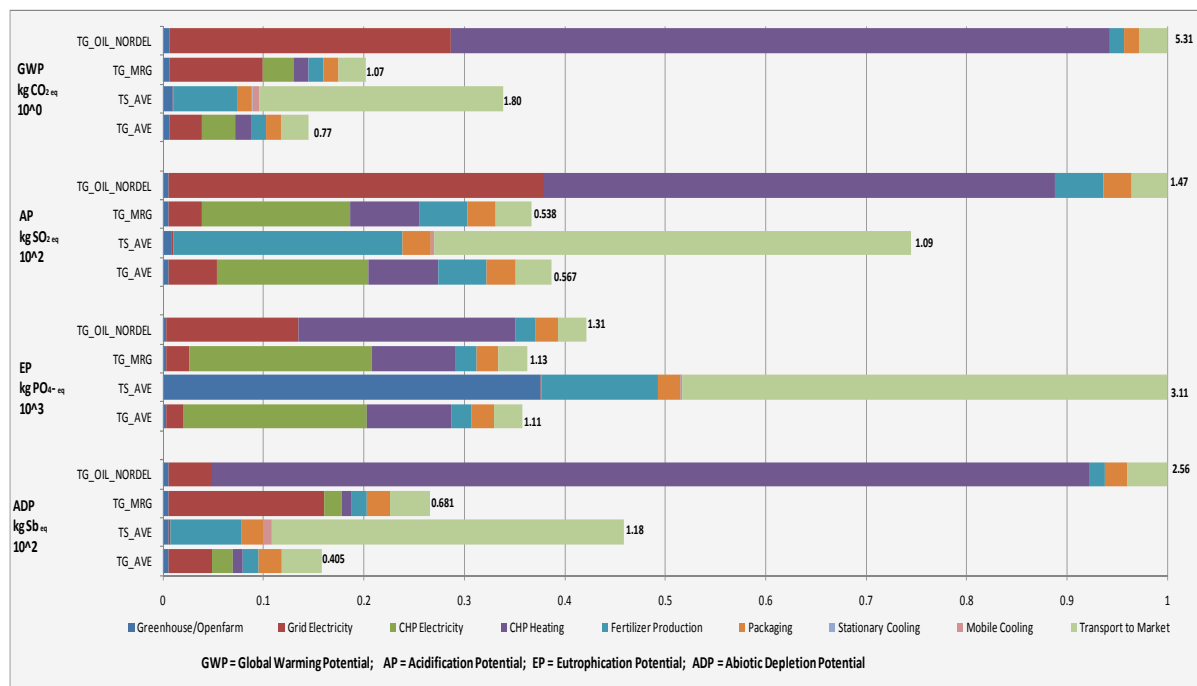


Figure 2. Impact Contribution Analysis of the Different Scenarios

GWP (global warming potential): TG_AVE, TG_MRG and TS_AVE contribute 15%, 22%, and 34%, respectively, of what the TG_OIL_NORDEL system contributes (5.31 kg CO_{2eq}). TG_AVE contributes 43% of what TS_AVE contributes (1.8 kg CO_{2eq}). For TS_AVE, tomato transportation (72%) and fertilizer production (19%) contribute the most to total GWP. For TG_AVE, impact is more evenly distributed with CHP electricity (23%), grid electricity (22%) and tomato transportation (19%) being the most significant processes. CO₂ emissions contribute 78-95% of the total GWP.

AP (acidification potential): TG_MRG, TG_AVE and TS_AVE contribute 37%, 39%, and 74%, respectively, of what the TG_OIL_NORDEL system contributes (1.47E-2 kg SO_{2eq}). TG_AVE contributes 52% of what TS_AVE contributes (1.09 kg CO_{2eq}). For TS_AVE, tomato transportation (64%) and fertilizer production (31%) contribute the most to total AP. For TG_AVE, the impact is quite distributed amongst CHP electricity (39%), CHP heating (18%), grid electricity (12%), fertilizer production (12%), tomato transport (9.2%) and box-board production (7.3%). The majority of the total AP is split between two emissions: NO_x (23-55%) and SO₂ (42-76%).

EP (eutrophication potential): TG_AVE, TG_MRG and TG_OIL_NORDEL contribute 35.7%, 36.3%, and 42%, respectively, of what the TS_AVE system contributes (3.11E-2 kg SO_{2eq}). For TG_AVE, CHP electricity (51%) and heating (24%) contribute most to total EP. For TS_AVE, tomato transportation (48%) and farming (38%) contribute the most to total EP. For TS_AVE, NO_x (48%), and leaching of nitrates (35%) cause the greatest potential. For the TG systems NO_x emissions contribute the most potential (66-82%).

ADP (abiotic depletion potential): TG_AVE, TG_MRG and TS_AVE contribute 16%, 27%, and 46%, respectively, of what the TG_OIL_NORDEL system contributes (2.56E-2 kg Sb_{eq}). TG_AVE contributes 34% of what TS_AVE contributes (1.18E-2 kg Sb_{eq}). For TS_AVE, tomato transportation (76%), and fertilizer production (15%) contribute the most to total

ADP. For TG_AVE, grid electricity (27%) and tomato transport (25%) make up the majority of total ADP. Depletion of fossil fuels (natural gas, oil and coal) contributes nearly 100% to this impact category.

4 DISCUSSION AND CONCLUSION

The objective of this study was to explore whether it is environmentally preferable to grow tomatoes in greenhouses for local production in northern latitudes or to transport produce long distances from geographically optimum open farm fields. The results show that it might be environmentally preferable to grow in greenhouses for local consumption, if the greenhouse heating demand can be fuelled with bio-energy.

4.1 Sensitivity Analysis

By varying the foreground electricity mixes and the greenhouse energy technologies, insight into the sensitivity of the systems has been gained. In fact, the various electricity mixes for the open-farming Spanish case created negligible change to the total environmental impacts. Therefore, only the average electricity mix was chosen to illustrate this system. Since electricity demand is much higher for the greenhouse system, choice of foreground electricity mix significantly changed the resulting impact in all impact categories considered. The results in this study are in agreement with [4] where she calculated that oil heating based greenhouse grown tomatoes in Sweden created a total GWP impact of 4.2 kg CO_{2eq} per kg tomatoes for the system. For the TG_OIL_NORDEL scenario 5.31 kg CO_{2eq} was calculated.

4.2 Seasonal Variation and the Potential to Replace Norwegian Imports

Tomatoes produced in Norway are usually sold out by the beginning of November [21]. This is sensible, since the greenhouse production system considered here was assumed to have a growing season from January 15 to October 15. Spain (44%), the Netherlands (42.8%) and Italy (5.0%) constitute the majority of Norway's tomato imports—an average of 91.7% total imports (21.5 million kg) [22]. Assuming seasonal greenhouse tomatoes are available from mid-May to the end of October, such a system can replace 5.86 million kg total imports in this time frame. Considering Dutch and Scandinavian tomato imports to Norway as having the least environmental impact the remaining imports that could be replaced is around 940,000 kg of tomatoes. Such a substitution amounts to around 4.4% of the total year-round imports and this would require around 23,500 m² or 2.35 hectares of greenhouse area. If the total seasonable tomato import substitution is considered (i.e. including the Netherlands and other Scandinavian countries) a total area of 146,500 m² or 14.7 hectares tomato greenhouse production would be needed. This would mean replacing 27% of total tomato imports. Of course there are many other fruits and vegetable where similar substitution benefits can be found.

5 CONCLUSION

In this study we carried out a comparative, cradle-to-gate LCA of two tomato production systems. The results have shown that substitution of Mediterranean grown tomatoes on open-

fields transported over long distance with bio-fuelled greenhouse tomato production for regional consumption can be environmentally preferable in all impact categories studied.

ACKNOWLEDGEMENTS

This study has been financed by a PhD stipend from NTNU. We are very grateful for the available funding that made this research possible through the CENBIO program that came from the Norwegian Research Council.

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