Sveriges lantbruksuniversitet
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Faculty of Landscape Architecture, Horticulture and Crop Production Science

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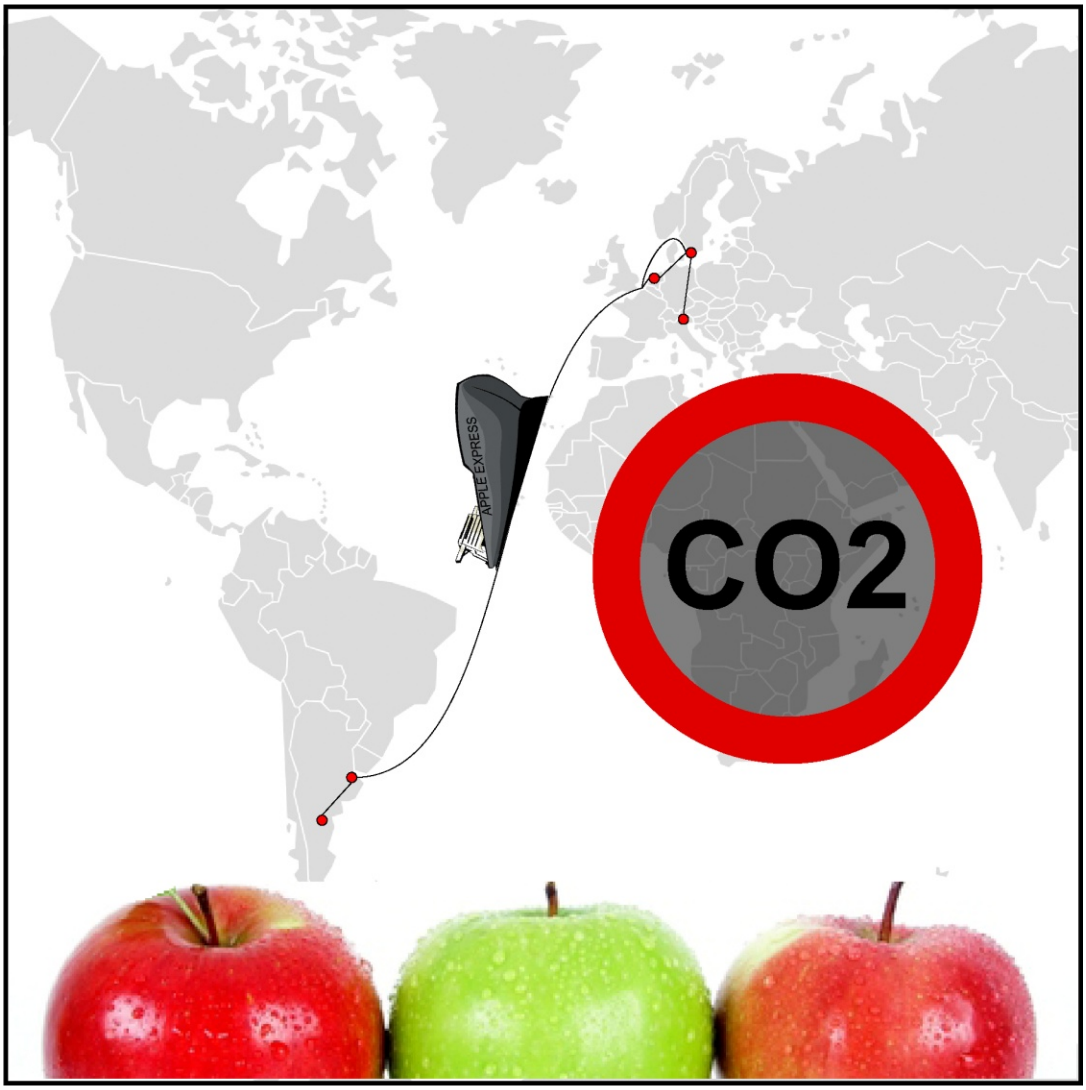

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Life cycle assessment (LCA) of apples
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Livscykelanalys (LCA) på äpple

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Abstract

Agricultural greenhouse gas emissions have great impact on climate change and need to be reduced. The production and transport of food accounts for up to 25% of total greenhouse gas emissions. Life cycle assessment (LCA) can be used to measure Global Warming Potential (GWP) between production systems and transports to identify sources of greenhouse gas emissions.

In this study, GWP was measured as carbon dioxide equivalents (CO_{2eq}) and was calculated for Swedish IP-certified apples, Swedish organic certified apples (KRAV), IP-certified apples imported from Italy and IP-certified apples imported from Argentina. The system boundaries were 1) production, 2) sorting, packaging and cold storage, 3) transport to retailer.

Production of Swedish IP apples had lowest emission of CO_{2eq} compared to Swedish organic and Italian IP. Diesel consumption was a major source of CO_{2eq} emissions in the production, independent of production system. Swedish IP-certified apples stored for 3 months had much lower CO_{2eq} emissions than imported apples transported directly at harvest from Italy and Argentina by truck and boat. It is CO_2 efficient to increase the market share of Swedish apples if storage time is less than 12 months, as CO_{2eq} emissions are lower than imported apples from Italy and Argentina.

Sammanfattning

Produktion och transport av livsmedel står för upp till 25% av de totala utsläppen av växthusgaser. En minskning av utsläppen från jordbruket krävs för att minimera påverkan på klimatförändringen. Livscykelanalys (LCA) är en metod för att jämföra produktionssystem och transporter genom att mäta Global Warming Potential (GWP) i CO_2-ekvivalenter (CO_{2eq}).

I denna studie beräknades växthusgaser som CO_{2eq} för svenska IP-certifierade äpplen, svenska ekologiska certifierade äpplen (KRAV), IP-certifierade äpplen som importerats från Italien och IP-certifierade äpplen importerade från Argentina. Systemavgränsningen inkluderade, 1) produktionsledet av äpple, 2) sortering, packning och kyllagring (3 månader), 3) transporter från fruktodling till butik (båt, lastbil).

Svenska IP producerade äpplen hade lägst utsläpp av CO_{2eq} jämfört med Svenska ekologiska och Italienska IP äpplen. Utsläpp av CO_{2eq} från användning av diesel och elektricitet var en betydande faktor i produktionen av äpple oavsett produktionssystem. Svenska IP-certifierade äpplen som lagrats i 3 månader hade lägre utsläpp CO_{2eq} än importerade äpplen transporterade direkt vid skörd från Italien och Argentina. Det är CO_{2eq} effektivt att öka marknadsandelen för svenska äpplen om lagringstiden är mindre än 12 månader, eftersom CO_{2eq} utsläppen är lägre än för importerade äpplen från Italien och Argentina.

Table of contents

Abbreviations

FU = Functional unit

GWP = Global Warming Potential

LCA = Life Cycle Assessment

SIK = Swedish Institute for Food and Biotechnology

SLV = Swedish National Food Administration

SJV = Swedish Board of Agriculture

NV = Swedish Environmental Protection Agency

IP = Integrated Production

SLF = Swedish Farmers' Foundation for Agricultural Research

CO_{2eq} = Carbon dioxide equivalents

Introduction

The agricultural production chain is a large contributor to global greenhouse gas emissions. Levels of CO_{2eq} in the atmosphere have never been higher (EPA 2015). The horticultural production chain has become a global industry and apples are available at the retailers throughout the year. End consumers can select from Swedish and imported, conventionally, integrated and organically cultivated apples. Production and transportation of food products accounts for up to 25% of total greenhouse gas emissions (EPA 2013, Moreau et al. 2012). Gases emitted from agricultural production consist primarily of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). It is important to minimize emissions, but a reduction in food consumption is difficult to achieve as an average person require 700-900 kilos of food produce per year (Wallgren 2000, Saxe et al. 2012). It is more realistic to minimize or optimize the use of fossil fuel and energy throughout food products life cycle (Huang & Rust 2010, Griggs et al. 2013).

Life Cycle Assessment (LCA) is a method to measure environmental impact of products and services with a focus on energy use and emission of CO_2 equivalents (CO_{2q}) (Guinee 2004). The debate on climate change is probably one reason to the increased publication rate of LCA analyses on agricultural products the last 15 years (Ruviaro et al. 2012). An LCA by Stadig (1997) compared apple production systems in Sweden, France and New Zeeland. The analysis included acidification, eutrophication and energy consumption in MJ/kg, and global warming potential (GWP) measured in CO_{2eq} (Stadig 1997). Due to changes in production systems and transportation since then, the information needs to be updated.

The Swedish Institute for Food and Biotechnology (SIK) has requested new LCA analyses on several horticultural products with a focus on GWP measured in CO_{2eq}.

This new LCA on apples is funded by the Swedish Farmers' Foundation for Agricultural Research (SLF). The analysis is based on apple production systems in Sweden, Italy and Argentina, as Italy and Argentina are the most important sources for import of apples to Sweden (Johansson 2010). The analysis includes measurement of GWP in CO_{2eq} while acidification and eutrophication is excluded. The system boundaries are from orchard to retailer doors. In England, 77% of fresh produce are sold through retailers (Jones 2002). It is feasible to assume that the situation in Sweden follows the same pattern, and that the majority of apples are sold by the three largest retailers; ICA, COOP and Axfood, that represents 85% of the market (Delfi 2012). It is however important to remember that transport from retailer to end consumer is an important contributor to greenhouse gas emissions. Large shopping mall centers outside urbanized areas promote transport by car and according to Blanke (2008) the end consumer represents 20% of total energy consumption of a products life cycle.

Apple is a popular and high valued crop in Sweden with more than 115 000 tonnes consumed every year or 12.5 kg per person and year not including home grown garden apples (SJV 2013). Apple plays an important part in human nutrition (Eberhardt et al. 2000, Hyson 2011). Apples have a plentiful array of beneficial attributes such as hepatoprotective and anticancerogenic properties (Yang et al. 2010, Gossè et al. 2005) and are also a part of a balanced and healthy diet and as fruit in general, it is useful in weight control (Oliveira et al. 2003).

Swedish apple production covers 1 400 hectares with an average yield of 22 000 tonnes per year and that corresponds to approximately 20% of total Swedish apple consumption (SCB 2014). The growers selected for the LCA were all certified according to integrated production (IP). Environmental considerations are an important part of integrated production (Pettersson 2013). A minimum of insecticides, fungicides and herbicides should be used and only after a documented need for action (Äppelriket 2013, Konsumetverket 2003). The most common cultivars in Swedish IP are 'Ingrid Marie', 'Aroma' and 'Discovery' (SCB 2014).

Approximately 10% of Swedish production is certified as organic production (KRAV). Organic production focuses on the use of resistant cultivars and non-chemical pest management. It is not allowed to use synthetic pesticides or mineral fertilizers but it is possible to use different types of manure, bi-products from food production, and nitrogen fixing interrow crop coverage (Konsumentverket 2003, KRAV 2015). The majority of organic apple orchards are small and the average orchard is approximately 2 ha. The most common cultivars in organic production are 'Rubinola', 'Santana', 'Aroma' and 'Holsteiner Cox' (Einarsson 2010).

Swedish apples are available at the retailers from August to Mars (Äppelriket 2015) but during high season (September to December) it only meets 50% of consumer demand (Johansson 2014). During this time apples are imported from southern Europe, mainly Italy (Johansson 2014). The apples are transported to Sweden by refrigerated truck and the apple production is primarily located around the Italian Alps (Neri 2004). The Italian orchards cover an area of approximately 40 000 hectares with a production of 2 200 000 tonnes (FAO 2009).

The most common cultivars are ‘Golden Delicious’, ‘Gala’, ‘Braeburn’, ‘Fuji’ and ‘Pink Lady’ with a net export of 785 000 tonnes in 2007 (Werth 2003).

A majority of apples consumed in Sweden during spring and summer are imported from South America, mainly Argentina (Johansson 2010). The production is located around the Rio Negro Valley, Mendoza, San Juan and Cordoba (Bendini & Steimbreger 2005, Balbi & Mergen 2009). The orchards cover an area of approximately 43 000 hectares with a production of 1 090 000 tonnes (FAO 2013). The most common cultivars are ‘Red Delicious’, ‘Gala’, ‘Braeburn’, ‘Fuji’ and ‘Jonagold’. In 2007 the Argentine net export was estimated to 283 000 tonnes and apples were transported to Sweden by refrigerated truck and boat (Balbi & Mergen 2009).

What is LCA?

LCA was developed in the late 1960s but was then commonly known as resource and environmental profile analysis (Baumann & Tillman 2004). In 1991 during a conference in Sheffield, UK, participants decided that the process of measuring environmental impacts should be called life cycle assessment or LCA (Jensen & Postlethwaite 2008). In 1997, LCA methodology was internationally standardized with ISO 14040 (Guinee 2004).

In a LCA there are three components to consider

1. The goal and scope definition
2. The inventory analysis
3. The impact assessment

The goal and scope definition

In the goal and scope, several factors are taken into consideration. The functional unit is explained and is the same for all compared product systems to ensure equivalence (Weidema et al. 2004). **In this LCA the functional unit (FU) is 1 kg of apples and calculated in CO_{2eq}.** The system boundaries are established, what processes to include and how the project is to be carried out (Baumann & Tillman 2004).

The intentional purpose of the study should be addressed: 1) why it is interesting to investigate and 2) who would benefit from the results (Rebitzer et al. 2004, Guinée 2012). It is also important to specify and describe the data, if the data is site specific, actual information from a production or service or published average data of a production or service (Rebitzer et al. 2004). In this LCA, all orchard activities are site specific but the transports are calculated as an average.

The inventory analysis

The flow model is included in the inventory analysis and describes the flow of ingoing and outgoing resources such as raw material, products and waste. Within the inventory analysis a presentation of the results is also included (Baumann & Tillman 2004).

The impact assessment

In the impact assessment, the classifications and characterizations are presented. In the classification the contribution of results are grouped into categories depending of environmental effects, such as resource depletion, toxicity and global warming potential. In the characterization, the calculations of emissions are presented for each life stage, such as storage and transport (Horne et al. 2009).

Target groups

For this LCA three different target groups were identified:

1. Swedish and foreign apple producers. The analysis can assist apple producers with information regarding CO_{2eq} efficient production, sorting, storage and transport for future strategic choices concerning expansion or reduction of apple orchards.

2. Importers and wholesalers. The analysis can have an effect on import and sales of apples by changing sales patterns such as choice of exporting country. It can also affect companies connected to logistics and technology that supply services within transports and storage solutions, for example, running trucks on biodiesel, reduction of long-hauling transport during the domestic season and implementation of energy efficient storage solutions.

3. The analysis could also be of interest for the Swedish National Food Administration (SLV), Swedish Board of Agriculture (SJV), Swedish Environmental Protection Agency (NV) in strategic planning concerning rules and regulations on the use of fertilizers, diesel consumption and import of apples. The analysis could also be used by end consumers that want to make an environmentally sound apple buying choice.

Objectives

The objectives of this LCA was to

1. Measure global warming potential (GWP) between imported and Swedish stored apples
2. Identify preference from a GWP point of view
3. Hotspots in the production chain.

The analysis included four production systems;

1. Apples grown according to integrated production (IP) in Sweden
2. Apples grown according to organic production (KRAV) in Sweden
3. Apples grown according to integrated production (IP) in Italy and imported to Sweden
4. Apples grown according to integrated production (IP) in Argentina and imported to Sweden.

Methodology and system description

Input data was collected by questionnaires (Appendix I). The questions concerned harvest levels and consumption of fuel, pesticides, fertilizers, electricity and packing materials. Swedish IP was calculated as an average of two IP growers and Swedish organic was calculated as an average from three KRAV certified growers.

Italian IP was calculated with information from one IP grower. In Argentinean production only transportation was calculated.

Articles were found using the search engines Web of knowledge, Scopus and Google scholar. SimaPro 7.0, a life cycle software program, was used to gather, analyze and monitor flows in the LCA (SimaPro 2010). General input data was taken from Ecoinvent 2.0, a large database that covers most variables in an LCA regarding energy consumption (EcoInvent 2015). The boundaries of the project were set at the orchard level and retail doors.

The health and environmental effect of pesticide sprays have been excluded from the analysis as SIK requested a focus on GWP. Included in the project are production, transport and application of pesticides. The effect on GWP between production systems after the apples left the retailer is not included as the systems are equal at that point. Sorting, packaging and storage data was only included from farms in Swedish IP as it was the only production system that had these operations at the orchard. Transport to wholesaler was not included for Swedish organic orchards because the growers sold the apples directly to the end consumer.

Data quality

Variations in data quality for the LCA are expected and connected to reliability of data sources and the chosen system boundaries. Planting of a new orchard with apple trees had a low impact since the trees, wires and poles are used for several years (10 years). The GWP on one kilo of apples is therefore low when calculated per FU per year independent of production system.

The use of reliable data to measure total GWP is important when comparing production systems because of differences in harvest levels, use of fertilizers, pesticides, and diesel consumption. Data quality on transport is also considered a key factor in the comparison between countries as distance and means of transportation has a high impact on total GWP.

Grower selection

Swedish growers were selected by Patrick Sjöberg, PhD student at SLU, Alnarp and Kirsten Jensen, Länsstyrelsen (county administrative board) in Västra Götalands Län. Marco Tasin, Post-doc at Fondazione Edmund Mach-IASMA in S. Michele all'Adige, Italy selected growers and conducted interviews in Italy. All growers represented commercially viable and active companies within fruit production in each country. No growers in Argentina participated in this LCA.

Production, postharvest and transport

IP production of apples in Sweden

The LCA analysis of Swedish IP production was calculated as an average of two orchards in Southern Sweden. Production of 'Ingrid Marie' was calculated on 10 hectares with a net production of 220 tonnes. The analysis included;

- Diesel consumption for planting of new apple trees, pruning and irrigation.
- Transport and production of pesticides.
- Diesel consumption from application of herbicides, fungicides and insecticides.
- Production, transport and application of fertilizers. Fertilizers containing nitrogen produce the greenhouse gas N_2O, especially if there is an overabundance of nitrogen in the soil.

All postharvest management was conducted at farm level. IP growers had sorting machines, packaging houses and storage facilities on farm. Apples were sold to wholesalers and to some extent through direct sales. The transport to wholesaler was calculated with refrigerated trucks leaving the orchard for transportation to warehouse in Helsingborg. Average transportation of 2*60 km has been used where 60 km was empty trucks driving from Helsingborg to the orchard. It was calculated with 4h cooling and a 100% cargo capacity. The transport from Helsingborg to distribution center (DC) was calculated with an average distance of 477 km with 12h cooling. In this category there was a 90 % cargo capacity compensating for the cases where the largest trucks were not used. Transport from DC to retailer was calculated with an average distance of 64 km with 1.4h cooling. Cargo capacity was calculated at 70 % compensation for smaller trucks driving in urban areas with numerous stops (Fig 1).

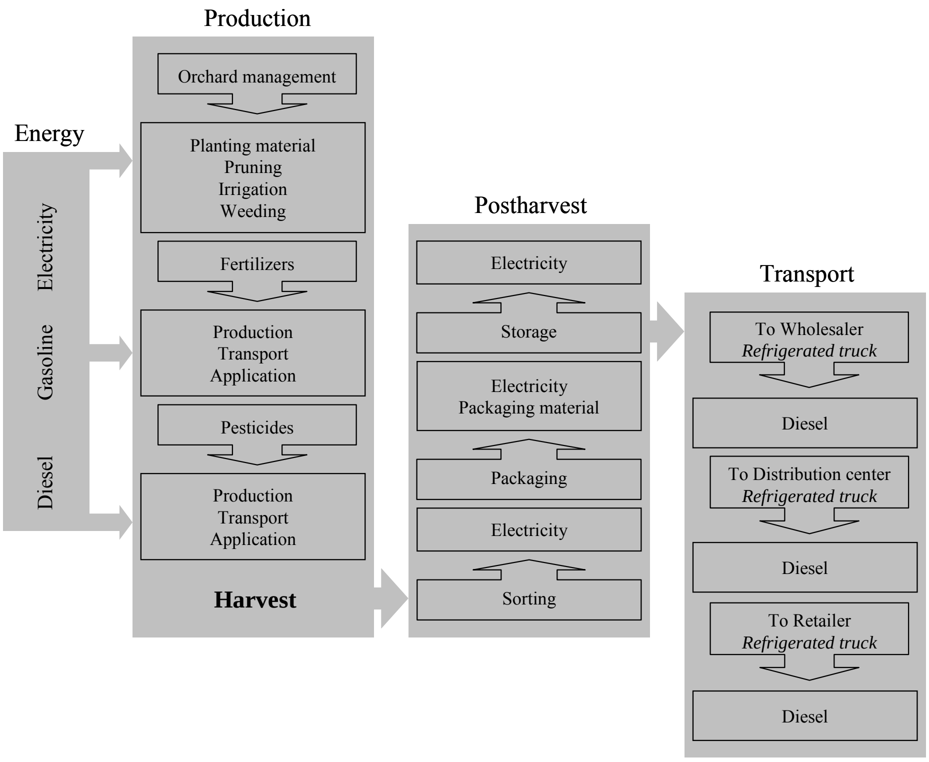

Figure 1: Flow chart of IP produced apples in Sweden

Organic production of apples in Sweden

The LCA analysis on Swedish organic production was calculated as an average of three orchards. Production of the most common cultivar 'Rubinola', was calculated on a total of 4 hectares with a net production of 22 tonnes. The analysis included;

- Diesel consumption for planting of new apple trees, pruning and irrigation.
- Transport and production of fertilizers and pesticides such as sulphur and quassia.
- Diesel consumption from mechanical weeding, application of sulphur and quassia.

Fertilizer applications used in organic production were mainly biofer and stable manure. Within this project all internal transport emissions and energy consumption, concerning an organic apple orchard were included. For example more energy was used for mechanical weed control and sulphur application.

Organic growers sold fresh apples, apples processed into juice or apples refined into other products directly (from the farm) to the end consumer. Sorting was carried out in the field while packaging and storage was done outside orchard boundaries. As the organic growers did not sell their apples to wholesalers, it was outside the system boundaries and no transportation to retailer was calculated for organic production in this LCA (Fig 2).

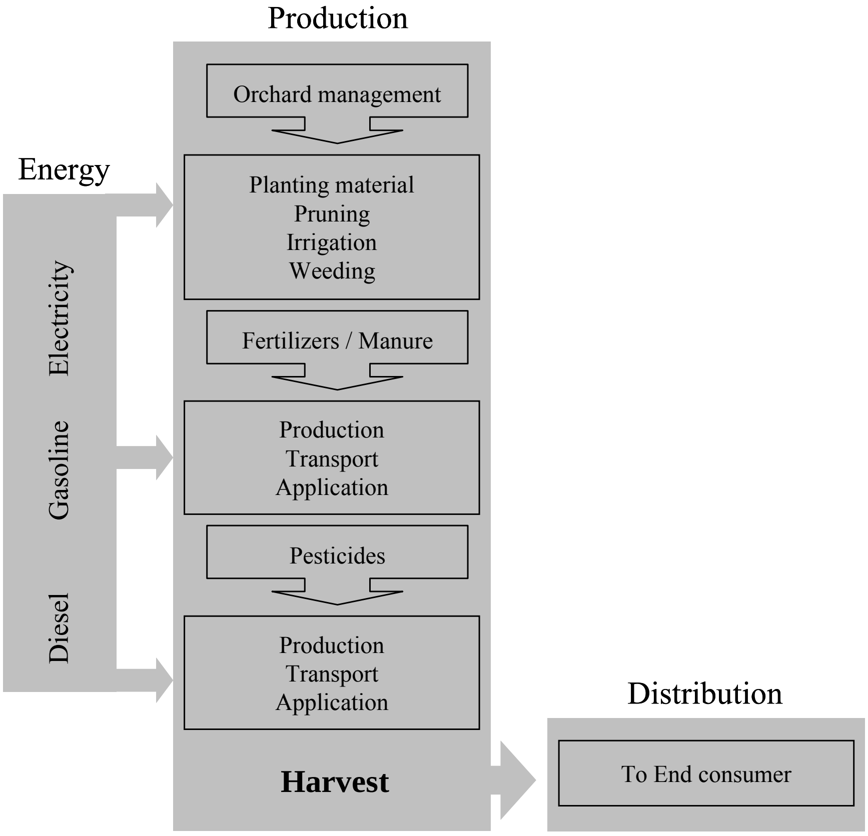

Figure 2: Flow chart of organically produced apples in Sweden

Apple production in Italy

The LCA analysis on Italian IP production was calculated using data from an orchard in northern Italy (Trento). Production of 'Golden Delicious' was calculated on 0.75 hectares with a net production of 32 tonnes. The analysis included;

- Diesel consumption for planting of new apple trees, pruning and irrigation.
- Transport and production of pesticides.
- Diesel consumption from application of herbicides, fungicides and insecticides.
- Production, transport and application of fertilizers.

Apples were sold to one of the 43 cooperatives present in this area. Sorting was carried out in field while packaging and storage was done outside orchard boundaries. Transport of apples from Trento, Italy to Helsingborg, Sweden is 1 115 kilometers one way as trucks are loaded with other products for the return trip. The apples were transported in refrigerated trucks with 100% loading capacity (Fig 3). Transport to DC and retailer was calculated as described in Swedish IP production (Fig 1).

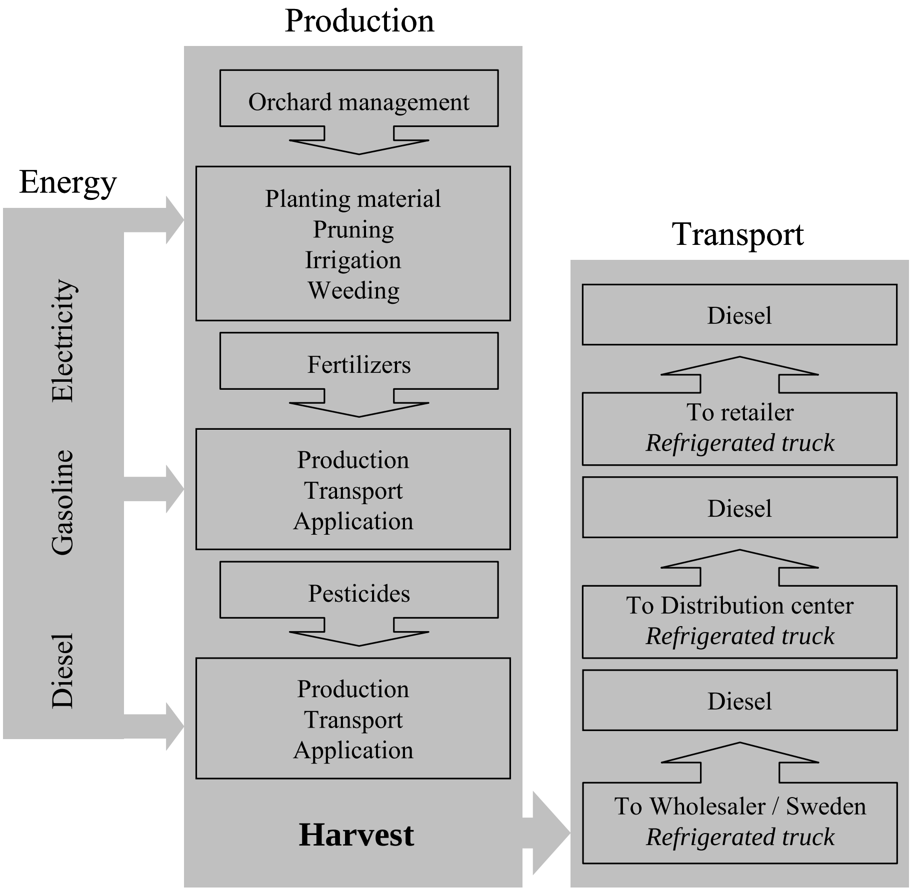

Figure 3: Flow chart of Italian apple production and transport to Sweden

Apple production Argentina

IP production of apples from Argentina was supposed to be compared with Swedish production. It was however difficult to get in contact with growers to answer the questionnaires. The only information available for the analysis was therefore transport with refrigerated truck and boat from Argentina to Sweden. The calculation was done with direct transport by boat to Helsingborg or indirect via Amsterdam with a reload to a refrigerated truck.

The distance from Buenos Aires to Helsingborg is 12 100 km and there was also an additional transportation of 1 000 kilometers by refrigerated truck from the Rio Negro Valley to Buenos Aires. The combined distance for direct freight to Sweden is 13 100 km. Indirect transport from Argentina to Sweden via Amsterdam will add a reload to refrigerated truck and the total distance increases to 13 300 km (Fig 4). Transport to DC and retailer was calculated as described in Swedish IP production (Fig 1).

Transport

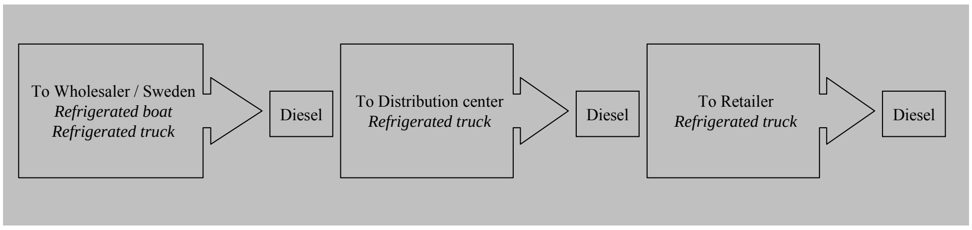

Figure 4: Flow chart of the apples transported to Sweden from Argentina

Results

The primary hot spot in Swedish IP was sorting and packaging due to high electricity usage during these operations (Fig 5). The hotspot in Swedish organic production was high CO_{2eq} emission of nitrous oxide as a result of large quantities of horse manure at one of the orchards (Fig 6). When the orchard was excluded from the LCA, CO_{2eq} from N_2O was reduced by 98% and total GWP from production was reduced by 70% with a total CO_{2eq} of 329g per kg apple.

The hot spot in Italian production was diesel consumption (Fig 7). CO_{2eq} emission was also higher for apples transported from Italy compared to Swedish IP production due to long-hauling transport by truck (Fig 7, 8). Swedish stored apples (3 months) had 66% less CO_{2eq} emissions compared to transported apples from Argentina by truck and boat, when production and postharvest was excluded from the LCA (Fig 9).

Integrated apple production in Sweden (IP)

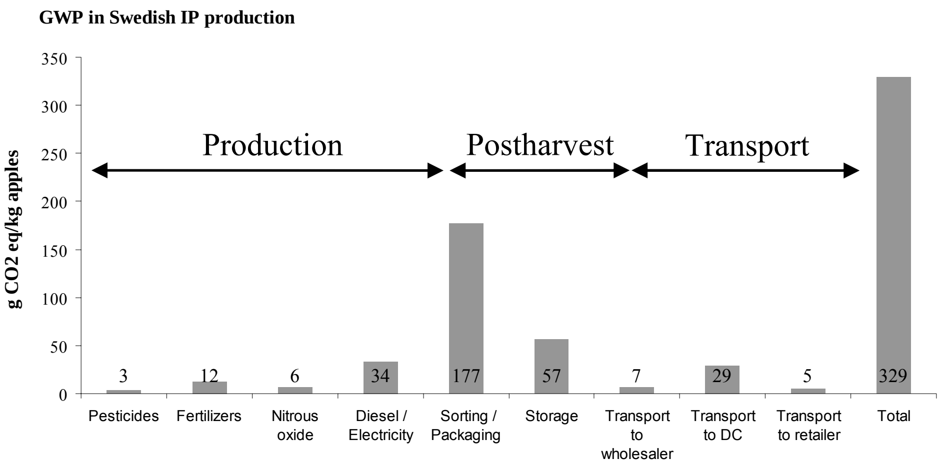

Figure 5: Emissions throughout the life cycle in Swedish apples produced according to integrated production (IP).

Production

CO_{2eq} emissions from Swedish IP grown apples derive only a low part from pesticides, fertilizers and diesel (16%) (Fig 5). The small overall effect of pesticides on total GWP was a result from the production, transportation and application. Diesel at farm level was mainly used for tractors and technical equipment for spraying, fertilizing, harvesting and pruning of apple trees. There was also minor emission of nitrous oxide from the ground (Fig 5).

Postharvest

There was a high use of electricity during cold storage but the most important factor was electricity needed for sorting and packaging. The use of electricity was the largest contributor (55%) of total GWP (Fig 5).

Transport

Transport of IP produced apples was approximately 13 % of the total GWP and the largest contributor was transport to the distribution center (DC) (Fig 5).

Organic apple production in Sweden

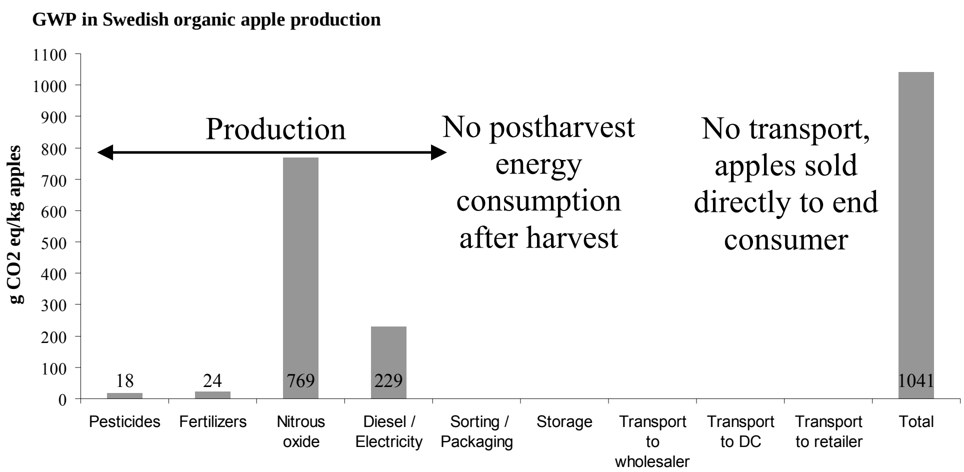

Figure 6: Emissions of CO_{2eq} in production of Swedish organic apples.

Production

The primary hot spot in Swedish organic production was allocated to the release of N_2O, due to high use of livestock manure at one of the three orchards. The emission from N_2O contributed to 71 % of total GWP. Diesel consumption was also an important hot spot in the production with 21 % of total GWP (Fig 6) due to a high use of machinery for mechanical weeding, pesticide application and other internal transports.

Postharvest

No hot spots were allocated in the organic production in storage, sorting and packaging as the production was sorted during picking and sold directly to end consumer (Fig 6).

Transport

There were no transport emissions from organic production system as none of the farms in the analysis had large enough harvest to sell to wholesalers and sold their apples directly to end consumer (Fig 6).

Italian apple production

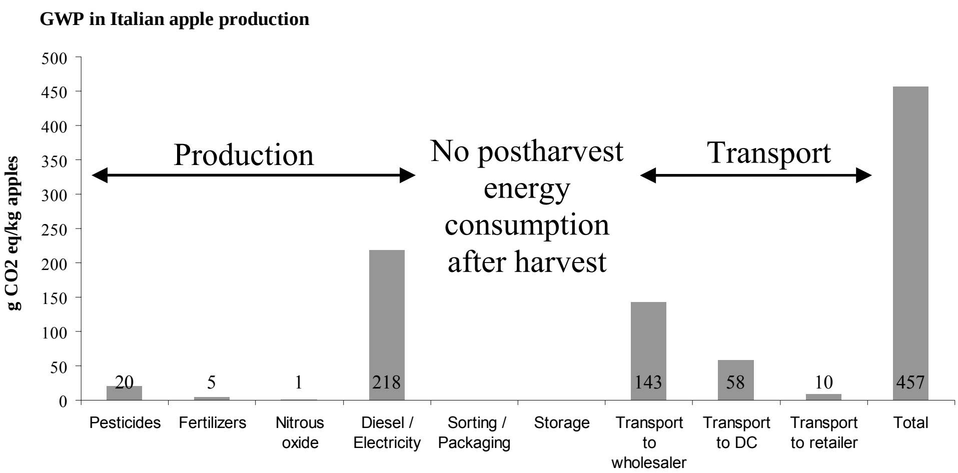

Figure 7: Emissions throughout the life cycle in Italian apples sold in Sweden.

Production

The primary hotspot in Italian IP production was diesel used in the apple production at the orchard. Diesel/electricity was the largest overall contributor being allocated to 62 % of total GWP (Fig 7).

Postharvest

As the farm area was small, sorting was done during harvest. There was no need for on farm storage due to direct transport to cooperatives. The grower in the analysis did not export directly and could not give an answer on packaging.

Transport

Transport from Italy to Sweden was done by truck with a cargo capacity of 100% and the transport represents 20 % of total GWP. Adding transport to retailers, which was considered to be equal to the transport for Swedish apples after distribution to the warehouse in Helsingborg, the transport represents 30 % of the total GWP (Fig 7).

Apple production Argentina

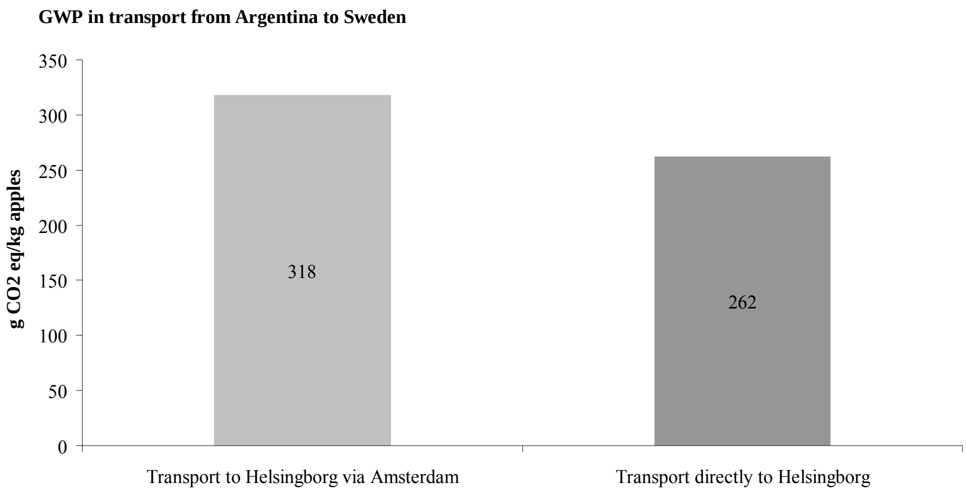

Figure 8: Emission of CO_{2eq} during transport of Argentinean apples to Sweden via Amsterdam or directly to Sweden.

Transport

There were two possible transport pathways for apples to reach Sweden from Argentina and both begin with transport by truck. The apples were then loaded to a refrigerated ship and transported either directly to Sweden or reloaded to trucks in Amsterdam and then driven to the warehouse in Helsingborg. The CO_{2eq} emission from transporting via Amsterdam was higher than direct transport to Sweden by boat (Fig 8). The transports within Sweden were considered equal no matter of production system (Fig 1).

Swedish stored apples vs. imported apples from Argentina

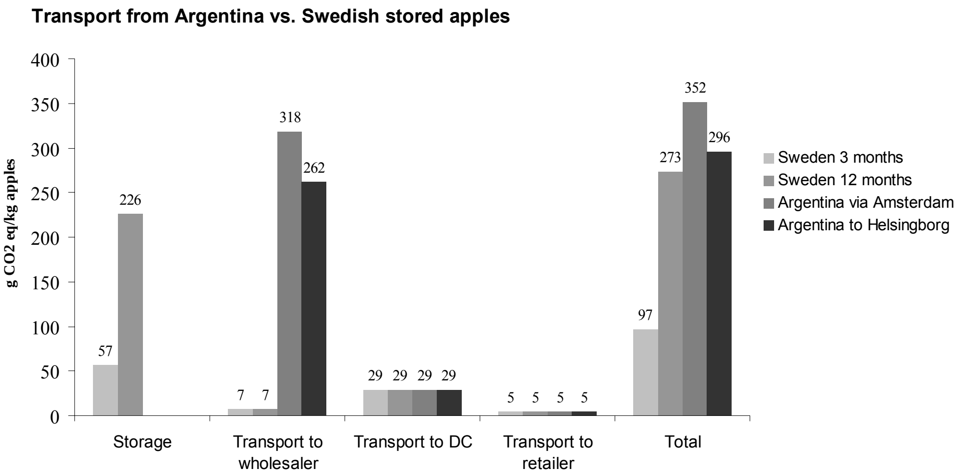

Figure 9: Differences in CO_{2eq} emissions between Swedish IP apples stored for 3 and 12 months and transported apples from Argentina directly to Sweden or via Amsterdam.

The emission of CO_{2eq} for Swedish IP apples stored in cold storage for 3 months was low compared to imported apples from Argentina (Fig 9). The emissions from apples stored for 12 months was however equal to apples directly imported with boat to Sweden (Fig 9). The emission of CO_{2eq} was highest for apples imported to the Netherlands and further transported to Sweden by truck (Fig 9).

Discussion

The objective of this LCA was to compare Swedish IP, Swedish organic, Italian IP and Argentinean IP in regards to production, postharvest and transport. Due to lack of data from apple production in Argentina, CO_{2eq} emissions were only calculated for three of the production systems. It was however feasible to assume that the production in Argentina was equal to European apple production (Milà i Canals 2007) but it was difficult to draw any conclusions regarding actual CO_{2eq} emissions. Postharvest was only available for Swedish IP production and it was difficult to compare systems in regard to sorting, packaging and storage. The lack of data from the other systems was due to differences in sales channels and postharvest was completed outside the system boundaries for this LCA. Transport was available for all production systems except Swedish organic production. It was however feasible to assume that if Swedish organic apples would be sold to retailer the emissions from Swedish organic would be equal to Swedish IP. Even though it was difficult to compare total GWP it was still possible to compare specific parts concerning production, postharvest and transport and give recommendations of CO_{2eq} efficient parts of total GWP between production systems.

Production of apples

Production of Swedish IP apples are CO_{2eq} efficient compared to Swedish organic and IP apples produced in Italy. The difference in GWP between Swedish and Italian production was similar to what was found in a previous LCA comparing Swedish and French IP apple production (Stadig 1997). It can be assumed that production conditions are equal in France and Italy as the countries are situated in southern Europe and for example use of machinery should be equal.

Greenhouse gas emissions from pesticides and fertilizers were low compared to other factors no matter of production system. Even though the GWP contribution of pesticides and fertilizers were low it has other negative environmental effects such as toxicity to aquatic and terrestrial systems, eutrophication and human health (Fenner et al. 2013, Rasmussen et al. 2012, Casida 2012, Decourtye 2013). A hot spot in Swedish organic production was high emissions of N_2O from excessive use of livestock manure. There was however a large variation in nutrient management between growers and the amount of manure used by one grower cannot be considered standard practice. Excluding the orchard with high amounts of livestock manure from the LCA decreased N_2O emissions from production to levels similar to Italian production but still higher than Swedish IP.

A large contributor of GWP was diesel and electricity consumption. In Italian production it was explained by transport of apples from farm to the cooperatives storage facilities and extra use of pesticides and machinery due to higher pest pressure. In organic production there was a high frequency of mechanical weeding and multiple applications of fungicides (sulphur) that increased diesel and electricity consumption. Emission of CO_{2eq} from Swedish IP production was lower compared to Swedish organic and Italian production due to less use of machinery and thereby the most efficient system from a GWP perspective.

Postharvest

LCA analysis of sorting, packaging and storage included only Swedish IP growers. The Swedish IP growers sort and package their apples on farm and store their apples in cold storage for periods of up to 5 months. If Swedish IP apples are to be available for a longer period of time it is necessary to invest in controlled atmosphere (CA) and/or ultra-low oxygen storage

(ULO) (Johnson 1999, Gorny & Kader 1996, Balla & Holb 2007). The energy consumption per FU is slightly higher in CA/ULO compared to normal cold storage but prolong the Swedish apple selling season (Ekman et al. 2003). CA/ULO storage does however not have positive effects on all apple varieties considering firmness, shelf life and taste (Konopacka & Płocharski 2002, Dixon & Hewett 2000, López et al. 1998). It is possible to grow apples that can ensure a supply for a longer period by choosing cultivars with harvest time spread over a larger part of the year and program the CA/ULO storage unit for the chosen variety, thereby minimizing loss of apple quality and thereby lowering energy consumption per FU (Johnson 1999). The shelf life of apples in cold storage is however equal to CA/ULO if storage time is shorter than 5 months (Awad & de Jager 2000, Aaby et al. 2001, Echeverria et al. 2004).

Even though storage was not included for other production systems than Swedish IP, cold storage or CA/ULO has the same energy consumption independent of country of origin. There is however a difference in CO_{2eq} emissions between countries in the production of electricity. In Sweden, a majority of the produced electricity comes from hydro power and nuclear power plants and only 1-9 % comes from fossil fuels (Ekonomifakta 2015). In Italy, as much as 67% of the electricity production comes from fossil fuel (Ekonomifakta 2015). Storage of apples in Sweden is therefore more CO_{2eq} efficient compared to storage of apples in countries with a majority of electricity deriving from fossil fuel sources.

Transport

The logistic pathway from wholesaler to retailer was the same independent of production system. Transport of apples is dependent of refrigerated road transport with centralized just in time warehouses. The importance of road transport is apparent as it has increased 4-5 times since 1950 and accounts for 25% of the total energy use in Sweden (Wallgren 2000). Of the transports conducted in Europe, one third is related to food (Wallgren 2000). It is likely to assume that road transport by trucks will continue to increase on a yearly basis. An effect of increased road transports leads to higher diesel consumption and emission of CO_{2eq}. To reduce CO_{2eq} emissions per FU it is possible to change from diesel and petrol to biofuel systems such as biodiesel and bioethanol (Lumbreras et al. 2008, Geerlings & van Duin 2011, Larson 2006, Rutz & Janssen 2003, Dorado et al. 2000). There are however practical problems connected with biofuels as it requires modifications of engines and a network of filling stations that have to be built and maintained (Köhler 2002).

There was a difference in CO_{2eq} when comparing direct transport and indirect transport with a reload in Amsterdam. It was CO_{2eq} efficient to transport goods with boat compared to truck, even for shorter truck distances (Knudsen 2010). Transporting apples over long distances gives a high impact on GWP per FU and Swedish apples were a better choice from a GWP point of view.

Storage and Import

It is more environmentally friendly to supply the market with Swedish apples stored for a period of up to 3 months compared to imported apples from Italy and Argentina. Swedish apples stored for 12 months has equal CO_{2eq} emissions compared with imported apples transported by refrigerated boat directly to Sweden. This corresponds well with the findings made by Milà i Canals et al. (2007) and Saunders & Barber (2008).

If Swedish apple growers were to supply 100% to the Swedish market it would in theory require 7 500 hectares as the current production cover 20 %. A well run, new planted organic orchard can produce 20 tonnes of apples per ha and year. The production is thereby 50% compared to IP and twice as much orchard area, 15000 ha, would be needed. The required expansion of orchard areas could be practically complicated to solve. Swedish climate is only suitable for commercial apple cultivars in the southern parts of Sweden and land prices are prices are high. Taking into account that the cost for IP growers to produce apples is 8 SEK/kg (after cultivation, storage and packing) (Ascard et al. 2010) and that the end consumer pay approximately 20 SEK/kg (after wholesalers, retailers and logistic companies), there is not a high profit for the grower; profits that could be used to invest in larger orchard areas (Ascard et al. 2010). Organic growers have a price advantage compared to IP but as the harvest levels are lower it would still be difficult to fill consumer demand.

Conclusion

- Swedish IP production had lower emissions of CO_{2eq} during production compared to Swedish organic and Italian IP.
- One of the most important hotspots in the production was the use of diesel and electricity independent of production system.
- Mechanical sorting and packaging is energy consuming and the largest contributor to total GWP in Swedish IP.
- It is CO_2 efficient to increase the market share of Swedish apples if storage time is less than 12 months, as CO_{2eq} emissions are lower than imported apples from Italy and Argentina.

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Appendix I (Questionnaire)

Farming per hectare

Total farmed area in ha	ha
Total farmed area of apple variety in ha	ha
Fruit trees bought from	
Other general information that you would like to share	

Incoming flows

Energy:	
Diesel	liter/year
Electricity	kWh/year
Other energy	?/year
If amount is unknown, please specify the following	
Machines in field e.g. for planting, weeding, fertilizing etc	
Transport to storage	
Please specify type of machine and time or fuel consumption	hours/year
	liter diesel/y
Fertilizers	
N	kg N/ha
Total amount N fertilizers (please specify if ammonium nitrate (NH_4NO_3), Calcium nitrate ($Ca(NO_3)_2$) or Urea	kg/ha
P	kg P/ha
Total amount P fertilizers	kg/ha
K	kg K/ha
Total amount K fertilizers	kg/ha
OR Total amount combined fertilizer, please specify what combination	kg/ha
Manure	
Total-N if known	kg/ha
Ammonium if known	kg/ha
Amount manure	kg/ha
Pesticides	
Herbicides, please specify active ingredient or which herbicide	kg/ha
Fungicides, please specify active ingredient or which fungicide	kg/ha
Insecticide, please specify active ingredient or which insecticide	kg/ha
Other, please specify active ingredient or which other	kg/ha
Other	
Fruit trees	amount/ha
Water	m3/ha
Watering materials	
Materials for binding the trees	m
Poles	st
Wires	m
Anchors	st
Other	

Outgoing flows

Harvest	
Variety	kg/ha

Other information

Total amount of plant debris e.g. twigs after pruning, apples on the ground etc	kg
Type of soil grown in	

Process system
Short description, e.g. storage, washing, packing etc

INCOMING FLOWS			
Incoming agricultural flows			E.g. distance
Apple variety from field	ton/year	From	
Energy			E.g. Town or distance
Diesel	liter/year	From	
Electricity	kWh/year	From	
Natural gas	m3/year	From	
Oil	m3/year	From	
Biodiesel	ton/year	From	
Other energy	other/year	From	
Packing material			E.g. company* or town/distance
Plastic (please specify PE, PP etc)	kg/year	From	
Cardboard	kg/year	From	
Well pap	kg/year	From	
Paper bags	kg/year	From	
Other	kg/year	From	
			In order to contact manufacturer
OUTGOING FLOWS			
Products			Distance
Apple variety, weight without packaging	ton/year	To	
Other products produced at the same time, please specify	ton/year	To	
Discharge to water			
N (e.g. N-tot or Nitrate)	kg/year		
P (e.g. Phosphate or P-tot)	kg/year		
BOD/COD	kg/year		
Other	kg/year		
Waste			E.g. Town/distance and treatment
Product waste	kg/year	To	
Other waste, e.g. packing material etc	kg/year	To	