CHALMERS

European Tomatoes

Comparing global warming potential, energy use and water consumption from growing tomatoes in Sweden, the Netherlands and the Canary Islands using life cycle assessment

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Abstract

Tomatoes consumed in Sweden originate mainly from Sweden, Spain and the Netherlands, and it is not obvious which tomatoes are best from an environmental point of view. This MSc thesis report use the framework of Life cycle assessment to compare global warming potential and energy use when growing tomatoes in the different countries, including transport to and storage and retail in Sweden. Data was collected from two growers in Sweden, one in the Canary Islands and one in the Netherlands. The results show that Swedish tomatoes emits the least amount of greenhouse gases, as long as they are heated with bio fuels, and that Spanish tomatoes use the least amount of energy, per kg tomatoes sold in Stockholm, Sweden.

Contents

1 Introduction

The public awareness of environmental problems have increased over the last few years. One of the most discussed environmental problems is climate change, largely due to reports and projections on global warming caused by our society and possible future effects of it. Huppes and colleagues (2006), as reviewed in Tukker, A. & Jansen, B. (2006), find that climate gas emissions related to food consumption are 31% of the total household emissions. One environmental issue in food consumption in Sweden is consumption of vegetables that either have to be grown in heated greenhouses or transported here from more favorable climates. The most common of the greenhouse vegetable in Sweden is the tomato, which is consumed all year around despite the cold climate. Tomatoes consumed in Sweden usually originate from either Sweden, the Netherlands or Spain. From an environmental point of view it can be hard to choose the most climate friendly origin since the Swedish tomatoes are grown in heated greenhouses but not transported very far while the Spanish ones are transported a long way but produced without heated greenhouses, and the tomatoes from the Netherlands are produced in heated greenhouses but not transported as far as the Spanish tomatoes.

Earlier studies in this field include Möller Nielsen, J. (2008)[1] whose resent study of Swedish greenhouse tomatoes show predicted greenhouse gas emissions of 0.94 kg CO2-equvalents per kg tomatoes for 2008; Lagerberg Fogelberg, C. & Carlsson-Kanyama A. (2006) who show that the emissions from Swedish tomatoes in 2005 were 2.7 kg CO2-eq., and the emissions from tomatoes grown in Holland in 2005 were 2.9 kg CO2-eq. per kg tomatoes; Antón, A. (2005) whose study on mediterranean greenhouses show that Spanish tomatoes account for between 81 and 120 g CO2-eq per kg tomatoes, depending on the growth technique used. One important reason for the large difference between tomatoes grown in 2005 and 2008 in Sweden is the shift in the main fuel used to heat the greenhouses, from fossil fuels to bio fuels. However, these studies do not include impact from transport, and it is not obvious how much the transport affects the total impact from growing and selling tomatoes in Sweden. Thus, there is need for a comparing study of the climate impact caused by growing tomatoes on a large scale in Sweden, the Netherlands and Spain, including impact from transport to Sweden.

This report uses the framework of *Life Cycle Assessment (LCA)* to compare *Global Warming Potential (GWP), energy use* and *water consumption* of five different tomato farming systems, originating from four different tomato growers in Sweden, the Netherlands and the Canary Islands, including impact from transport, storage and retail to/in Stockholm, Sweden.

[1] Möller Nielsens report, *Energin & koldioxiden i svensk växthusodling 2008 - TOMAT LCA* (only available in swedish), can be recommended as a good source of information on how tomatoes are grown in Sweden in 2008 and the climat impact from the business.

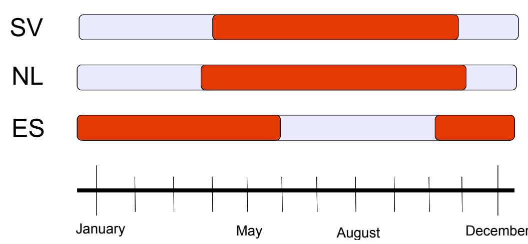

Figure 1: Times during the year when tomatoes are harvested at the growers studied in this report. Sweden (SV), the Netherlands (NL) and the Canary Islands (ES). Sweden and the Netherlands grow in the summer because they need the warmth and the light. In Spain they grow in the winter because it is too hot and dry in the summer.

The aim of the report is:

- To compare climate impact, energy use and water use caused by consumption of tomatoes in Sweden, depending on whether they originate from Sweden, the Nehterlands or Spain.

1.1 Outline of the report

This report consist of an Introduction, a Goal and Scope section, a Data collection section, a Results section, a Discussion section and a Conclusions section.

The Method section holds descriptions of the methods used to produce the results in the report.

The Goal and Scope section is present in all LCA reports and contains specific information of the system and the methods used to analyse it. It also includes a description of the purpose and targets of the report. This section contains most of the information on what was done, why it was done and how it was done.

The Data collection section has two main purposes; it contains all the data used to produce the results and a description of how the data was gathered.

The Results section contains the results of the calculations, and it is the foundation on which the two last sections are built.

In the Discussion section, the results are theoretically analysed and discussed. Included here is also a discussion on possible limitations in the research and on suggestions for future improvements in the tomato growing industry.

The Conclusions section holds the conclusions drawn from the discussion.

1.1.1 Tip to the inexperienced report-reader

For anyone who is mostly interested in the results of this report, and is not used to the art of report reading, I recommend first reading the *Short explanation of LCA* in the Method section, and then skipping ahead to the Results section, followed by Discussion and Conclusions. The Method and Goal & Scope sections can afterwards be read for better understanding, whereas the Data collection section is more for future reference and transparency reasons.

2 Method

The method used to calculate the results was Life Cycle Assessment, or LCA. It is a standardised framework documented in ISO 14040 and ISO 14044 (ISO 2006) which is used to calculate environmental impact. LCA was used in this report because it is a method that can capture the emissions and resource use from the whole life cycle of the production. LCA is commonly used when calculating different kinds of environmental impact from production or services, for example from production of food.

2.1 Short explanation of LCA

LCA is a tool for calculating environmental impact caused by a specified product or service (referred to as the *system*). The impact is calculated for a chosen function of the product; e.g. *traveling one km* by car or *consuming one kilo* of tomatoes. All the emissions and resources used throughout the life cycle are added together, including those caused by the production of sub-components; e.g. the production of the steel used in the car or the fertilisers used to grow the tomatoes. The different emissions may be added together using weighting tables and the results are presented in a number of impact categories; e.g. global warming potential, eutrophication and acidification.

In this report I have used the impact category Global warming potential over 100 years (GWP100) and energy use, both which will be defined in the Goal and Scope chapter. The water consumption has not been calculated using this approach, only the water used by the grower for watering the tomato plants is accounted for.

Doing a complete LCA on a product is often very time consuming since you need to find out the emissions of the producer, and the emissions of the sub-contractors, and of their sub-contractors, etc.. For this reason you are often forced to exclude parts of the life cycle from the calculations, focusing on the main flows and the parts that are believed to be relevant and possible to investigate.

Even though the quality of an LCA is dependent on what is and isn't included in the system model, conclusions can generally still be drawn from the results of an incomplete system model. This is possible due to experience from working with similar systems, and from working with LCA in general.

All the parts of the system that are included in the calculations are referred to as the *system model*, and are said to be inside the *system boundary*.

One should always be careful in how to interpret the results from an LCA since they depend on what is included in the system model. It can, for example, be misleading to compare the results of two different LCA's if the differences in the system model are not taken into account, even if they were made on two very similar, or even identical, products.

For a full introduction on how LCA works and is calculated, please read the book *Hitchhikers Guide to LCA* by H Baumann and A-M Tillman (2004).

2.2 Calculations

The calculations in this report were made using the LCA software SimaPro from PRe Consultants.

Global warming potential (GWP) is a way to add together the effect that different gases has on the greenhouse effect of the atmosphere. GWP is measured in carbon dioxide equivalents (CO2-eq) and all other gases have their greenhouse effect recalculated into units of CO2-eq.

The list of gases are presented and updated by the IPCC and can be found in their assessment reports (Solomon et al. 2006). The most important greenhouse gases, and their relative GWP over a 100 year perspective, are listed below [IPCC-2, 2007, chp 2, p 212].

CO2	-	1
Methane (CH4)	-	25
N2O	-	298

These numbers are subject to change as the research surrounding the climate move forward, the changes are however usually small. These are the numbers used in the calculations in this report.

3 Goal & Scope

3.1 Purpose and targets

This report is the result of a MSc thesis project which was initiated by SIK, the research institute for food and biotechnology in Sweden, as a means to get new inventory data on tomato farming. The gathered data was also used in a project involving ICA Sverige AB, a leading food retail company in Sweden, and all the growers who supplied the data were at the time delivering tomatoes to ICA.

The purpose of this report is to answer the question; Which tomatoes should be bought by a consumer or retail store purchaser in Sweden, from a pro-climate point of view?

The main targets of the report are grocery store purchasers and consumers in Sweden. Secondary targets are the tomato growers and policy makers in Europe and the scientific communities working with food science, climate change and sustainable resource use (energy and water).

3.2 Accounting LCA

This LCA is a so-called *accounting* LCA, meaning that it is comparing and retrospective. The different tomato growers have been analysed separately and the results of the analysis are compared. The calculated impact can be associated with a product or service. Accounting LCA's are commonly used when comparing different products or services.

An option would have been to make a consequential LCA, which is also comparing but prospective instead of retrospective. Had this been a consequential LCA then the focus could have been on the change created when choosing one kind of tomatoes over another kind. E.g. when choosing Swedish tomatoes you actively choose not to buy Dutch or Spanish tomatoes, thus decreasing the amount of tomatoes transported through Europe.

The primary reason for doing an accounting LCA, instead of a consequential LCA, is that there is no obvious product that can be substituted for tomatoes, except other tomatoes. One could have made a consequential LCA where one include the assumption that when buying tomatoes from one country one doesn't buy tomatoes from another country, but since the origin of tomatoes sold in Sweden vary with season the results would not hold most of the year.

3.3 Cradle to Gate system model

The system model used is a cradle to gate model, meaning that production of raw materials (the "cradle") are included but that the product life cycle is not followed all the way to waste/recycling (as it would have been in a "cradle to grave" model), instead it is cut of at some point (called the "gate"). There are several reasons for not doing a cradle to grave model.

First, this is a comparing LCA and since tomatoes generally are treated equally once they arrive in the store there would be no addition of interest from the last part of the life cycle. Secondly, it is very complex to find out how tomatoes are generally treated once they leave the store, compared to finding out how they got there.

3.4 Present system

This LCA focuses on the present system since the tomato growing business has undergone large changes in terms of energy efficiency and heating methods in recent years, and since it is hard to foresee how the tomato market, and growth systems, will change in the future.

3.5 Growing of fresh and industrial tomatoes

Tomatoes can be divided into two groups; tomatoes that are grown for processing in the food industry, and tomatoes that are grown for fresh consumption. There are also many varieties within these two groups, especially among the fresh tomatoes where one, appart from the the classical round tomato, can find many different sizes, shapes and colours ranging from beef tomatoes to cherry tomatoes. This report focus on fresh tomatoes of the classical round sort.

Tomatoes aimed for the industry are usually grown on open field, or in soil in primitive greenhouses in warm countries like Spain or Italy.

Tomatoes aimed for fresh consumption are grown both in warm countries, that have no need for extra heating, and in colder countries, that need to use heated greenhouses for their production. In intensive tomato production you often use large amounts of fertilisers to increase yield.

3.5.1 Greenhouses

Both warm and colder countries make use of greenhouses to protect the crops from weather. In the warm countries they are often made of plastic sheets or nets and in the colder countries they are made of glass. The plastic helps to shield the plants from the sun in the hottest part of the day, as well as keep the heat and moisture trapped during the night. The glass helps the greenhouses in the north to utilise as much of the heat and sunlight as possible. It is also more important for the growers in the colder countries to isolate their greenhouses since heating is a cost for them, compared to the growers in warmer countries who get all their heating from the sun.

3.5.2 Soil and hydroponic growth systems

In a soil based growth system the plants are grown in soil enriched with fertilisers, fertilisers are also added several times during the growth season. The watering is either done with flooding or some sort of drip irrigation, the later which generally decrease water use.

A hydroponic growth system is soilless and the plants are grown in a substrate, for example rock wool, through which water and nutrients are flowing. In modern hydroponic greenhouses the nutrient water is circulated and monitored so that an exact nutrient level can be keept at all times, this generally results in greatly reduced use of fertiliser compared to growing in soil. The substrate is generally thrown away along with the used plants after each growth season.

3.6 Systems descriptions

This report covers five different farm systems originating from four different tomato growers, all which are delivering fresh tomatoes to Sweden to be sold in retail stores. Each grower has one system and the extra system is a copy of one of the Swedish systems, using the same data, but with a wood chip furnace as heating source instead of the original heat source. The reason for including the extra farm system is that it represents a common, and presently expanding, heating technology for greenhouses in Sweden.

The five different farming systems are:

1. Tomatoes grown in a hydroponic system in greenhouses heated with fossil fuels in southern Sweden
2. Tomatoes grown in a hydroponic system in greenhouses heated with waste heat[2] in southern Sweden
3. Tomatoes grown in a hydroponic system in greenhouses heated with a mix of waste heat (75 %) and fossil fuels (25 %) in the Netherlands
4. Tomatoes grown on open field[3] under plastic nets on the Canary Islands
5. Tomatoes grown in a hydroponic system in greenhouses heated with bio fuels in southern Sweden

3.6.1 Comparability with other greenhouses in the same regions

All four farms viewed here are assumed to be representative to a general tomato farm in the specific countries using similar growth and heating systems, but the farm on the Canary Islands can not be said to represent a general tomato farm on the Spanish mainland since it is more common with hydroponic growth systems there.

Swedish tomatoes are generally grown in the most southern part of Sweden in greenhouses heated by either fossil fuels or bio fuels. The

[2]Waste heat is heat from a nearby industry that is produced as a bi-product of the process and thus holds no real value for the industry. The waste heat is regarded as "environmentally free" in the calculations, meaning that it does not add to GWP. Another way to do it would have been to use economic allocation, i.e. to compare the economic value of the heat and the main product of the process, and then dividing the pollution from the process according to the ratio between the two. This way of calculating would have resulted in higher GWP, but it would depend on what kind of process was used in the actual industry, and also on the value of the main product.

[3]Open field means that the plants are grown in soil outdoors.

farms presented in this report represents modern Swedish tomato farms in terms of energy efficiency and water consumption. The results also hold for greenhouse gas emissions given that one compares with another greenhouse using the same heating system.

Tomatoes from the Netherlands are generally grown with hydroponic systems in greenhouses heated, more or less, directly with natural gas. The greenhouse in this report is heated with 75 % waste heat (which here is counted as environmentally free) and 25 % natural gas. A similar greenhouse heated with 100 % natural gas would have over three times as high global warming potential (GWP) values from the farming part of the life cycle, all other aspects covered in this report will however be the same.

The farm in the Canary Island cultivates the tomatoes in soil which represent a growth technic used both in Spain and in the Canary Islands, but more and more growers have switched to hydroponic growth technics in the resent years to increase yield. On the Spanish mainland it is now more common to use hydroponic systems when growing fresh tomatoes, why the farm presented in this report probably have higher impact from fertilisers than the generic Spanish farm. However, impact from transport to Sweden should be lower or equal to a Spanish farm since tomatoes from the Spanish mainland can be transported by truck all the way, which has a larger impact than transport by ship. The Canarian tomatoes viewed in this report are transported by ship to Rotterdam, this is also the case for some tomatoes grown on the Spanish mainland why it can not be said that all Spanish (mainland) tomatoes have a larger impact from transport.

3.6.2 Bio fuels in Swedish greenhouses

Large scale greenhouses in Sweden are traditionally heated with fossil fuels, but the percentage of greenhouses fueled with bio fuels have increased rapidly during the years 2006 to 2008. For the 2008 growth season 67% of all tomato greenhouses in Sweden will be heated with bio fuels [Möller Nielsen, 2008, p10]. The reason for the switch is often economical due to a high oil price, and the belief that price will stay high [Blekingegrönt, 2007].

3.7 Functional unit

The functional unit is the reference flow of the measured product, it includes both a unit and a specified place in the life cycle flow. Here the functional unit is set to *1 kg of tomatoes at a retail store in Stockholm, Sweden*.

3.8 System boundaries

The system model stretches from the production of inputs to the farms, to the retail store in Stockholm, Sweden. The flowchart (see Figure 2) show the parts that are included (inside the system boundary), and a few important parts that are not included in the system model (outside the system boundary).

3.8.1 Geographical

The geographical boundary includes the farms (in the respective countries), the transport, the storage and retail in Sweden.

3.8.2 Time horizon

The time frame studied in this report covers the years 2007 and 2008, and the data is estimated to hold for five years, with the possible exception of the Spanish farm and the Swedish farm heated with fossil fuels. The Spanish farm uses old and inefficient growing technics that are not representative to common spanish tomatoes, therefor it is not unlikely that their production will change in the next few years. The Swedish farm heated with fossil fuels could possibly change its heating unit to use biofuels instead in the coming years since there is a general trend towards biofuels in the business in Sweden.

3.8.3 Cut-off criteria

Only the most influential, and common, inputs used at the farms are included. The reason for this was to simplify the information gathering process and calculation. This exclusion of information could be done thanks to long experience working with similar LCA:s, showing that the impact on the result from doing it is small. The knowledge of what to include was given by experts working with LCA and agriculture at SIK.

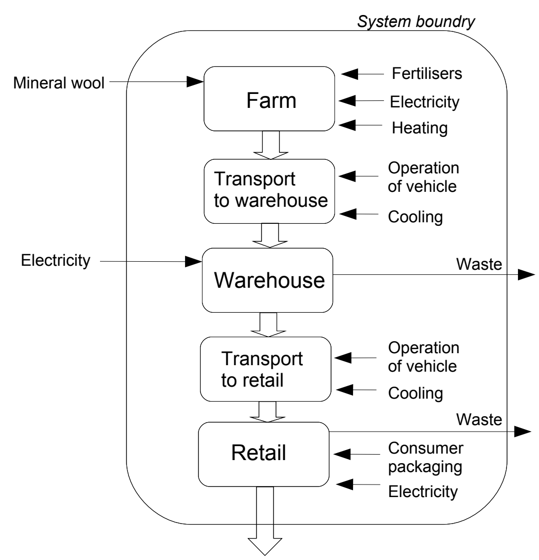

Figure 2: Flowchart

3.9 Included parts in the system model

3.9.1 Farm

Production of electricity include direct emissions and maintenance of the electrical grid (different conditions are used depending which country the farm resides in). Production of heat include direct air emissions from combustion, infrastructure, fuel consumption, waste and auxiliary electricity use. Production of fertilisers include emissions from production. Production of plastic nets include production of raw material (only used on the farm on the Canary Islands).

Included in the farm are also direct N2O-emissions from N-fertilising and total water use. Following the IPCC guidelines [IPCC, 2006] N2O-emissions are only included for growing in soil, thus it is only applied to the tomatoes from the Canary Islands. The water use does not impact the GWP or energy calculations in the model. The water use from the farm is the only water use included in the model.

3.9.2 Transports

Included in all transports are fuel production, direct airborne emissions, maintenance and disposal of vehicle (not included in the freight ship transport), construction and maintenance of road (not included in the freight ship transport), and increased energy use due to chilled compartment (not the local transport on the Canary Islands since it is not chilled).

3.9.3 Warehouse

The only impact of the warehouse is the waste going out, which is an estimated 2% discard [ICA, 2007] of all tomatoes arriving. The remaining 98% is charged with the environmental burden of the discarded tomatoes. The waste treatment is not included.

3.9.4 Retail

Included in the consumer packing, which is a small plastic bag commonly used in Sweden when shopping vegetables, is production of the raw material. Secondary packaging is not included. Production of electricity include direct emissions and maintenance of the electrical grid. The waste, estimated to 5% discard [ICA, 2007] , is handled in the same way as in the warehouse, described above.

3.10 Important excluded parts in the system model

The most important excluded parts are leakage of cold media, pesticides, mineral wool and production of the greenhouse.

Tomatoes are chilled during transport, storage and sometimes also retail. The cold media used is generally hydrofluorocarbons which is a very strong greenhouse gas. The reason for the exclusion of leakage of cold media is that there was no scientific data available on the size and impact of it. Leakage of cold media could possibly change the results notably in favor of short transport alternatives. However, parts of the transport industry are starting to change to other, more climate friendly, cold media which if used would drastically lower the impact of the leakage.

Pesticide use can vary notably between different growers, the reason for it not being in the model is that more than one grower either had trouble finding that data or didnt want to share it with the public. However, the main negative environmental effect of pesticides is not any of the those covered in this report, but toxicity.

Mineral wool, which is used by the growers in the Netherlands and Sweden, was excluded because of lack of scientific data. This does produce a balance problem towards the Spanish grower since the plastic nets used there are included, the effect of this imbalance appears however to be small.

Production of the greenhouse was not included because of time limitations and lack of literature data.

4 Data collection

4.1 Gathering of data

The data was gathered through direct contact with the growers company in the respective countries. The contact was initiated by Sune Lindberg at Fruits and Vegetables department of ICA, the largest grocery store chain in Sweden. Aside from the initial contact, ICA has taken no part in the information gathering, neither active nor passiv.

The communication with the grower on the Canary Islands and in the Netherlands was done using e-mail written in english, the communication with the Swedish growers was conducted in Swedish using mostly e-mail but also telephone and fax machine. The company in the Netherlands was Bakker Barendrecht and the contact person was Esther Schenk. The company on the Canary Islands was Bonny and the contact person was José García. The company of both the Swedish growers was Blekingegrönt and the contact person was Kjell Gustavsson.

4.2 References

Literature data was used to calculate the emissions from transport, fuels, electricity and fertilisers.

4.2.1 Fuel

Diesel

Diesel at regional storage [Ecoinvent-1, 2003]

4.2.2 Transport

Chilled Swedish 40t truck (90% load factor)

Emissions per tkm, used to calculate GWP	
Carbon dioxide, fossi	35 g
Nitrogen oxides	0.22 g
Hydrocarbons, unspecified	0.018 g
Carbon monoxide, fossil	0.031 g
Particulates	0.0035 g
Sulfur dioxide	0.000044 g
Inputs per tkm, used to calculate energy use	
Diesel	0.48 MJ

Numbers above according to NTM, including direct emissions and inputs from operation of vehicle, extracted in 2006.
(40 ton truck, Euro 3, Mk 1, 4.9 l/10km, 90% load factor)
http://www.ntm.a.se/ntmcalc/Main.asp

+ 15% for infrastructure (estimate by SIK)
+ 11% for chilled transport (estimate by SIK)

Chilled Swedish 40t truck (70% load factor)

Emissions per tkm, used to calculate GWP	
Carbon dioxide, fossi	44 g
Nitrogen oxides	0.28 g
Hydrocarbons, unspecified	0.023 g
Carbon monoxide, fossil	0.040 g
Particulates	0.0046 g
Sulfur dioxide	0.000057 g
Inputs per tkm, used to calculate energy use	
Diesel	0.62 MJ

Numbers above according to NTM, including direct emissions and inputs from operation of vehicle, extracted in 2006.
(40 ton truck, Euro 3, Mk 1, 4.9 l/10km, 70% load factor)
http://www.ntm.a.se/ntmcalc/Main.asp

+ 15% (of base) for infrastructure (estimate by SIK)
+ 11% (of base) for chilled transport (estimate by SIK)

Chilled European 40t truck (90% load factor)
Operation lorry, 40t, 90%/CH S [Ecoinvent-2, 2003]
+ 11% for chilled transport (estimate)

European 16t truck (100% load factor)
Operation lorry, 16t [Ecoinvent, 2004]

Chilled freight ship
Operation, transoceanic freight ship/OCE S [Ecoinvent-2, 2003]
+ 11% for chilled transport (estimate by SIK)

4.2.3 Electricity

Electricity (SE)
Electricity, medium voltage, at grid/SE [Ecoinvent-3, 2003]

Electricity (NL)
Electricity, medium voltage, production NL, at grid/kWh/NL [Ecoinvent-1, 2007]

Electricity, wind (ES)
Electricity, at wind power plant 800kW/kWh/RER [Ecoinvent-2, 2007]

Electricity, solar (ES)
Electricity, production mix photovoltaic, at plant/kWh/ES [Ecoinvent-3, 2007]

4.2.4 Fertilisers

Fertiliser N
Fertiliser N [Frischknecht et al, 1994]
updated according to Fertiliser Society [2003] after consultation between SIK and Yara [SIK, 2007]

Fertiliser P
Fertiliser P [Frischknecht et al, 1994]

Fertiliser K
Potassium chloride, as K2O, at regional storehouse/RER S [Ecoinvent-4, 2003]
Multiplied with 1.2 to recalculate to pure K.

N_2O from fertilizer N
N_2O leakage from fertilizer N used on soil is calculated as 1.25% of the N applied [IPCC, 2000].

4.2.5 Miscellaneous

Plastic nets
Polyethylene, HDPE, granulate, at plant/kg/RER [Ecoinvent-4, 2007]

Consumer packaging
Polyethylene, HDPE, granulate, at plant/kg/RER [Ecoinvent-4, 2007]

4.3 Description of farm system models

The five farm system models used in this thesis are described below. All the system models use the same values for the impact of the warehouse storage and retail:

Warehouse:
Included inputs and waste per kg tomatoes [ICA, 2007]:

Waste	2%

Retail:
Included inputs and waste per kg tomatoes [ICA, 2007]:

Electricity (SE)	0.02 kWh
Waste	5%
Consumer packaging	1.5 g

4.3.1 Farm system 1, Swedish fossil heat

The first farm system is built on data from Lindgårdens Tomatodling in Blekinge, Sweden.

The tomato farm consists of a large heated greenhouse, made of glass.

The growth season takes place between March and September, with the tomatoes being harvested between April and September.

The greenhouse is heated mainly with gasol (liquid petroleum gas), and to a lesser extent oil.

The tomatoes are grown in a hydroponic system where the tomato plants are grown directly in mineral wool and all nutrients are solved in water that is circulated through the mineral wool. The mineral wool is exchanged each growth season.

Included inputs per kilo tomatoes produced [Blekingegrönt, 2007]:

Fertiliser, N	3.782 g
Fertiliser, P	0.5425 g
Fertiliser, K	4.811 g
Electricity (SE)	0.7524 MJ
Heating, Liquid Petrolium Gas	13.9 MJ
Heating, oil	6.63 MJ
Water	15.6 l

Transport to Stockholm:

- Road transport from grower in Blekinge to warehouse in Stockholm using a chilled large trailer truck, 726 km (estimated 90 % load factor)
- Road transport from warehouse to retail store in a chilled medium sized truck, 40 km (estimated 70 % load factor)

Included transport:

	Swedish 40 ton truck
Farm to warehouse	726 km
Warehouse to retail store	40 km

4.3.2 Farm system 2, Swedish waste heat

The second farm system is built on data from Elleholms Tomatodling in Blekinge, Sweden.

The tomato farm consists of a large heated greenhouse, made of glass. The growth season takes place between March and September, with the tomatoes being harvested between April and September.

The greenhouse is heated with waste heat from the nearby paper industry Södra Cell Mörrum, with the exception of one week every 18 months when the industry is shut down for maintenance. During that week the greenhouse is heated with oil.

The tomatoes are grown in a hydroponic system where the tomato plants are grown directly in mineral wool and all nutrients are solved in water that is circulated through the mineral wool. The mineral wool is exchanged each growth season.

Included inputs per kilo tomatoes produced [Blekingegrönt, 2007]:

Fertiliser, N	4.2 g
Fertiliser, P	0.61 g
Fertiliser, K	5.8 g
Electricity (SE)	0.54 MJ
Heating, waste heat	20.376 MJ
Heating, oil	0.1089 MJ
Water	18.5 l

Transport to Stockholm:

- Road transport from grower in Blekinge to warehouse in Stockholm using a chilled large trailer truck, 746 km (estimated 90 % load factor)
- Road transport from warehouse to retail store in a chilled medium sized truck, 40 km (estimated 70 % load factor)

Included transport:

	Swedish 40 ton truck chilled
Farm to warehouse	746 km
Warehouse to retail store	40 km

4.3.3 Farm system 3, Netherlands, waste and fossil heat

This farm system is built on data from one of Bakken Braendracht's tomato farms outside Rotterdam, in the Netherlands.

The tomato farm consists of a large greenhouse, made of glass, that produces tomatoes. The growth season takes place from December to November, with the tomatoes being harvested between March and November.

The greenhouse is heated mainly with waste heat from a nearby industry, and to a lesser extent natural gas. 75 % of the heating comes from waste heat and 25 % comes from natural gas.

The tomatoes are grown in a hydroponic system where the tomato plants are grown directly in mineral wool and all nutrients are solved in water that is circulated through the mineral wool. The mineral wool is exchanged each growth season.

The greenhouse has a small combined heat and power plant that produces both heat and electricity for the greenhouse, this is very common for all greenhouses in the Netherlands. The electricity produced in that plant is not included here, only the natural gas used to produce it.

Included inputs per kilo tomatoes produced [Bakken Braendracht, 2007]:

Fertiliser, N	8 g
Fertiliser, P	7.418 g
Fertiliser, K	5.152 g
Electricity (NL)	1.62e-5 MJ
Heating, waste heat	21.92 MJ
Heating, natural gas	7.307 MJ
Water	16.7 l

Transport to Stockholm:

- Road transport from Rotterdam to warehouse in Stockholm using a chilled large trailer truck, 1 490 km (estimated 90 % load factor)
- Road transport from warehouse to retail store in a chilled medium sized truck, 40 km (estimated 70 % load factor)

Included transport:

	Swedish 40 ton truck chilled	European 40 ton truck chilled
Farm to warehouse	-	1 490 km
Warehouse to retail store	40 km	-

4.3.4 Farm system 4, Spanish, open field

This farm system is built on data from one of Bonny's tomato farms on Gran Canaria, Spain. Bonny is a company on the Canary Islands that grow tomatoes and cucumbers and sell them to retailers in europe.

The tomato farm consists of a large field covered with plastic nets, the tomatoes are grown in soil and nutrients are applied directly on the soil. The growth season is from September to April with the tomatoes being harvested from November to April.

There is no need for heating because of the warm climate. They also produce their own electricity, through wind power and solar panels.

Included inputs per kilo tomatoes produced [Bonny Group, 2007]:

Fertiliser, N	19.2 g
Fertiliser, P	12.8 g
Fertiliser, K	32 g
Electricity (wind)	0.126 MJ
Electricity (solar)	0.0148 MJ
Plastic nets (HDPE)	1.5418 g
Water	31.9 l

Included emissions per kilo tomatoes produced:

N_2O from N-fertilisers	0.3771 g

Transport to Stockholm:

- Road transport to Las Palmas harbour with a small truck, 35 km (estimated to be empty on the way back)
- Sea transport from Las Palmas to Rotterdam in a chilled compartment in a large sea freighter, 3 200 km

- Road transport from Rotterdam to warehouse in Stockholm using a chilled large trailer truck, 1 490 km (estimated 90 % load factor)
- Road transport from warehouse to retail store in a chilled medium sized truck, 40 km (estimated 70 % load factor)

Included transport:

	European 16 ton truck	European 40 ton truck chilled	Freight ship chilled
Farm to warehouse	70 km	1 490 km	3 200 km

	Swedish 40 ton truck chilled
Warehouse to retail store	40 km

4.3.5 Farm system 5, Swedish bio heat (theoretic)

The last farm system is also built on data from Elleholms Tomatodling (same as farm system 2) but the heating system has been replaced by a furnace fueled with wood chips responsible for 80% of the heating and a natural gas burner responsible for the remaining 20%. The reason for having 80% bio heating is that it is the suggested lower limit to qualify as a good climate choice tomato, approved by the Swedish eco labeling organisation KRAV, according to KRAV's official referral of the climate demands (KRAV, 2008).

The reasoning for including this extra farm system is that there is an ongoing shift towards heating greenhouses with bio fuels in Sweden.

Included inputs per kilo tomatoes produced [Blekingegrönt, 2007]:

Fertiliser, N	4.2 g
Fertiliser, P	0.61 g
Fertiliser, K	5.8 g
Electricity (SE)	0.54 MJ
Heating, bio heat	16.3879 MJ
Heating, natural gas	4.0970 MJ
Water	18.5 l

Transport to Stockholm:

- Road transport from grower in Blekinge to warehouse in Stockholm using a chilled large trailer truck, 746 km (estimated 90 % load factor)
- Road transport from warehouse to retail store in a chilled medium sized truck, 40 km (estimated 70 % load factor)

	Swedish 40 ton truck chilled
Farm to warehouse	746 km
Warehouse to retail store	40 km

5 Results

The results for Global Warming Potential (GWP) and energy use are presented two different scopes; only the farm, and the farm plus transport, storage and retail. Since heating often is a very dominating source are each of the four main charts for GWP and energy followed by a chart showing the contents of the non heating sources (the main charts are noted with ”total”, the following charts are noted with ”non heating”).

The charts showing the energy and water use only present results for the four first farms. This is because the fifth farm is a theoretical scenario built on data from the second farm, and it thus has the exact same energy use as the second farm.

First is a figure comparing the water use, then follows four figures comparing GWP and the last four figures compare energy use. *All units in the charts are displayed per functional unit.*

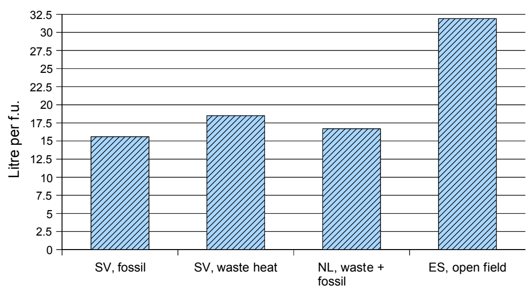

Figure 3: Water use

The open field growing in the Canary Islands use notably more water than the hydroponic growing in Sweden and the Netherlands, as shown in figure 3.

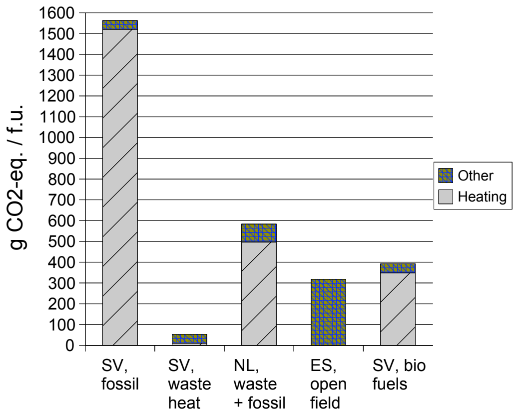

Figure 4: GWP; farm

The heating is the dominant source of greenhouse gas emissions from the farm, except from the Swedish farm heated with waste heat and the Spanish farm. The waste heat used in the Swedish farm is counted as environmentally free, which explains the lack of impact there. The Spanish farm uses only the sun to heat up the greenhouse. This is illustrated in figure 4.

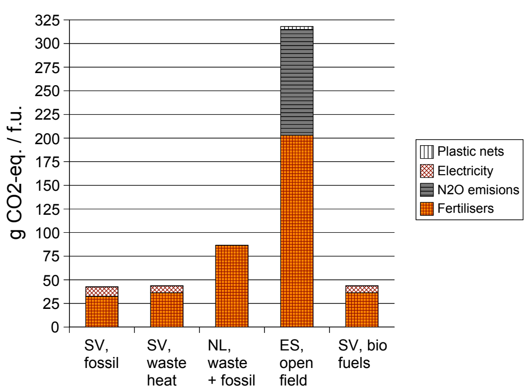

Figure 5: GWP; farm (heating excluded)

In figure 5 we can see that, apart from the heating, it is the fertilisers that have the largest impact on the global warming potential (GWP) from the farm. We can also see that the Spanish farm uses notably more fertilisers than both the Dutch and Swedish farms, and N_2O emissions stands for a large part of the total Spanish impact. The reason for the higher fertiliser use, and N_2O emissions, on the Spanish farm is that they grow in soil. N_2O emissions come from microbial transformation of nitrogen in soils [IPCC-1, 2007] which is why it is not included in the Swedish and Dutch farms.

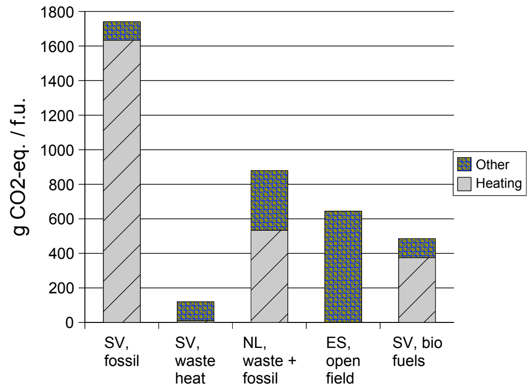

Figure 6: GWP; farm, transport, storage, retail

The heating is a large factor in the over all GWP impact of tomatoes, as shown in figure 6. The exceptions are the Spanish tomatoes which does not need extra heating, and the Swedish tomatoes heated with waste heat which is counted as environmentally free.

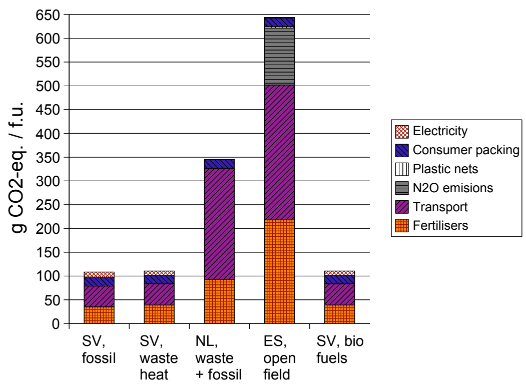

Figure 7: GWP; farm, transport, storage, retail (heating excluded)

Figure 7 shows that the transport generally is responsible for a large part of the GWP impact when excluding the heating, and that there is large difference in the amount of fertilisers used. We also see that electricity and plastic nets have relatively small impact.

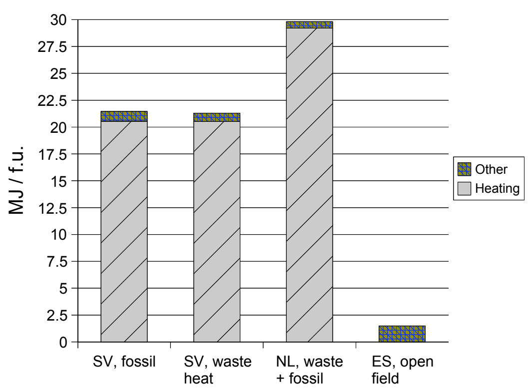

Figure 8: Energy; farm

In figure 8 we see that the energy use on the farm is totally dominated by the heating, except on the Spanish farm where no heating is needed. We also see that the Spanish farm uses much less energy to grow its tomatoes, compared to the Swedish and the Dutch farm.

Figure 9 shows that the main energy use on the Swedish farms, appart from heating, is electricity, while it is the fertilisers that dominate on the Dutch and Spanish farms. The reason for the higher electricity use for the Swedish farms is that the Spanish farm doesn't use much electricity and the Dutch farm, having their own small combined heat-and-power plant, produces most of its electricity when producing heat. So their electricity is hidden inside their heating in this model.

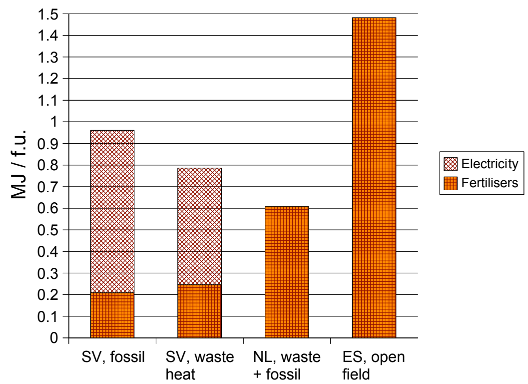

Figure 9: Energy; farm (heating excluded)

In figure 10 we see that even when all transport have been included the heating is still totally dominating the energy use of the Swedish and Netherlands farms. And that the Spanish tomatoes sold in Sweden use much less energy than tomatoes from Sweden or the Netherlands.

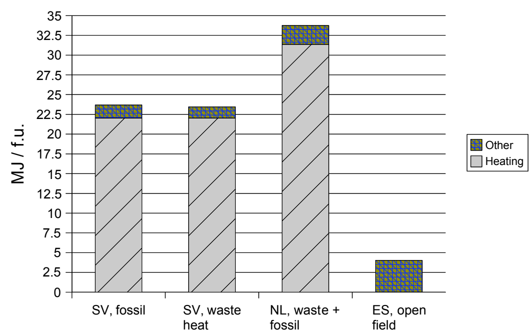

Figure 10: Energy; farm, transport, storage, retail

The transport and fertilisers are dominating the Spanish energy use, as shown in figure 11. When the heating is not taken into account, the Spanish tomatoes are much more energy intense than the Swedish and Dutch tomatoes. The energy use of the Dutch tomatoes suffer from the long transport compared to the Swedish tomatoes.

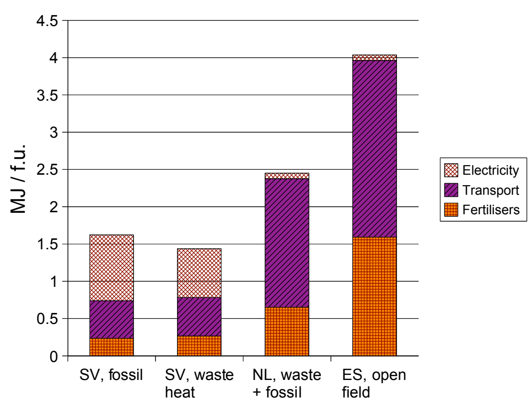

Figure 11: Energy; farm, transport, storage, retail (heating excluded)

6 Discussion

6.1 System model exclusions

Some, possibly important, parts of the system were not included in the model: Leakage of cold media, pesticides, mineral wool and production of the greenhouse.

Since leakage of cold media was not included, and since all major transports are chilled, it can be assumed that all global warming potential (GWP) impacts from transports are higher than calculated.

Pesticides and mineral wool will of course add to both energy use and GWP but it is not certain they would make a notable difference. Since mineral wool is only used by the growers using hydroponic growth systems (the Swedish and Dutch farms) they will obviously gain from this exclusion, compared to the Canary Island farm.

The excluded production of the greenhouse also gains the Swedish and Dutch farms since the Canary Island farm doesn't have a greenhouse, and the plastic nets that, in some way, could count as their greenhouse are in fact included. The plastic nets are however consumed in a, straight forward, measurable way unlike a greenhouses made of glass.

6.2 Transport

The impact from the transport varies much between the systems. Transport is a larger absolute factor to the impact the longer the route is. But it is also a larger relative factor the lower the impact is from the farm itself. For example, in the case of the swedish farm heated with fossil fuels the transport is negligible while in the case of the swedish farm heated with waste heat or bio fuels it makes a large difference. The tomatoes from the Canary Island farm system are transported the furthest and the transport is, together with the fertilisers, the largest contributing factor to the impact.

6.3 The tomato farms in Sweden

The Swedish farm systems, including one heated with fossil fuel, one heated with waste heat and one heated with bio fuels[4], are all relatively good in term of fertiliser efficiency but use a lot of energy to heat up the greenhouse, and when looking at GWP it varies depending on the fuel used. This was all expected since the cold climate makes it energy demanding, and thus expensive, to grow tomatoes in Sweden. The high costs forces the growers to be as efficient as possible in order to be able to compete against growers in countries with milder climate.

6.4 The tomato farm in the Netherlands

The farm system from the Netherlands has the highest energy use of all the growers and the second highest GWP. The reason why the dont have the

[4]The Swedish farm heated with bio fuels is a theoretical system built using the data from the farm heated with waste heat but with a wood chip furnace to supply the heat.

highest GWP is that they use 75 % waste heat to heat up the greenhouse, which in these calculations is considered to be environmentally free. Using waste heat to heat up greenhouses is not common in the Netherlands but it is very common to use heat from combined heat and power (CHP) plants which increases the over-all efficiency of the power production compared to producing the heat and the power (electricity) separately.

6.5 The tomato farm in the Canary Islands

The farm system from the Canary Islands is very different from the systems in Sweden and the Netherlands since they grow the tomatoes in soil and doesn't have to heat up a greenhouse. The lack of heating results in very low energy usage, and also relatively low GWP. Growing in soil increases the use of fertilisers and water, and it also separately increases the impact from using N-fertilisers[5], compared to hydroponic systems. Much of the tomatoes produced in Spain today are however produced using hydroponic systems which would decrease the impact from the farm, compared to this report.

The long transport to Sweden stands for half of the total GWP impact, but it is probably even more since leakage of cold media isn't included in the calculations. If looking at an efficiently and hydroponically grown tomato in Spain the transport to Sweden would probably stand for over 90% of the GWP, since the spanish farm uses over 5 times as much fertilisers as the swedish farms, and since there would be no N_2O leakage.

6.6 Comparison between Swedish and Dutch farms

A surprising result is that the Swedish farms use 30% less energy per kilo tomatoes produced to heat up their greenhouses compared to the farm in the Netherlands, which have a slightly warmer climate (ref: temperature statistics at www.worldclimate.com). One explanation to this could be that the Swedish farmers are more optimized, they simply produce more tomatoes per area of greenhouse. This theory is supported by the notably lower amount of fertilisers used by the Swedish farms per kilo tomatoes produced compared to the farm in the Netherlands. Other things that could effect the lower energy use could be better insulated greenhouses, better routines for not airing out the warm air inside the greenhouse or local differences in weather and temperature conditions from the regional average. It should also be noted that the Swedish greenhouses investigated here both are considered to be top of the line in terms of efficiency according to the company running them.

6.7 Best option: GWP

The best option, when only looking at GWP, is Swedish tomatoes grown in greenhouses heated with waste heat or bio fuels. This holds true both

[5] N_2O is created by bacteria in the soil when applying N-fertilisers on it. According to the IPCC one should include N_2O when calculating GWP from growing in soil, but not when growing in a hydroponic system.

when looking only at the farm part and when looking at the cradle to store system (farm, transport, waste, storage and retail). The reason for this is that the heating has low fossil intensity in combination with the high efficiency, and thus low amounts of fertilisers. It is also better, in terms of GWP, to use a hydroponic growth system, compared to growing in soil, since N-fertilisers (nitrogen) are partly changed into the very potent climate gas N_2O when used on soil[6].

6.8 Best option: Energy use

The best option, when only looking at energy use, is the tomatoes from the Canary Islands. The simple reason for this is that grower is the only one that doesn't use energy to heat up a greenhouse. This also holds true when looking at tomatoes grown on the Spanish mainland. It is worth noting that the Swedish farmers use 30% less energy per kilo tomatoes produced than the grower in the Netherlands. The reason for this could be that the Swedish growers have better insulated greenhouses, or better routines to keep the warmth trapped.

6.9 Future improvements

It would improve the resource efficiency to shift from open field growing to hydroponic growth technics.

A possible improvement, for heated greenhouses, is higher energy efficiency in the greenhouse through better insulation and heat exchanging technics in the ventilation. This kind of improvement will be more interesting to the grower the higher the price of energy is and less interesting the warmer the climate is.

The GWP impact from the production of mineral fertilisers can be decreased by over 50% through use of modern production techniques. This is an area of focus for the companies producing fertilizers, and it is expected that a large part of the fertilizers on the european market will produced with this technique in a few years.

Leakage of cold media is an area not covered in this report, but there are probably large improvements that can be made there, both through use of cold media with low or no climate impact and through shorter transport routes, and better equipment.

6.10 Future research

This research should be done all over but with more farms that better represent the market, especially in the Netherlands and in Spain.

A new area that is in need of more research is impact from chilled transport. At present the extra impact from the cooling equipment is often added to the transport with flat percentage of 10-15% of the impact of the same transport without cooling.

[6] N_2O is created by bacteria in the soil when applying N-fertilisers on it. According to the IPCC one should include N_2O when calculating GHG emissions from growing in soil, but not when growing in a hydroponic system.

The business of growing tomatoes in the three countries viewed in this report will probably keep changing over the next coming years why it would be interesting to review it again in a few years. The driving forces behind this change will be demands for decreased climate impact as well as rising food prices and technical development.

7 Conclusions

7.1 Best options for the Swedish consumer

- The best option, when only looking at GWP, is Swedish tomatoes grown in greenhouses heated with waste heat or bio fuels. (In 2008 this represents over 65% of the tomatoes produced in Sweden, a share that will probably increase over the next few years.)
- The best option, when only looking at energy use, is the tomatoes from the Canary Islands. This also holds true for tomatoes from the Spanish mainland.
- Swedish tomato growers use 30% less energy than Dutch growers per kg tomatos.
- It is not possible to name a best choice in terms of both energy use and GWP since the tomatoes from the farm in the Canary Islands are best from an energy perspective and the tomatoes from the Swedish farms heated with waste heat and bio fuel are best from a global warming perspective.
- Both Swedish and Spanish/Canarian tomatoes should be chosen over Dutch tomatoes, in terms of GWP and energy use.
- Since the growing season of the Spanish tomatoes differs so much, compared to the Swedish and the Dutch (see figure 1, page 2), the choice of origin is often limited in the Swedish stores. However, this doesn't affect the conclusions.

References

[Tukker, A. & Jansen, B. (2006)] Tukker A. and Jansen B., 2006. Environmental impacts of products; A detailed review. *Journal of Industrial Ecology*, Vol. 10, No. 3, 2006 p 159-182.

[Möller Nielsen, 2008] Möller Nielsen, J., 2008. Energin & koldioxiden i svensk växthusodling 2008 - Tomat LCA. Available at: http://www.cascadaab.se/publicationer.html (Cascada) [accessed june 2008]

[Lagerberg Fogelberg, C. & Carlsson-Kanyama A. (2006)] Lagerberg Fogelberg, C. & Carlsson-Kanyama A. 2006. Environmental Assessment of Foods - An LCA Inspired Approach. *FOI - Totalförsvarets forskningsinstitut, Rapport FOI-R–1903-SE. Chapter 3 55-84. ISSN 1650-1942. Stockholm.*

[Antón, A. (2005)] Antón, A., Montero, J. I. & Muoz, P. 2005. LCA and tomato production in Mediterranean greenhouses. *International Journal Agricultural Governance and Ecology*, Vol. 4, No. 2. 2005 p 102-112.

[ISO, 2006] International Organization for Standardization, ISO 14040:2006 - Environmental management – Life cycle assessment – Principles and framework. Availeble at: http://www.iso.org [accessed september 2008]

[Baumann and A-M Tillman (2004)] *Hitchhikers Guide to LCA*, Studentliteratur AB, Lund, Sweden

[Blekingegrönt, 2007] Personal correspondance with Kjell Gustavsson at Blekingegrönt during the fall of 2007.

[Bonny Group, 2007] Personal correspondance with personel at the Bonny Group on Gran Canaria during the fall of 2007.

[Bakken Braendracht, 2007] Personal correspondance personel at Bakken Braendracht during the fall of 2007.

[ICA, 2007] Personal correspondance with Sune Lindberg at the Fruit and Vegetables department of ICA, regarding waste at their warehouses in the fall of 2007.

[IPCC-1, 2007] IPCC, 2007: *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 501 pp.

[IPCC-2, 2007] IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[IPCC, 2006] IPCC, 2006. Guidelines for National Greenhouse Gas Inventory, vol 4 chp 11.2.3.

[IPCC, 2000] IPCC, 2000. IPCC Special Report on Emissions Scenarios, chp 3.5.5. Available at: http://www.grida.no/publications/other/ipcc_sr/ [accessed march 2009]

[Ecoinvent-1, 2003] ewJungbluth, N. (2003) Erdl. Sachbilanzen von Energiesystemen. Final report No. 6 ecoinvent 2000. Editors: Dones R.. Volume: 6. Swiss Centre for LCI, PSI. Dbendorf and Viligen, CH.

[Ecoinvent-2, 2003] Spielmann M., Kgi T., Stadler P.,Tietje O. (2003) Life Cycle Inventories of Transport Services. Final report ecoinvent 2000. Volume: 14. Swiss Centre for LCI, UNS. Dbendorf, CH.

[Ecoinvent, 2004] Spielmann M., Kgi T., Stadler P.,Tietje O. (2004) Life Cycle Inventories of Transport Services. Final report ecoinvent 2000. Volume: 14. Swiss Centre for LCI, UNS. Dbendorf, CH.

[Ecoinvent-3, 2003] Frischknecht, R., Faist Emmenegger, M. (2003) Strommix und Stromnetz. Sachbilanzen von Energiesystemen. Final report No. 6 ecoinvent 2000. Editors: Dones R.. Volume: 6. Swiss Centre for LCI, PSI. Dbendorf and Villigen, CH.

[Ecoinvent-1, 2007] Frischknecht, R., Tuchschmid, M., Faist Emmenegger, M.,Bauer, C., Dones, R. (2007) Strommix und Stromnetz. Sachbilanzen von Energiesystemen. Final report No. 6 ecoinvent data v2.0. Editors: Dones R.. Volume: 6. Swiss Centre for LCI, PSI. Dbendorf and Villigen, CH.

[Ecoinvent-2, 2007] Burger, B., Bauer, Ch. (2007) Windkraft. Sachbilanzen von Energiesystemen. Final report No. 6 ecoinvent data v2.0. Editors: Dones R.. Volume: 6. Swiss Centre for LCI, PSI. Dbendorf and Villigen, CH.

[Ecoinvent-3, 2007] Jungbluth, N., Tuchschmid, M. (2007) Photovoltaics. Sachbilanzen von Energiesystemen. Final report No. 6 ecoinvent v2.0. Editors: Dones R.. Volume: 6. Swiss Centre for LCI, PSI. Dbendorf and Villigen, CH.

[Frischknecht et al, 1994] Frischknecht R, Hofstetter P, Knoepel I, Menard M, Dones R, Zollinger E. (1994). Ökoinventare für Energiesysteme. Zürich: Bundesamt für Energiewirtschaft.

[Fertiliser Society, 2003] Proceedings 509, 2003. Fertiliser Society.

[SIK, 2007] Internal document at SIK summarising the content of a discussion between Christel Cederberg and representatives of Yara on october 16, 2007.

[Ecoinvent-4, 2003] Nemecek, T., Heil A., Huguenin, O., Meier, S., Erzinger S., Blaser S., Dux. D., Zimmermann A., (2003) Life Cycle Inventories of Agricultural Production Systems. Final report ecoinvent 2000. Volume: 15. Swiss Centre for LCI, FAL & FAT. Dübendorf, CH.

[Ecoinvent-4, 2007] Hischier R. (2007) Life Cycle Inventories of Packaging and Graphical Paper. Final report ecoinvent data v2.0. Volume: 11. Swiss Centre for LCI, Empa - TSL. Dbendorf, CH.