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CLIMATE IMPACT FROM FRESH FRUIT PRODUCTION

- a systematic review and meta-analysis

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Abstract

The climate impacts by greenhouse gas (GHG) emissions from the agricultural sector have increased immensely since the mid-1900s. The main sources are synthetic chemicals, use of machinery and intensive cultivation of the soil. The aim of this MSc-thesis was to conduct a systematic review and meta-analysis in order to assess the collected climate impact from fruit production, using data mainly from life cycle assessments (LCA) and carbon footprint (CF) studies. The review included nine types of fruits (apple, pear, apricot, peach, grapes, orange, banana, pineapple and kiwi fruit) and one group of fruits (small citrus fruits with tangerines, mandarins, Citrange Troyer and Sidi Aissa). There were three cultivation methods included; conventional, integrated and organic. Integrated method uses distinctive rules for fertilization, energy use, pest control etc. to minimize environmental impacts. The system boundary was cradle to farm gate and the functional unit (FU) was kg CO_2-eq/kg fresh fruit at farm gate. The literature search was performed in Web of Science and Scopus for LCA, CF and fruit production publications from 2006-2017. The climate impacts from fruit production were statistically analyzed on difference between types of fruit, production countries, continents, production methods and yields. Hotspots in the production process such as fertilization as well as correlation between GHG emissions and yields were also investigated. Hotspots are activities or inputs in the life cycle that shows an enlarged environmental impact. The tests for difference were performed with Kruskal-Wallis and Mann-Whitney *U* test, since the data was not normal distributed. The Mann-Whitney *U* test was used as a post-hoc test, to identify which fruit types that differed. After screening 798 abstracts, many were duplicates, 55 articles about fruit production were included in the systematic review, which covered 28 countries from all continents except Antarctica. The result from the meta-analysis showed that apple production had the smallest climate impact, 0.11 kg CO_2-eq/kg apples, and the apricot production the largest, 0.36 kg CO_2-eq/kg apricots. Apple production methods were significantly different from each other. There was also a significant difference between production methods when all types of fruit were included in the test. The integrated production method had the smallest climate impact, and the organic production method had the largest. When the yields from fruit production increase, there is a decrease in climate impact. The integrated production method gave the largest yields when all fruits were included and for apple production. The main hotspots for all types of fruit were fertilization, closely followed by fuel and electricity. Both categories include the production phase and the use phase. The climate impact from fresh fruit production is relatively small, though there is room for improvements. There is a need of, strategic decisions about use and application of fertilizer and planned operations of machinery use, which utilize renewable fuel and electricity. There was no difference between production countries for none of the fruit types. This indicates that locally produced fruit would be a better choice from a global warming perspective. However, when all types of fruit were included a significant difference was found between countries and between continents. There are no fruit species that can be optimally produced in all climates, which means that fruits that are not adapted to the local climate will need more resources. I conclude that integrated fruit production is to be preferred, since it had the smallest climate impact and the largest yields. I also conclude that integrated produced apples are the best choice from a global warming perspective.

Keywords: Fruit, Climate impact, CO_2-eq, Life Cycle Assessment, Carbon Footprint, Conventional fruit production, Integrated fruit production, Organic fruit production

Sammanfattning

Sedan mitten av 1900-talet har utsläppen av växthusgaser från jordbrukssektorn ökat markant, vilket till stor del beror av användandet av syntetiska kemikalier, maskiner och intensiv odling. Syftet med denna MSc-uppsats var att genomföra en systematisk litteraturstudie och meta-analys för att analysera fruktproduktionens klimatpåverkan. Data extraherades huvudsakligen från livscykelanalyser (LCA) och Carbon Footprint (CF) studier. Det ingick nio frukttyper (äpple, päron, aprikos, persika, vindruvor, apelsin, banan, ananas, kiwi) och en fruktgrupp (små citrusfrukter: mandariner, Citrange Troyer och Sidi Aissa). Studien omfattade tre odlingsmetoder; konventionell, integrerad och ekologisk. Den integrerade produktionsmetoden följer specifika riktlinjer vid gödsling, energianvändning, skadedjurskontroll etc. för att minimera miljöpåverkan. Systemgränsen var vagga till gårdsgrind och den funktionella enheten (FU) var kg CO_2-ekv/kg färsk frukt vid gårdsgrind. Litteratursökningen utfördes i Web of Science och Scopus, vilket omfattade LCA och CF publikationer från 2006-2017. Skillnaden i klimatpåverkan från fruktproduktionen analyserades statistiskt mellan olika frukttyper, produktionsländer, kontinenter, produktionsmetoder och avkastning. Andra aspekter som undersöktes var korrelation mellan växthusgasutsläpp och avkastning, samt hotspots i produktionsprocessen som t.ex. gödning. Hotspots är aktiviteter eller input inom livscykeln som har en stor miljöpåverkan. Testen för skillnad utfördes med Kruskal-Wallis och Mann-Whitney U-testet, eftersom data inte var normalfördelad. Mann-Whitney U-testet användes som ett post-hoc-test för att identifiera vilka frukttyper som skilde sig åt. Efter att abstracts screenats och dubbletter avlägsnats återstod 112 artiklar, och efter ytterligare selektering inkluderades i slutändan 55 artiklar om fruktproduktion i meta-analysen, vilket omfattade 28 länder från alla kontinenter utom Antarktis. Resultatet från metaanalysen visade att äppelproduktionen hade minst klimatpåverkan, 0,11 kg CO_2-ekv/kg äpplen och aprikosproduktionen hade störst 0,36 kg CO_2-ekv/kg aprikoser. De olika äppelproduktionsmetoderna var signifikant skilda från varandra. Det var också en signifikant skillnad mellan produktionsmetoderna när alla frukttyper var inkluderade i testet. Den integrerade produktionsmetoden hade minst klimatpåverkan och den ekologiska produktionsmetoden hade störst. När avkastningen från fruktproduktionen ökar, minskar klimatpåverkan. Den integrerade produktionsmetoden gav störst avkastning när alla frukter var inkluderade och för äppelproduktionen. Alla frukttyper hade störst hotspots inom gödsling, följt av bränsle och elektricitet. Båda kategorierna omfattade produktionsfasen och användningsfasen. Klimatpåverkan från färsk fruktproduktion var relativt liten, men det finns utrymme för förbättringar. Det behövs strategiska beslut vid användning och tillämpning av gödningsmedel och planerad användning av maskiner, som utnyttjar förnybart bränsle och elektricitet. Det var ingen skillnad mellan produktionsländer för någon av frukttyperna. Detta indikerar att lokalt producerad frukt skulle vara ett bättre val ur ett globalt uppvärmningsperspektiv. När alla frukttyper inkluderades i testet var skillnad mellan länder och mellan kontinenter signifikant. Det finns inga fruktarter som kan produceras optimalt i alla klimat, vilket innebär att frukter som inte är anpassade till det lokala klimatet kommer att behöva mer resurser. Jag drar slutsatsen att integrerad fruktproduktion är att föredra, eftersom den uppvisade den minsta klimatpåverkan och de största avkastningarna. Jag drar också slutsatsen att äpplen producerade med en integrerad metod är det bästa valet från ett globalt uppvärmningsperspektiv.

Nyckelord: Frukt, Klimatpåverkan, CO_2-ekv, Livscykelanalys, Carbon Footprint, Konventionell fruktproduktion, Integrerad fruktproduktion, Ekologisk fruktproduktion

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Annika

List of Abbreviations

GHG	Greenhouse gas
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CH_4	Methane
N_2O	Nitrous oxide
CFCs	Chlorofluorocarbons
RF	Radiative forcing
GWP	Global warming potential
LCA	Life cycle assessment method
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
CF	Carbon footprint method
EPD	Environmental Product Declaration
FU	Functional unit
SPSS	Statistical Package for the Social Sciences
SD	Standard Deviation
SE	Standard Error
CI	Confidence Interval
Q_1 & Q_3	Lower and upper quartiles are values exceeded by 25 % and 75 % of the data points
IQ	Interquartile range
IPCC	Intergovernmental Panel Climate Change
AFOLU	Agriculture, Forestry and Land-Use
Con	Conventional production
IP	Integrated production
Org	Organic production

Contents

1 Introduction

1.1 Agricultural development and Climate Change

Since the 1950s the agricultural productivity has increased immensely, mainly due to the intensive use of synthetic fertilizers, such as nitrogen (N), phosphorus (P) and potassium (K), the use of pesticides, improvements in irrigation and large scale mechanization (Cunningham, 2005; Purvis *et al*. 2006; Schröder *et al*. 2010). These intensive activities and synthetic inputs have over time contributed to global warming, and in 2010, did the Agriculture, Forestry and Land-Use (AFOLU) sector account for 24% of the world's total emissions of greenhouse gases (GHGs) (IPCC, 2014). In 2015, the GHG emissions from Swedish agriculture accounted for 12% of Sweden's total GHG emissions, excl. Land-Use Change and Forestry (LULUCF) and transports abroad (Swedish Environmental Protection Agency, 2017).

The cultivated area of fruit production has grown with more than 240% worldwide since the 1960s (1961-2014) (FAOSTAT, 2017). However, in the European Union (EU) the cultivated area has diminished with 30% in that same period (FAOSTAT, 2017). In 2015, EUs total fruit production area was, 32.4 km^2, and Spain had the largest share of that, about two-fifths (EUROSTAT).The fruit production growth, since the 1960s, of specific types of fruit varies, from a 70% increase in apple production yield, worldwide, to a 220% increase in kiwi fruit yield (FAOSTAT, 2017).

Besides impacts on the climate, the agriculture development has contributed to soil erosion, water pollutions and excessive strain on water sources, loss of biodiversity, spread of pesticides to natural ecosystems and with negative impacts on human health (Vinyes *et al*. 2017).

1.1.1 Fruit production and resource inputs

Fruits are produced when flowering plants are pollinated and the ovules transforms into seeds with the ovary surrounding as a protective coating (Sadava *et al*. 2014). This coating can be fleshy and edible, or developed into a dry and/or inedible seed cover (Sadava *et al*. 2014). The fruits we mostly consume in Sweden are the herbaceous perennial plant species banana and woody perennials, such as apples and oranges (Bessou *et al*. 2013; Sadava *et al*. 2014; Swedish Board of Agriculture, 2017). Many fruit trees can live and thrive for centuries, although in fruit production the lifetime is about 10 and 50 years, depending on production method (SLU, 2007; Alaphilippe *et al*. 2016; Goossens *et al*. 2017).

An orchards life begins with preparation of the soil through tillage and fertilization, thus establishing favorable concisions for plant growth, and installation of infrastructure, such as irrigation systems and frost protection (Goossens *et al*. 2017). When the trees arrive at the orchard, they are two to three years old or in the form of a sucker[1] e.g. banana (Iriarte *et* al. 2014; Goossens *et al*. 2017). The climate impact from the trees starts already in the nursery phase, which is not always included in environmental assessment studies.

[1] A shoot that grows from the root (Sadava *et al*. 2014; Svanes *et al*. 2013)

There are both unproductive and productive stages in an orchards lifetime. To receive a good estimation of the climate impact from fruit production the whole lifespan should be included in the analysis.

During the orchards first year to years, the yields from the vine/herb/tree will be at a minimum, and the phase is therefore referred to as unproductive (Goossens *et al*. 2017). When the plant has matured the productive years start, and lasts for more than a decade (Alaphilippe *et al*. 2016). With age, the productivity diminishes and the orchard is terminated. The main inputs used in cultivation of fruits are fertilizers, pesticides, water for irrigation and energy in the form of fuel and electricity (Alaphilippe *et al*. 2016). The corresponding cultivation activities are soil management, fertilization, pest control, irrigation, pruning, thinning, use of machines and harvest (Alaphilippe *et al*. 2016; Goossens *et al*. 2017).

Soil fertilization requires access to macronutrients such as N, P and K (UNIDO, 1998; Schröder *et al*. 2010). In agricultural practice, these elements are supplied in the form of synthetic and organic fertilizers (UNIDO, 1998). Synthetic fertilizers are mined and manufactured, unlike organic fertilizers, which comes from manure, green manure, urea and compost (UNIDO, 1998). The production of synthetic fertilizers requires vast amount of energy and creates many waste products (UNIDO, 1998).

About 100 pest species causes 90% of all crops damage worldwide (Cunningham *et al*. 2005). Pest control includes many types of pesticides and biological control, in form of living organisms such as ladybugs or toxins extracted from organisms (Cunningham *et al*. 2005).

The irrigation system can be used for more than distributing water, such as frost protection and as delivery system of chemicals (Mithraratne *et al*. 2010). Drip irrigation or sprinklers are commonly used, and the water is usually pumped up from wells, which require inputs of fuel or electricity (Mithraratne *et al*. 2010).

Pruning is a method for controlling the growth by removing branches and leaves with mechanical assistance, and by doing so increasing the yields and quality of the fruit (Longo *et al*. 2017). The residues from the pruning can be incorporated into the soil to enhance the structure and nutrient level (Longo *et al*. 2017). The process of thinning is the removal of some flowers in order to leave sufficient space for the remaining flowers to develop into healthy full sized fruits. The process includes the use of chemicals that are mixed with water and applied with machines (Longo *et al*. 2017).

Tractors and other machinery that require fuel or electricity are used in all cultivation phases, in one way or another. Harvest is mostly performed by hand with use of elevated platforms (Keyes *et al*. 2015).

Post-harvest activities involve transportation from the farm to distribution centers (DC) or similar, where the product often is stored for shorter or longer periods (Audsley *et* al. 2009; Keyes *et al*. 2015). From the DC the product is transported to ripening centers followed by retail, and then the product enters the so-called user phase. Fruits that are not eaten will end up in the disposal phase (Audsley *et* al. 2009; Keyes *et* al. 2015; Eriksson *et al.* 2017)

1.1.2 Greenhouse gas emissions from fruit production

The most abundant GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), (excl. ozone and water vapor) which all absorbs some of the thermal radiation that leaves the earth's surface, which then are re-emitted in all direction including at the earth's surface (Houghton, 2015).

The GHG emissions from using fossil fuels in agriculture worldwide contributed with 400-600 Mt CO_2-eq/yr. in 2010; however, those emissions are not categorized under the AFOLU sector, which means that they are not included in the Intergovernmental Panel Climate Change (IPCC) statistics (IPCC, 2013).

Carbon dioxide

Many of the processes and inputs in fruit production contribute to emissions of CO_2. Inputs, such as fertilizers, lime, pesticides, water, fossil fuels and electricity, emits CO_2 when produced, stored and/or transported (IPCC, 2014; FAO, 2015). These inputs are utilized in different cultivation phases, which is cause to additional emissions of CO_2 (IPCC, 2014; FAO, 2015). Irrigation system pumps water and the application of fertilizers, pesticides and lime are done with use of machinery (Mithraratne *et al*. 2010; Keyes *et al*. 2015). All these processes need some form of equipment that uses diesel fuel or electricity (Mithraratne *et al*. 2010; Keyes *et al*. 2015).

Fruit production like other agricultural practice can be considered both as a sink for CO_2, through soil carbon sequestration, and as a source of it by soil management such as tillage (IPCC, 2014).

Methane

Anthropogenic sources of CH_4 that can be assigned to fruit production are energy production, from coal and gas, burning of biomass from e.g. pruning, and from manure storage (Swedish Environmental Protection Agency, 2006; Cederberg, 2010; Aguilera *et al*. 2015; Houghton, 2015). Atmospheric concentrations of the CH_4 has more than doubled since the 1800s and the concentration is higher than it has ever been during the last 800 000 years, according to ice core records (Houghton, 2015; IPCC, 2013). Out of the yearly emissions of CH_4, about 50% comes from agriculture, and if food waste handling is added, the percentage goes up to 60% (Cederberg, 2010).

Nitrous oxide

The anthropogenic emissions of N_2O is dominated by production and use of ammonia as fertilizer, storage of manure, cultivation of legume, combustion of fossil fuels and burning biomass (Cederberg, 2010; IPCC, 2014). All of these are processes used within fruit production, depending on production method. Conventional fruit production use large amounts of synthetic fertilizers, and the emissions of N_2O from it was in 2015, 660 Mt/yr. worldwide (FAOSTAT). The emissions from manure, which is an important part of organic fruit production, was much smaller, 147 Mt/yr., (FAOSTAT). The formation of N_2O in the soil is an unavoidable by-product from denitrification, which means that a high input will probably lead to increased emissions (Cederberg, 2010).

1.1.3 Production methods

Three different agricultural production methods were considered in this thesis: conventional, integrated and organic fruit production. The three production methods are briefly described below.

Conventional production

Conventional production (Con), also known as intensive farming, is an agricultural system that utilizes a high input management. The large quantities of synthetic fertilizers, pesticides, irrigation and energy added to the system aims to maximize the yield per unit cultivated area (Tamburini *et al*. 2015).

Integrated production

Integrated production (IP) utilizes a holistic method involving, planning, evaluation and improvement management (EISA, 2012). The cultivation should include the use of resistant species, crop rotation, intercropping and reduced tillage (EISA, 2012). The soils nutritional status ought to be monitored, so that accurate amounts of fertilizers can be added at the right time (EISA, 2012). Integrated pest management (IPM) is a method that aims to minimize the use of different pesticides (EISA, 2012). The objective is prevention, observation, informed decisions and intervention (EISA, 2012). If there is need of pest control, biological methods will be considered first and chemicals only as a last resort (EISA, 2012). It is important to aim for fuel efficiency use of renewable energy and avoiding excessive use of machinery (EISA, 2012). Carbon sequestration is also included in the method (EISA, 2012).

Organic production

Organic production includes crop rotation, minimum tillage, strictly confined use of synthetic pesticides and synthetic fertilizers, and no use of genetically modified organisms (GMO) (European Commission, 2017). On site resources, such as manure, should be utilized (European Commission, 2017). Species that are resistant to diseases and easily adapt to local conditions ought to be prioritized (European Commission, 2017). Soil conservation is an important part of organic production since it contributes to soil fertility (Morgera *et al*. 2012). Accordingly, to a meta-analysis by Ponti *et al*. (2012) the fruit yields from organic production were about 72% of conventional fruit yields.

1.2 Assessing environmental impact from products

1.2.1 Life Cycle Assessment and Carbon Footprint

Life cycle assessment (LCA) and carbon footprint (CF) are methods that aim to describe a products impact on the environment, by examining its whole life cycle (Baumann & Tillman, 2015; Sonesson *et al*. 2010). The life cycle refers to the cradle of the product, which includes all inputs needed to produce it, the use phase, and its grave when the product no longer exists in its intended form (Baumann & Tillman, 2015). The term product includes e.g. services, software, hardware, processed materials and food processing (Baumann & Tillman, 2015; Sonesson *et al*. 2010).

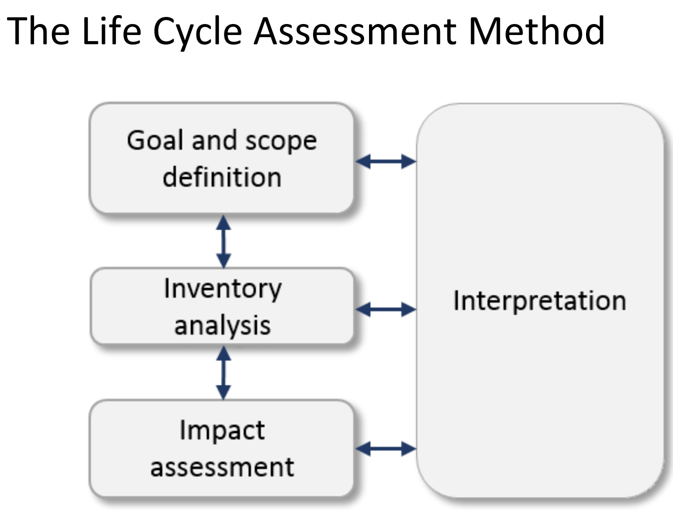


Figure 1: Life cycle assessment process, which includes three main steps and the need for feedback between them. All three processes are also interpreted which also result into feedback.

There are three main steps (Figure 1) to follow when conducting a LCA (Plassmann & Edwards-Jones, 2010; Baumann & Tillman, 2015). The first step is to define the goal and scope of the study, which gives the direction and purpose of it. The idea is to state the intention of the study and to whom it is directed, and to define the product. Aspects to consider in this stage are the system boundaries for the product, which environmental impacts to analyze (CF only assess affects from GHGs), the functional unit (FU) and how detailed the inventory should be (Plassmann & Edwards-Jones, 2010; Baumann & Tillman, 2015).

The concept FU is important in LCA and CF since it defines the function of the studied product, and all the flows in the system relates to it (Plassmann & Edwards-Jones, 2010; Tillman, 2010). The FU is expressed in quantitative term (Tillman, 2010), such as 1 kg fresh fruit at farm gate, which is the FU used in this thesis. When the FU is framed, the system boundary is defined by considering boundaries to natural systems, in space and time, within the technical system and to other products (Nguyen *et al*. 2010).

Step two is the life cycle inventory (LCI) analysis, which comprise collection and calculation of system input and output data (Baumann & Tillman, 2015). Based on the established system boundaries, a flowchart over the different phases in the life cycle of the product is drafted (Baumann & Tillman, 2015). The flowchart facilitates the collection of data by highlighting the focus areas.

The third step is the life cycle impact assessment (LCIA), which aims to interpret the inventoried data to its environmental impact (Baumann & Tillman, 2015). The impacts can be many and affect different environmental impact categories, so they are first classified into specific impact groups such as global warming (Baumann & Tillman, 2015; Sonesson *et al*. 2010). Then, the category indicator for emissions and resources are calculated, known as the characterization factor (Baumann & Tillman, 2015). In this context, the characterization factor for global warming is global warming potential (GWP) discussed more below.

Hotspots are those activities that show an increased environmental impact, and it is important to identify them in order to be able to make improvements of the system (Tillman, 2010). Life cycle assessment and CF is often used to identify hotspots in production systems (Plassmann & Edwards-Jones, 2010; Baumann & Tillman, 2015).

The difference between LCA and CF is the fact that CF only assesses the impacts of GHG emissions, in contrast to LCA where several environmental categories can be assessed (Plassmann & Edwards-Jones, 2010). Besides that, CF follows the same steps as the LCA, and both methods are ISO standardized, which provides a manual to follow. ISO 14040 and 14044 are used by both methods, and ISO 14067, which is a technical specification, is used as well when applying the CF method. Initially, the CF method focused on CO_2 emissions but it has evolved to cover more types of GHG, such as CH_4, N_2O and CFCs (Lillywhite, 2010). By using LCA or CF, the climate impact associated with e.g. fruit production can be assessed.

1.2.2 Radiative Forcing and Global Warming Potential

Radiative forcing (RF) is the change in mean net radiation in the upper part of the troposphere, which occurs because of a change in concentration of GHGs or in a changed level of incoming solar radiation (IPCC, 1990; IPCC, 1995; Houghton, 2015). The response to the system change results in a climate change, where a positive RF lead to a warmer surface and a negative RF to a cooling effect (IPCC, 1990; IPCC, 1995; Houghton, 2015).

To simplify the comparability of RF levels generated by different GHGs an index called GWP, was introduced in 1990 by Danial Lashof and Dilip Ahuja and further developed by the IPCC (Lashof & Ahuja, 1990; IPCC, 1990; IPCC, 1995). The index describes the cumulative energy added to the climate system by a substance compared to the amount of energy added by one molecule of CO_2 to the climate system (IPCC, 2013).

The GWP values (Table 1) reflect the gases efficiency in causing RF and takes into account their lifetime in the atmosphere and is calculated as the ratio of time-integrated RF of the emissions from 1 kg of a specific gas relative to that of 1 kg of CO_2 (IPCC, 1995; Houghton, 2015). Carbon dioxide equivalent (CO2-eq) is the unit used to compare and add the climate impact of different GHG (IPCC, 2013). Since different GHG have different lifespans in the atmosphere, the GWP value can be calculated for different time horizons, i.e. 20, 100 and 500 years (IPCC, 1995; IPCC, 2001; IPCC, 2007; IPCC, 2013). With every new assessment report from IPCC the different GWP values has changed as a result of the latest scientific evidence (Table 1). In this thesis, the included studies used GWP 100 years; however, the index version used differed as a result of different publication years.

Table 1: Different GWP values for carbon dioxide, methane and nitrous oxide, with the time horizon of 100 year. The first is from IPCC second assessment report (SAR), and the values have changed in every assessment report that has been published by IPCC. TAR (third assessment report), AR4 (fourth assessment report) and AR5 (fifth assessment report).

Global Warming Potential index – time horizon 100 year					
GHG	Life time (year)	SAR (1995)	TAR (2001)	AR4 (2007)	AR5 (2013)
CO_2	variable	1	1	1	1
CH_4	12.4 [a]	21	23	25	28
N_2O	121 [a]	310	296	298	265 [b]

[a] IPCC, 2013, [b] Excluding climate carbon feedbacks

1.3 Aim and research questions

This MSc project was conducted as a subproject to the research program NEXUS, led by RISE (Research Institutes of Sweden) and KI (Karolinska Institutet), which aims to connect the environmental impacts of food with its health aspects. The types of fruit included in this thesis are a part of the NEXUS project.

The aims of this thesis were to conduct a systematic review and meta-analysis concerning the GHG emissions from different types of fruit production and to analyze possible differences in climate impact.

Research questions:

1. Does the climate impact from production of different types of fruits diverge from each other?

2. Does the climate impact from production of different fruit genera diverge from each other?

3. Are there any hotspots of GHG emissions within the production of the different types of fruit?

4. When investigating the fruit types separately:
   - Does the climate impact differ between production countries and between continents?
   - Does the climate impact differ between production methods (i.e. conventional, integrated and organic)?

5. Is there a correlation between the yields and GHG emissions from fruit production?

2 Methods and Materials

2.1 Systematic review

The systematic review was conducted by following the directives from Pullin & Stewart (2006), Siddaway (n.d.) and the PRISMA 2009 checklist (Moher, *et al*. 2009). The process was divided into several distinctive steps, which are described below. The review list is found in Appendix I.

2.1.1 The process of the systematic review

Framing the subject

The type of fruits include in this thesis were eight woody perennials, i.e. apple, pear, apricot, peach, small citrus (tangerines, mandarins, Citrange Troyer and Sidi Aissa), orange, grapes and kiwi fruit, along with two herbaceous perennials i.e. banana and pineapple. All the included fruit types are listed by genus in Table 2. Two genera, *Prunus* and *Citrus*, both had more than one fruit type belonging to them. Peach and apricot both belong to *Prunus* and the *Citrus* genus hold small citrus, oranges and mandarin.

Table 2: The included fruit types divided into genera. There were eight genera, ten fruit types, and one group of fruits included.

The fruits by genus							
Malus	*Pyrus*	*Prunus*	*Citrus*	*Vitis*	*Musa*	*Ananas*	*Actinida*
Apple	Pear	Apricots	Small citrus fruits	Grapes	Banana	Pineapples	Kiwi fruit
		Peaches	Oranges				

Literature search

The data searches were conducted between July and September 2017. They were preceded by selecting specific search words, which for this study were LCA, carbon footprint, carbon, fruit and the name of the selected types of fruit separately. The search word combinations were (LCA & fruit*), (LCA & "fruit name"), (carbon footprint & fruit*) and (LCA & fruit & carbon). The databases and sources used were Web of Science (all databases), Scopus, Google Scholar, Google, Environmental Product Declaration (EPD) and article reference lists.

The first screening of articles focused on title and abstract, and the following on the full text. This process was made easier by formulating specific inclusion and exclusion criteria's (Table 3). The first criteria focused on the methods used to assess climate impact from GHG emissions i.e. LCA method and CF method. The FU was kg CO_2-eq /kg fresh fruit at farm gate. The system boundaries for the fruit production systems were also considered and focused on cradle to farm gate. However, studies with system boundaries stretching further than farm gate were included if the GHG emissions from cradle to farm gate could be extracted. The included articles were limited to publications between 2006 and 2017.

Table 3: The criteria's for inclusion and exclusion of articles and other data sources are summarized here. The important categories for inclusion were which assessment methods that been used, the FU, system boundary, the timeframe and if it was a primary study.

The criteria´s for selecting articles about fruits effect on the climate	
Included	Excluded
Assessment methods ▪ Life cycle assessment method (LCA) ▪ Carbon footprint method (CF) **Functional unit** ▪ CO_2-eq /kg fresh fruit ▪ CO_2-eq /ha (provided that the value for yield was stated) ▪ CO_2-eq /milliliter (provided that information of how many g & kg of fruit it contained) **System boundaries** ▪ Cradle – farm gate ▪ Cradle – grave (provided that emissions for specific stages in the life cycle were available) **Time frame** ▪ Year: 2006-2017 **Other** ▪ Reference lists were used as an additional source of articles	▪ Ecological footprint method ▪ Functional unit CO_2-eq / ha (if value for yield was not stated) ▪ System boundaries including emissions beyond farm gate (if emissions for specific stages of the life cycle were not available) ▪ Climate impact not expressed in CO_2-eq. ▪ Carbon sequestration

Data extraction and quality evaluation

The extraction of data from the selected studies focused on the output values of GHG emissions from the LCA or the CF, expressed in kg CO_2-eq/kg fresh fruit at farm gate, and data about GHG emission from different production phases. Other information collected from the included studies was the use of method, software and databases, which was used to evaluate the quality and consistency of the studies.

To avoid bias in the data set both published and unpublished data should be included (Siddaway (n.d.); Pullin & Stewart, 2006). In this thesis, mostly peer-reviewed articles were used as data source, although some data came from EPDs, government and organization reports, conference proceedings and master theses. Other types of bias to consider are publication bias, language bias and selection bias (Pullin & Stewart, 2006; Rosenthal, 1979; Siddaway (n.d.)). Publication bias can become a problem if studies with undesired results are not published or not available in other ways (Rosenthal, 1979).

2.2 Climate Impact Assessment

When comparing climate impact data from different studies it is crucial that they use the same or at least similar system boundaries, otherwise the result may be misleading. Figure 2 illustrates the system boundaries, with inputs and outputs, used in this thesis. The system boundaries were from cradle to farm gate, and included those processes needed for production of fresh fruit, which were soil management, fertilization, pest control, irrigation, pruning, thinning, machinery and transportation, and harvest process. The production and acquisition of all inputs were also include, and the output was in the form of GHG emission.

As stated, the FU was 1 kg fresh fruit produced at farm gate. The GHG emissions were converted into CO_2-eq by using GWP index 100 year.

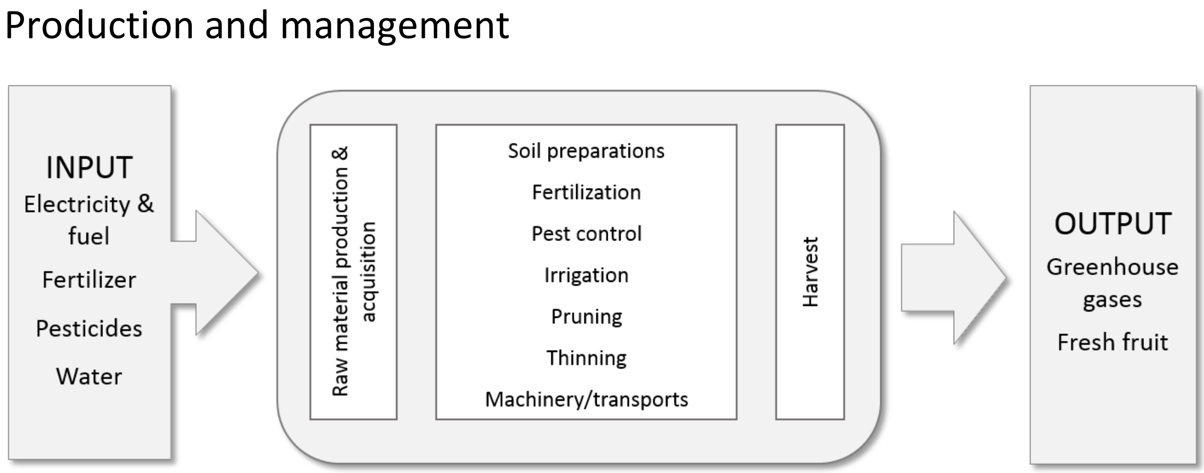


Figure 2: The expected inputs, outputs and processes that the different fruit studies included in their system boundary, which stretch from cradle to farm gate.

In addition, to the production methods, i.e. conventional, integrated and organic, some articles reported other types of production methods, such as intensive, extensive and biodynamic production method. The intensive method was classified as conventional production, and the extensive and biodynamic as organic production. Those articles that did not report which production method they used were assigned as conventional production.

Hotspots

Hotspots are processes or activities that have an enlarged environmental impact and by identifying these hotspots, system-improvements are possible (Tillman, 2010). In this thesis, the hotspots represent the GHG emissions from those processes or activities.

Several studies included hotspots in there analysis and for those categories that were frequently reported the data were collected and mean values were calculated, in this case mean percentage. Only those hotspots that were equal to or larger than 20% of the climate impact were included. The included processes and activities were energy (fuel and electricity), fertilization, pest control, irrigation, harvest and packing on site, and N_2O emissions. The studies reporting hotspots had divided the emissions of GHGs differently, for example, irrigation could be in the energy category and N_2O could be included in fertilization. Some studies has chosen to separate these categories, and the reason may be that they want to highlight those processes or/and activities.

2.3 Statistics

2.3.1 Meta-analysis

Descriptive statistics such as mean, median, standard deviation (SD), standard error (SE), minimum and maximum value, confidence interval (CI) and the quartiles for 25 % (Q_1) and

75% (Q_3) of the values were calculated with the statistical software IBM SPSS statistics 24 (Statistical Package for the Social Sciences). These statistics were calculated for all fruit types and for genera. The results were visualized in a box and whisker plot. The Levene's test of homogeneity of variance was also conducted for the set of measurements from the different fruit productions (Ennos, 2012).

2.3.2 Statistical tests

Statistical tests suitable for exploring the difference between more than two sets of measurements and the effect of one factor are Kruskal-Wallis test and one-way ANOVA (analysis of variance) (Ennos, 2012). Before deciding which test to use the distribution and variance of the sets of measurements need to be tested. The one-way ANOVA is only valid if the sets of measurements are normally distributed and that the variances of the dataset are the same or similar, though it is not as important as the distribution (Ennos, 2012). If the samples are not normally distributed the non-parametric Kruskal-Wallis test can be used, which compares the median score between samples instead of the mean values (Ennos, 2012).

The non-parametric Mann-Whitney *U* test investigates difference between two unpaired sets of samples (Ennos, 2012). The test was used as a post hoc test for the Kruskal-Wallis test to identify which sets that was significantly different from each other. The dataset with the smallest climate impact in the different categories was used as a baseline, to which all other datasets were compared.

A correlation test investigates relationship between data, and Spearman rank correlation test is used on skewed data (Ennos, 2012). In this thesis a correlation between the climate impact from fruit production and the yields were tested.

When testing the normality of distribution in SPSS it gives result from two tests i.e. Kolmogorov-Smirnov test and Shapiro-Wilk test. The null hypothesis is that the distribution of the sample do not differ from normal distribution if the $P \geq 0.05$ (Ennos, 2012).

The null hypothesis, when conducting a difference test, is that there is no difference in the mean or median score between different sets of measurements (Ennos, 2012). Four different aspects were statistically tested.

- Differences between fruit types and between genus
- Differences between countries and between continents
- Differences between production methods (e.g. conventional, integrated and organic production)
- Difference between yields from different production methods

The null hypothesis for Spearman rank correlation is that there is no association between the two sets of measurement (Ennos, 2012). One correlation test between climate impact and yields was conducted.

The significant probability is the chance that a result would be obtained when the null hypothesis is true (Ennos, 2012). If the significant probability, for example, is less than or equal to 0.05 (5%), then the null hypothesis can be rejected, however if it is larger than 5% the null hypothesis cannot be rejected (Ennos, 2012). The significance level for all tests was $P \leq 0.05$.

3 Results

3.1 Systematic review

The initial database search resulted in 798 articles, after screening of title and abstract 217 articles remained (Figure 3). Exclusion of duplicates and articles not meeting the inclusion criteria has further reduced the number. The full text screening included 112 articles and the final analysis included 55 articles, of which were 45 peer-reviewed articles, five reports, two conference reports, two master theses and one EPD (Appendix I).

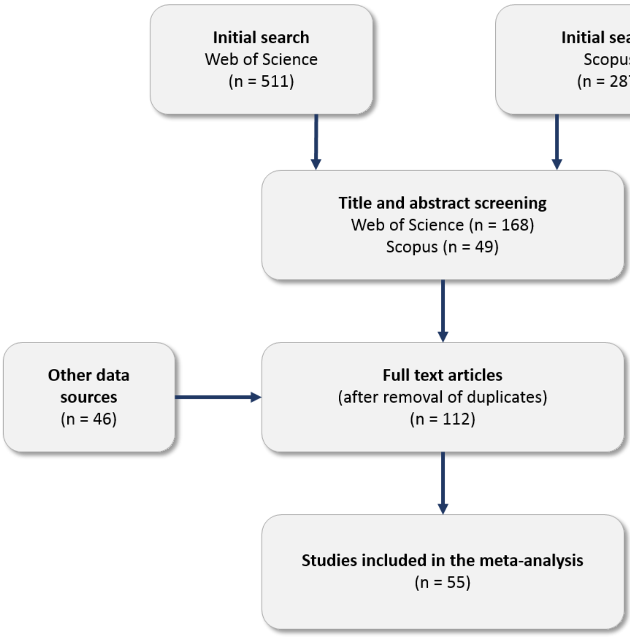


Figure 3: Flow chart over the selecting process of articles. The initial database searches gave 798 articles from web of science and 287 from Scopus. Other sources gave 46 articles, reports or similar. In the end, 55 sources were included in the meta-analysis.

3.1.1 Synthesis of the literature

All articles included analyzed the climate impact of fruit production using system boundaries from cradle to farm gate. Some articles included the nursery phase as well, and post-harvest activities, which emissions were added to the system boundaries if it took place on the farm.

Of the included articles, most LCA and CF studies followed the ISO-standardized guidelines (ISO, 2006; ISO, 2013) and in addition, PAS 2050, when conducting CF studies. Several LCA software programs and databases were used, and the most frequently used were SimaPro, PAS 2050, ReCipe and Ecoinvent. All studies used GWP index over 100 years, though only a few of the articles reported which version for GWP values that were used.

Apples

The systematic review resulted in 20 articles about apple production, of which 16 were peer-reviewed articles, two were conference reports and two were master theses. The articles were published between 2006- 2017. The production took place in 13 countries spread around the world (Sweden, Belgium, France, Italy, Portugal, Switzerland, Hungary, United Kingdom, China, Peru, New Zealand, United States and Canada).

Some of the studies account for the whole production lifetime (15-30 year), which means that both unproductive and productive years were included (Bartl *et al*. 2012; Tamburini *et al*. 2015; Alaphilippe *et al*. 2016; Basset-Mens *et al*. 2016; Goossens *et al*. 2017). In addition, some studies include the nursery phase and even the destruction phase, thus striving for a better understanding of apple productions climate impact, since yield has a major impact on calculated climate impact (Mouron *et al*. 2006; Cerutti *et al*. 2013; Alaphilippe *et al*. 2016; Basset-Mens *et al*. 2016; Goossens *et al*. 2017).

Pears

The review resulted in four articles about pears, of which three were peer-reviewed articles and one was a conference report. The articles originated from three countries (China, Italy and Portugal). The articles were published between 2010 and 2017.

Out of the four studies, only Tamburine *et al*. (2015) included unproductive and productive phases, with a 20-year orchard lifespan perspective. The two studies about pear production in China reported the use of cover bags to protect the product from e.g. birds (Liu *et al*. 2012; Yan *et al*. 2016).

Apricot

Apricot was represented by one peer-reviewed article from Italy, in which two integrated apricot orchards and one biodynamic orchard was studied (Pergola *et al*. 2017). According to Pergola *et al*. (2017), the integrated production method is the most common practice in Policoro municipality, southern Italy. Unlike the integrated production, the biodynamic production took place in greenhouses and used only organic fertilization and soil cover of nitrogen fixing plants.

The included phases were plantation, soil tillage, fertilization, pest control, irrigation, harvest and destruction. Further, manufacturing processes of all inputs were included and the apricot productions whole lifetime of 20 year was considered.

Peaches

The review resulted in seven articles on peach production, of which six were peer-reviewed articles and one a conference report. The articles represented five countries (Peru, Iran, China, Spain and France). The articles were published between 2012 and 2017.

In most of the studies the whole lifetime, 15-20 years, of an orchard was considered (Bartl *et al*. 2012; Basset-Mens *et al*. 2016; Vinyes *et al*. 2015 & 2017). This means that both unproductive and productive phases were included. The Basset-Mens *et al*. (2016) study also included the nursery phase. Protective cover bags in paper or plastic were included in the Yan *et al*. (2016) study. None of the other studies mentioned emissions from cover bags.

Grapes

All twelve articles about grape production were peer-reviewed and they represented five countries (United States, Canada, Spain, Italy and Cyprus). The articles were published between 2010 and 2017.

In five studies, the unproductive and productive phases were included, and an orchard lifespan of 20-100+ years was taken into consideration (Fusi *et al*. 2014; Aguilera *et al*. 2015; Steenwerth *et al*. 2015; Falcone *et al*. 2016; Meneses *et al*. 2016). Some studies also explored carbon stock changes as an output from grape production (Aguilera *et al*. 2015; Bartocci *et al*. 2017; Litskas *et al*. 2017).

Orange

The orange production was covered by five peer-reviewed articles, from three countries (Italy, Spain and China). The articles were published between 2012 and 2017.

Three studies considered an orchard lifespan of 50-100 years, thus including both unproductive and productive phases (Pergola *et al*. 2013; Aguilera *et al*. 2015; Ribal *et al*. 2017). The Yan *et al* (2016) study also included emissions from use and production of paper or plastic cover bags.

Small citrus

Three countries, Morocco, China and Peru, gave three peer-reviewed articles and one conference report. The articles were published between 2012 and 2017. All studies, besides Yue *et al* (2017), considered a whole orchard lifespan from 10-35 years (Bartl *et al*. 2012; Basset-Mens *et al*. 2016; Bessou *et al*. 2016)

Bananas

The banana production included six peer-reviewed articles and two reports originated from seven countries (Guatemala, Honduras, Panama, Costa Rica, Ecuador, Spain and China). One article represents banana production in four countries, Guatemala, Honduras, Panama and Costa Rica. The articles were published between 2010 and 2016. The two studies, Svanes *et al* (2013) and Aguilera *et al* (2015), both considered a whole lifespan of 10 years. The rest only calculated for one to five years of production.

Pineapple

The pineapple production was represented by three peer-reviewed articles, two reports and four countries (Colombia, Costa Rica, Ghana, Mauritius and Thailand). The articles were published between 2010 and 2017. All studies considered one fruit cycle, which takes 12-18 months (Usubharatana & Phungrassami, 2017).

Kiwi fruit

Five countries, Italy, Korea, New Zealand, Iran and Greece, all spread around the world gave five peer-reviewed articles, one report and one EPD. The articles were published between 2010 and 2017. The whole lifespan of the kiwi fruit plantation was only considered in the study by Baudino *et al* (2017).

3.2 Fresh fruit production

3.2.1 Meta-analysis

The climate impact of different fruit types ranged from 0.108-0.364 kg CO_2-eq/kg fresh fruit at farm gate. Apple production had the smallest impact on the climate (median = 0.108) and apricot production has the largest (median = 0.364). Table 4 shows the climate impact from the analyzed fruit types expressed as mean, median, minimum and maximum value, SD, SE, CI, Q_1 and Q_3. The results are also visualized in a box and whisker plot (Figure 4)

The climate impact per genus are presented in Table 5, and visualized in a box-plot (Figure 5). Altogether, there were eight genera, and they were *Malus*, *Pyrus, Prunus, Citrus*, *Vitis*, *Musa*, *Ananas* and *Actinida*. *Malus*, which only include apple, still had the smallest climate impact and the largest impact had genus *Musa*, which represent banana production.

Most of the fruit types and genus had outliers (Figures 4 and 5), which are the ones marked with a circle and with an asterisk, where the latter are called extreme outliers (IBM SPSS 24). Four types of fruit, i.e. apple, kiwi fruit, banana and grapes, showed extreme outliers. Out of them, the grape production showed the largest interquartile range (IQ). However, the pear productions had the largest IQ of all types of fruit. Orange had the smallest variation, though it only contained four production values. For *Prunus*, which included peach and apricot, there were no outliers anymore.

Tests of normality were performed for all sets of measurements and they showed that approximately half of them were normally distributed (Table 4 & 5). The result of the Levene's test of homogeneity of variance showed that the variance between the sets of measurements were to be considered equal F (10, 142) = 0.66, P = 0.76.

Table 4: The meta-analysis of fruit production, presented by type of fruit, by increasing climate impact. The system boundary was cradle to farm gate. Test of normality, values under significant level ($P \leq 0.05$) were not considered normally distributed. Apple had the smallest climate impact and apricot the largest, regarding median value. SD = Standard deviation, SE = Standard Error, CI = Confidence limit, lower and upper quartiles are values exceeded by 25% (Q_1) and 75% (Q_3).

GHG emissions: kg CO_2-eq /kg fresh fruit at the farm gate

Fruit	Cradle to farm gate										
	median	Q1	Q3	min/max	mean	SD	SE	CI 95% of mean	No. studies	No. GHG values	Test of normality
Apples	**0.108**	0.073	0.22	0.04-1.04	0.185	0.178	0.026	LB: 0.133 UB: 0.236	20	53	P = 0.000 (K-S)[b]
Oranges	**0.125**	0.06	0.137	0.04-0.14	0.11	0.046	0.023	LB: 0.035 UB: 0.18	3	4	P = 0.085 (S-W)
Orange & mandarin	**0.156**	0.154	0.273	0.10-0.31	0.181	0.09	0.045	LB: 0.037 UB: 0.325	2	4	P = 0.259 (S-W)
Peach	**0.177**	0.156	0.328	0.13-0.59	0.247	0.144	0.046	LB: 0.144 UB: 0.350	7	10	P = 0.034 (K-S)
Kiwi fruit	**0.19**	0.148	0.224	0.12-0.82	0.243	0.188	0.046	LB: 0.146 UB: 0.339	7	17	P = 0.000 (K-S)
Grapes	**0.2**	0.156	0.335	0.07-0.85	0.27	0.173	0.028	LB: 0.211 UB: 0.327	12	37	P = 0.009 (K-S)
Pineapples	**0.211**	0.165	0.32	0.06-0.41	0.229	0.111	0.042	LB: 0.127 UB: 0.332	5	7	P = 0.200 (K-S)
Pears	**0.225**	0.134	0.354	0.06-0.38	0.229	0.118	0.042	LB: 0.130 UB: 0.328	4	8	P = 0.200 (K-S)
Bananas	**0.275**	0.249	0.328	0.05-0.64	0.294	0.128	0.035	LB: 0.217 UB: 0.372	8	13	P = 0.038 (K-S)
Small citrus [a]	**0.329**	0.255	0.478	0.20-0.66	0.367	0.151	0.051	LB: 0.251 UB: 0.484	5	9	P = 0.131 (K-S)
Apricots	**0.364**	0.262	-	0.26-0.42	0.349	0.081	0.047	LB: 0.148 UB: 0.550	1	3	P = 0.699 (S-W)[c]

[a] Tangerines, mandarins, Citrange Troyer and Sidi Aissa. [b] K-S (Kolmogorov-Smirnov). [c] S-W (Shapiro-Wilk)

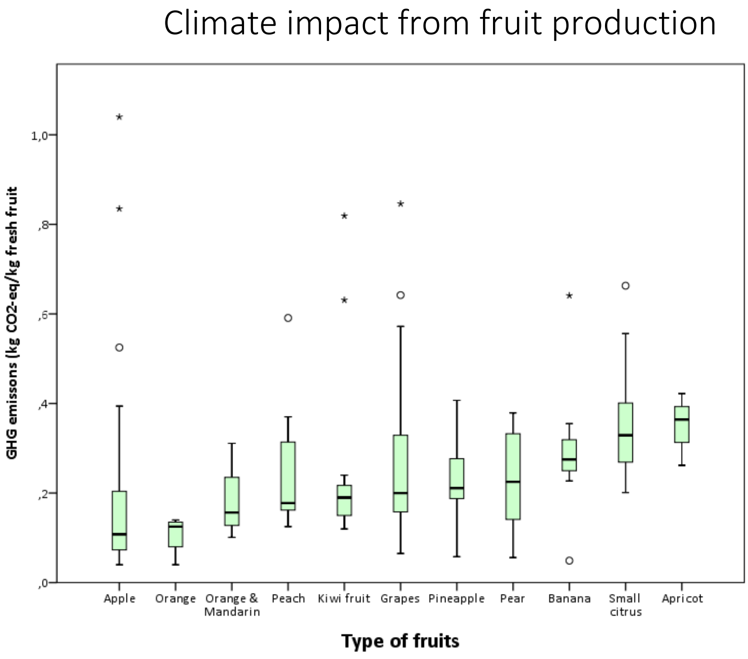


*Figure 4: A box-plot of the climate impact from different fruits included in this thesis. Apple production had the smallest impact; however, there were three outliers (o and *), which of two were extreme outliers (*). Kiwi fruit production, banana production and grape production also had extreme outliers. Apricot production had the largest climate impact of all included fruits.*

Table 5: The meta-analysis of fruit production presented by genus. The system boundary was cradle to farm gate. Test of normality, all values under significant level ($P < 0.05$) are divided from normal distribution. Malus had the smallest climate impact and Musa the largest, regarding median value. SD = Standard deviation, SE = Standard Error, CI = Confidence limit, lower and upper quartiles are values exceeded by 25% (Q_1) and 75% (Q_3).

GHG emissions (kg CO_2-eq /kg fresh fruit)

Genus	Cradle to farm gate										
	median	Q1	Q3	min/max	mean	SD	SE	CI 95% of mean	No. studies	No. GHG values	Test of normality
Malus	**0.108**	0.073	0.22	0.04-1.04	0.185	0.178	0.026	LB: 0.133 UB: 0.236	20	53	P = 0.000 (K-S)[b]
Actinida	**0.19**	0.148	0.224	0.12-0.82	0.243	0.188	0.046	LB: 0.146 UB: 0.339	7	17	P = 0.000 (K-S)
Vitis	**0.2**	0.156	0.335	0.07-0.85	0.27	0.173	0.028	LB: 0.211 UB: 0.327	12	37	P = 0.009 (K-S)
Ananas	**0.211**	0.165	0.32	0.06-0.41	0.229	0.111	0.042	LB: 0.127 UB: 0.332	5	7	P = 0.200 (K-S)
Pyrus	**0.225**	0.134	0.354	0.06-0.38	0.229	0.118	0.042	LB: 0.130 UB: 0.328	4	8	P = 0.200 (K-S)
Citrus	**0.24**	0.135	0.334	0.04-0.66	0.263	0.165	0.04	LB: 0.178 UB: 0.347	10	17	P = 0.200 (K-S)
Prunus	**0.25**	0.166	0.367	0.13-0.59	0.271	0.137	0.038	LB: 0.188 UB: 0.354	8	13	P = 0.153 (K-S)
Musa	**0.275**	0.249	0.328	0.05-0.64	0.294	0.128	0.035	LB: 0.217 UB: 0.372	8	13	P = 0.038 (K-S)

[a] K-S (Kolmogorov-Smirnov)

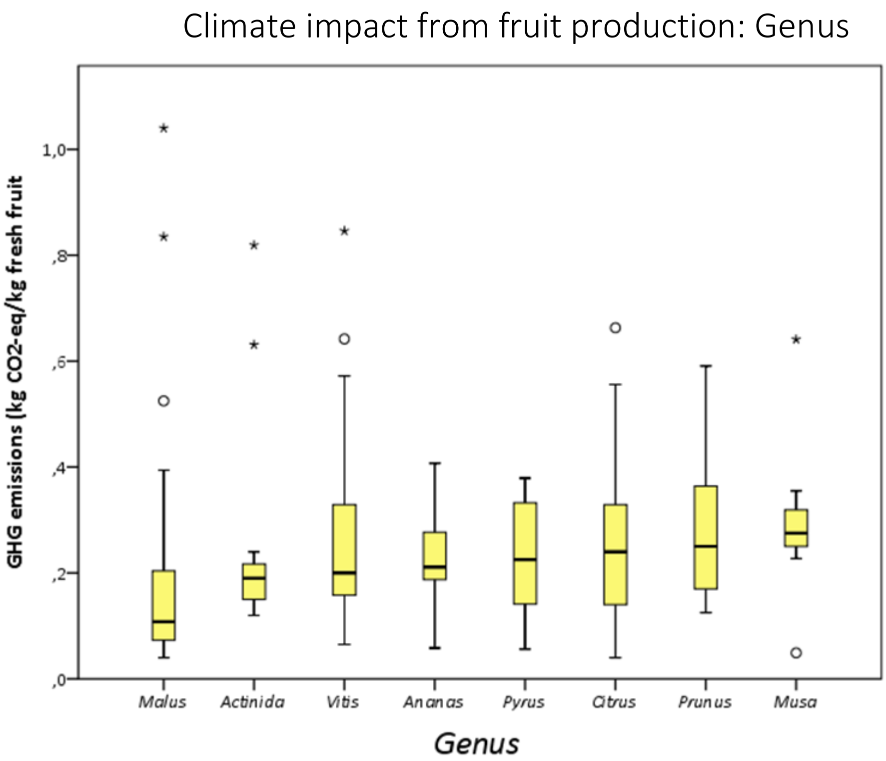


*Figure 5: A box-plot of climate impact from fruit production. The included fruits divided into genera. When the fruits were grouped, the largest climate impact came from Musa. o = outliers and * = extreme outliers.*

3.2.2 Statistical tests: climate impact from fruit production

The knowledge about the distribution and variance of the sets of measurements led to the use of the non-parametric Kruskal-Wallis test for exploring the differences between the median values.

The first research question explores the potential differences between the GHG emissions from the studied fruit types. The result from the Kruskal-Wallis test between all fruit types showed that their median scores were significantly different from each other (χ^2 = 37.4 *P* = 0.000 df = 10 n = 166). The *P*-value was less then <0.05, which means that the climate impact from the analyzed fruit types significantly differed from each other.

A Kruskal-Wallis test between the different fruit genera also showed a significantly difference between the median scores (χ^2 = 23.9 *P* = 0.001 df = 7 n = 166).

Post Hoc test: Mann-Whitney U test

A Mann-Whitney *U* test was performed with apple production as baseline, which showed that the GHG emissions in apple production were significantly different from GHG emissions in production of peach, kiwi fruit, grapes, banana, small citrus and apricot.

The climate impact from apple production and from apricot production was the smallest and the largest, and accordingly to the *U* test there were a significant different between them (*U* = 20, *P* = 0.03, n = 56). When comparing apple production with pear production the test showed no difference between them (*U* = 143, *P* = 0.140, n = 61). However, when comparing apple production with banana production there was a significant difference between their climate impact (*U* = 158.5, *P* = 0.003, n = 66).

Table 6: Mann-Whitney U test was used as post hoc test, with apple as a baseline. The results show that there were significant differences between apple; and peach, apricot, kiwi fruit, banana, small citrus and grapes.

Post Hoc test: Multiple comparisons

Fruits		P-value (<0.05)	U-value	n
Apple (baseline)	Orange	0.563	87.5	57
	Orange & mandarin	0.408	79.5	57
	Pear	0.140	143	61
	Pineapple	0.126	119	60
	Peach	**0.037**	154	63
	Apricot	**0.030**	20	56
	Kiwi fruit	**0.017**	277	70
	Banana	**0.003**	158.5	66
	Small citrus	**0.001**	67.5	62
	Grapes	**0.001**	567	90

The Mann-Whitney *U* test was also used to investigating which of the genus medians that was set apart from each other (Table 7). Comparing *Prunus* with *Malus* (*U* = 174, *P* = 0.006, n = 66) the difference between their median scores was more significant, than the *U* test between apricot and apple. A test between *Malus* and *Citrus* also showed a significant difference (U = 271.5, P = 0.014, n = 70). However, when comparing the median scores of *Prunus* and *Citrus* there was no difference between them (U = 97, P = 0.572, n = 30).

Table 7: Mann-Whitney U test was used as post hoc test, with Malus as a baseline. The results show that there were significant differences between Malus; and Actinida, Citrus, Prunus, Musa and Vitis.

Post Hoc test: Multiple comparisons				
Genus		P-value (<0.05)	U-value	n
Malus (baseline)	*Pyrus*	0.160	114	50
	Ananas	0.130	94	49
	Actinida	**0.022**	220	59
	Citrus	**0.014**	271.5	70
	Prunus	**0.006**	174	66
	Musa	**0.005**	116	54
	Vitis	**0.001**	453	79

3.2.3 Hotspots in fruit production

Several of the studies reported hotspots within the fruit production, cradle-farm gate, which was expressed as the percentage of the total GHG emissions coming from specific phases in production.

In Table 8, the mean percentages for the different hotspot categories are visualized, and a minimum level was set to 20% of the productions total GHG emissions value. The data was divided into three intervals, the first from 20≤39% (yellow), the second from 40≤59% (pink) and the third 60%≤ (dark orange). The results are divided by the different fruit types and production methods, i.e. conventional (con), integrated (IP) and organic (org).

The division of the climate burden between the different hotspot categories were not always performed the same in the different studies, some included irrigation in the energy category and the N_2O in fertilization. This means that the result in Table 8 should be regarded as a means to recognize patterns, and not as decisive results.

Fertilization, including production and use, was identified as an extreme hotspot for GHG emissions in fruit production, especially from conventional fruit production. Fertilization was for all the studied fruit types a hotspot. The energy category was also a hotspot, especially in organic grape production.

Irrigation and pest control both contributed with GHG emissions ranging from 21% to 42% of the total climate impact from fruit production up to farm gate. Emissions of N_2O ranged from 26% to 40%, all production methods included.

Table 8: The table shows the mean percentage of reported hotspots in the fruit production divided by fruit type, production method and process categories. Only hotspots from 20% of total GHG value were included. They are color coordinated and yellow represent values between 20<39, pink 40<59 and dark orange 60≤. In gray scale, from light to dark.

Hotspots within fruit production (mean percentage)

	Energy			Fertilization			Pest control			Irrigation			Harvest and packing on site			N_2O emissions		
	Con	IP	Org	Con	IP	Org	Con	IP	Org	Con	IP	Org	Con	IP	Org	Con	IP	Org
Apple	53	58	38	33	32	31				21								26
Oranges			44	53		54				22		42				26		30
Peach				44	69		22	21		29								
Kiwi fruit	29	21	24	37	51	49										29	25	30
Grapes	43		78	37					41									
Pear			51	28								33						
Pineapple	30			62													40	
Banana				70			36			23			30					
Small citrus				60			24			33								
Apricot					29						21	35						

Apple and pear

The two categories, energy and fertilization, represented the main hotspots for apple production, which embraced all three production methods. Emissions of N_2O from organic apple production were the third largest hotspot. The organic pear production had hotspots from the energy category and irrigation. The fertilization category resulted in hotspots for conventional pear production.

Banana, pineapple and kiwi fruit

The articles about banana production focused on reporting the levels of GHG emissions from fertilization, pest control, irrigation, harvest and post-harvest. All the proceedings after the harvest were handled on the farm; hence, it was included within the system boundaries for banana production. The harvest hotspot in banana production was relatively large, in fact the hotspots from fertilization was in fact the highest GHG emission value of all the studied fruit types. However, it was closely followed by the pineapple production, which had large GHG emissions from energy and from N_2O. Similar results from kiwi fruit production.

Grapes

The organic grape production showed extreme GHG emissions from the energy category, followed by large GHG emissions from pest control. The conventional grape productions main hotspots were from energy and fertilization.

Apricot, peach, small citrus and oranges

Apricot, peach, small citrus and orange production all had large hotspots from the irrigation category and from fertilization. The orange production also had large emissions of N_2O and from energy.

3.3 Production countries and continents

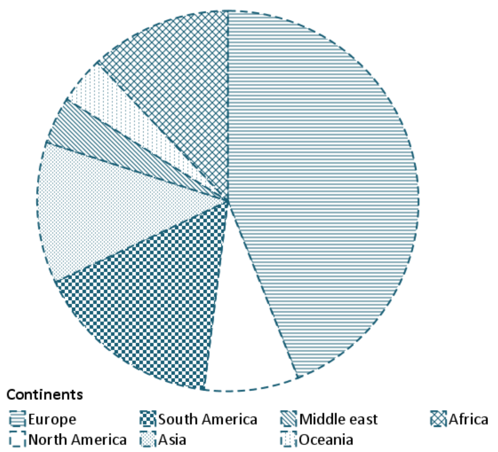
The selected articles represented fruit production in 28 countries from all continents except Antarctica. Most articles reported on production in European countries, followed by South America (Figure 6).

The number of studies and GHG emission data were highest for European countries, with 33 studies resulting in 85 individual data on GHG emissions (Table 9). Many of the articles addressed more than one production country, which means that one article could represent data on GHG emissions for different countries and for different types of fruit.

Table 9: The production countries divide into continents. Number of studies and GHG values per continent. Europe has the highest number of countries, studies and GHG-values.

Continent	Countries	No. of studies	No. of GHG-values
Asia	China, Korea and Thailand, Iran	7	19
Africa	Ghana, Mauritius and Morocco	4	8
Europe	Belgium, Cyprus, France, Greece, Hungary, Italy, Portugal, Spain, Sweden, Switzerland and United Kingdom	33	85
North America	Canada, United States of America	5	21
Oceania	New Zealand	5	14
South America	Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Panama and Peru	8	15
Global		1	4

Figure 6: A summary of countries included in this thesis divided by continents. Most articles are about fruit production in Europe.



3.3.1 Statistical tests: climate impact between production countries and between continents

The result from the Kruskal-Wallis showed that there were no significant differences between the median values for anyone of the fruit types (Table 10). This means that the production countries of individual fruit types had no significant difference between them.

Apricot and the group of oranges and mandarin were only represented by one production country, so no statistical test could be executed. The statistical test for apple production included

15 countries and 53 GHG emission values. The grape production was only represented by five countries; however, they reported 37 data points on GHG emissions.

Table 10: Kruskal-Wallis test was used to test differences in climate impact between different production countries of individually types of fruit. There was no significant difference between the productions countries for none of the tested types of fruit.

Differences in GHG emissions between production countries				
Fruit	χ^2	*P* – value (<0.05)	n country/ region	n
Grapes	8.38	0.079	5	37
Apples	17.58	0.23	15	53
Peaches	6.08	0.3	7	10
Small citrus	2.29	0.32	3	9
Kiwi fruit	4.59	0.33	5	17
Pears	2.08	0.35	3	8
Pineapples	4.29	0.37	6	7
Oranges	1.8	0.41	3	4
Bananas	1.47	0.92	8	12
Apricots			1	
Oranges & mandarin			1	

In contrast to the result from individual fruit types, the test between all types of fruit and all production countries showed a significant difference in climate impact (χ^2 = 57.8, *P* = 0.000, n = 165). Grouped into continents the result showed again a significant difference between the climate impact (χ^2 = 20.1, *P* = 0.003, n = 165).

Table 11: Several Mann-Whitney U test were used as post hoc test, with Europe as a baseline. The results show that there were differences between Europe; and Africa, South America and Asia.

Post Hoc test: Multiple comparisons				
Continent	P-value (<0.05)	U-value	n	kg CO_2-eq/kg fruit (median)
Europe (baseline)				0.15
Africa	0.004	132.5	93	0.33
South America	0.004	307	99	0.32
Asia	0.041	564.5	104	0.24
North America	0.132	702.5	106	0.19
Oceania	0.764	565	99	0.19

Post hoc test with Europe as baseline, showed that Europe's climate impact significantly differed from Asia, Africa and South America (*P* = 0.041, *P* = 0.004 and *P* = 0.004) (Table 11). Of the six continents, Europe had the smallest climate impact (0.15 kg CO_2-eq/kg fruit) and Africa had the largest (0.33 kg CO_2-eq/kg fruit).

3.4 Production methods

The studies reported mainly three different production methods i.e. conventional, integrated and organic production. The majority of the studies used a conventional production method (Figure 7), followed by organic production. All the three production methods were represented for cultivation of apples, grapes and kiwi fruit, although the most commonly used method was conventional production.

3.4.1 Statistical tests: climate impact from production methods

The Kruskal-Wallis test showed a significant difference between methods when all types of fruit were included ($\chi^2 = 15.2$, $P = 0.000$, n (con) = 108, n (IP) = 22, n (org) = 35).

Several statistical tests for each type of fruit were performed to analyze whether there was any difference in climate impact between the production methods (Table 11).

The Kruskal-Wallis test was used again, and it showed that there was a significant difference in GHG emissions between median values for apple production methods ($\chi^2 = 13.4$, $P = 0.001$, n = 53). The median values from apple production showed that the smallest climate impact came from integrated production (median = 0.066 kg CO_2-eq/kg apples), followed by conventional production (median = 0.11 kg CO_2-eq/kg apples), and the largest climate impact from the organic production (median = 0.27 kg CO_2-eq/kg apples).

The banana production included conventional and organic production methods, and the difference in GHG emissions between them was close to the significance level of 0.05 ($\chi^2 = 3.74$, $P = 0.053$, n = 12). The median values showed that the organic production (median = 0.15 kg CO_2-eq/kg bananas) had the smallest climate impact, and conventional production method (median = 0.3 kg CO_2-eq/kg bananas) was twice as large as the organic.

The grape production methods were also near a significant difference ($\chi^2 = 5.8$, $P = 0.055$, n = 37). The integrated production had the smallest climate impact (median = 0.11 kg CO_2-eq/kg grapes), and the organic productions was just a little bit larger (median = 0.17 kg CO_2-eq/kg grapes). The conventional grape production (median = 0.24 kg CO_2-eq/kg grapes) was more than twice as large as the integrated production.

For cultivation of small citrus and pineapple, the included articles only studied conventional production methods; hence, no statistical tests were performed.

Table 12: The results from the Kruskal-Wallis tests of difference between the three production methods, i.e. conventional, integrated and organic. Apple production had significant difference between the production methods. System boundaries: cradle to farm gate

Differences in GHG emissions between production methods

Fruit	χ^2	*P* - value	n	n (method)		
				Con	IP	Org
Apples	13.4	0.001	53	26	12	15
Bananas	3.74	0.053	12	10	-	2
Grapes	5.8	0.055	37	28	2	7
Peaches	3.15	0.076	10	5	5	-
Kiwi fruit	4.22	0.12	17	13	1	3
Oranges & mandarin	2.4	0.12	4	2	-	2
Orange	1.8	0.18	4	3	-	1
Apricots	1.5	0.22	3	-	2	1
Pears	0.33	0.56	8	4	-	4
Pineapples				7	-	-
Small citrus				9	-	-

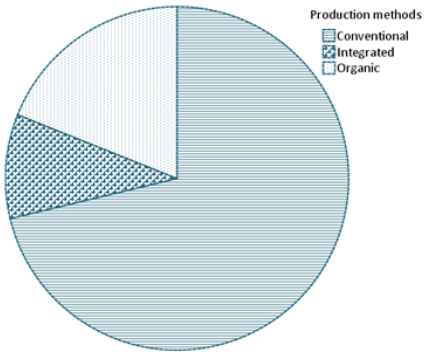


Figure 7: The division of production methods included in this thesis. The conventional production method was over represented.

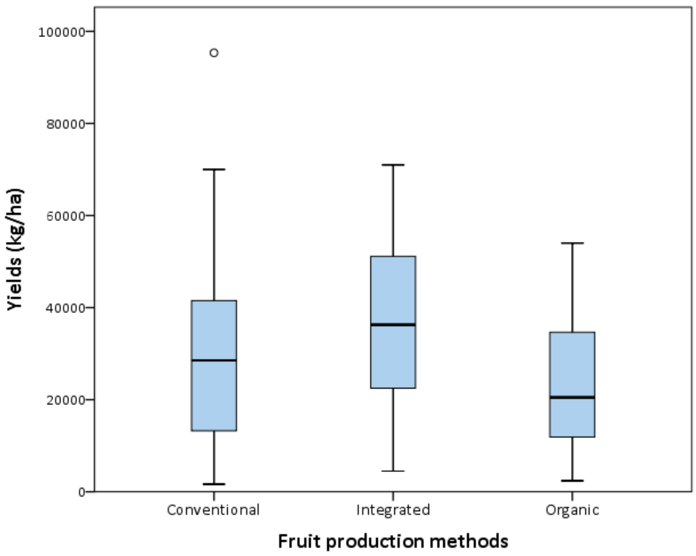


Figure 8: Average yields from conventional, integrated and organic production methods. The integrated production has the highest average yield. The conventional production has an outlier.

According to the Spearman rank correlation test there were a significant association between yields and GHG emissions (r_s = -0.306 *P* = 0.001 n = 119 (yields) n = 165 (GHG)).

There were a significant difference in yields between countries (χ^2 = 50.7, *P* = 0.000, n = 119) and between continents (χ^2 = 19.2, *P* = 0.002, n = 119).

There was a significant differences in yields between production methods (χ^2 = 6.4, *P* = 0.040, n (con) = 72, n (IP) = 19 and n (org) = 28), which yields were largest for integrated production (38227 kg/ha), followed by conventional production (29976 kg/ha), and the smallest average yields came from organic production (23396 kg/ha) (Figure 8). The rates between organic production yields and the other methods were 78% of the conventional production yields, and 61% of the integrated production yields.

When the yields from the different apple productions methods were compared, the result showed that there were significant differences between them ($\chi^2 = 7.64$, $P = 0.022$, $n = 47$). The integrated production method had the largest average yield, 52742 kg/ha, followed by the conventional production with an average yield of 37168 kg/ha. The yield from the organic production was only 27919 kg/ha.

4 Discussion

4.1 Differences in climate impact from fruits

The first research question explored the possibility that there were differences between the fruit types climate impact. The statistical test showed that the difference was significant. The meta-analysis showed that the largest climate impact from fruit production came from apricot production (0.36 kg CO_2-eq/kg apricots) and the smallest from apple production (0.11 kg CO_2-eq/kg apples). Other types of fruit with small climate impacts were orange and mandarin production (0.13 kg CO_2-eq/kg orange and 0.16 kg CO_2-eq/kg orange & mandarin), while the production of small citrus was almost as large as the apricots climate impact (0.33 kg CO_2-eq/kg small citrus). The climate impact from apple production was significantly smaller than from peaches, kiwi fruit, grapes, banana, small citrus and apricots.

When the different fruit types were divided into genera, the two genera that included more than one type of fruit were *Citrus* and *Prunus*. Genus *Malus* which only included apples still had the lowest climate impact (0.11 kg CO_2-eq/kg *Malus*), however the largest impact shifted to *Musa*, which include bananas (0.28 kg CO_2-eq/kg *Musa*). With *Malus* as baseline, the post hoc tests showed a difference between *Malus* and *Citrus*, which was only the case with small Citrus. *Malus* was also significant different from *Prunus* (P = 0.006), which also became more significant when grouped into genus. This implies that the difference becomes clearer when divided into different genus, and more data points were added to the data set.

There were large variations among the median values of the different fruit types, which most likely is the result of including all types of production methods in the same value. In Johansson (2015) thesis about apple production the organic productions climate impact was 1.04 kg CO_2-eq/kg apples, which was the largest climate impact for all apple values included in this thesis. It is more than nine times higher than the median value for apple production in this thesis.

Comparing apricot production, which had the largest climate impact, with other food products, such as tomatoes produced in heated greenhouse, the systematic review from Clune *et al*. (2017) showed that apricots climate impact was about five times less (Clune *et al*. 2017). The apple production in that review was almost eight times less than the greenhouse grown tomatoes (Clune *et al*. 2017). A direct comparison between this thesis and the Clune *et al*. (2017) review were not possible since the system boundaries were different.

When exploring climate impact from cradle to farm gate the result shows that, the overall impact is relatively small for all of the included fruit types. Hence, fruit is a climate smart nutritious option that is regarded as a healthy food choice by the Swedish National Food Agency (2017), who recommends eating 500g of fruit and vegetables every day. Recommendations of climate smart and nutritious fruit alternatives can be made by examining the nutritive values of the different types of fruit and pair it to their climate impact.

4.2 Exploring hotspots in fruit production

The categories fertilization and energy (use and production) were clearly that the largest climate impact hotspots up to farm gate. In apple production, the energy category was the main hotspot for all the three production methods. The apricot production reported hotspots from integrated and organic production, which were fertilization and irrigation and they were all of similar magnitude. Conventional production of bananas, pineapples and small citrus all had extreme hotspots from fertilization. The main hotspot in production of organic grapes were energy (fuel and electricity), which was the largest hotspot of all hotspot categories and fruits.

There is room for improvements even though the climate impact from fresh fruit production is relatively small. To begin with, more strategic decisions about fertilization type, plant requirement and timing. Renewable energy such as solar power and wind power could be produced on site, to facilitate for instance irrigation systems, platform lifts at harvest, machinery for pruning and so on. Fuel efficient machinery, with all operations planned and regulated, would help to mitigate the climate impact from fruit production since energy is a major hotspot.

A review by Bessou *et* al. (2013) also recognized that the production and use of fertilizers represent a major hotspot in perennial crop production. Over time inputs of synthetic compounds within agriculture has become routine instead of applied when needed (Purvis & Smith, 2006).

Another issue is allocation of climate burden to activities outside of system boundary. Some allocated large part of the burden from manure to livestock (Goossens *et al*. 2017); however most include it within the system boundary. This will of course effect the GHG emission value that is connected to a specific type of fruit, production method and production country. Johansson (2015) reported that the organic apple production had a large emission of N_2O, due to manure. If the N_2O emission from the manure were allocated to livestock, the climate impact would decrease a lot. Hotspots of emissions from N_2O were reported separately from other fertilization related emissions in some studies (Brenton, 2010; Page *et* al. 2011; Ingwersen, 2012; Aguilera *et al*. 2015; Johansson, 2015, Litskas *et al*. 2017).

4.3 Fruit producing countries, production methods and yields

Twenty-eight countries spread around the world were included in this the meta-analysis of fresh fruit. All the types of fruit were separately tested for differences between production countries, and the result showed that there was no significant difference between the individual fruit types. However, when including GHG emissions from phases beyond farm gate, such as different means of transport, travel distance and production methods the result may differ between production locations.

Climate impact between production country and continent showed a significant difference when all types of fruit and production method were included. The average climate impact from fruit production per continent was smallest in Europe (0.15 kg CO_2-eq/kg fresh fruit) and the climate impact was largest in Africa (0.33 kg CO_2-eq/kg fresh fruit). Both pineapple and small citrus had large climate impact, and they were both produced in Africa. Apples, which had a small climate impact, were produced largely in European countries.

The difference is not between the production countries of a specific type of fruit, the difference has to do with which type of fruit that is produced. This indicate that locally produced fruit would be a climate smart alternative, if the production is well adapted to the local climate. No types of fruit are optimal for all types of climates and other environmental conditions.

From an environmental perspective, it is of interest to examine whether there is a difference in climate impact between production methods. The tests showed that there was a significant difference between production methods of apples. The apple production were represented by the three cultivation methods included in this thesis (conventional, integrated and organic), and the median GHG emissions values showed that the integrated production (median = 0.066 kg CO_2-eq/kg apples) had the smallest climate impact, and the organic production (median = 0.27 kg CO_2-eq/kg apples) had the largest.

The banana production in this thesis represent two production methods, i.e. conventional and organic, and the result was nearly significant (P = 0.053). If more studies were included, it may led to a significant difference between conventional and organic method. The organic banana production in Spain was only 0.049 kg CO_2-eq/kg banana according to Aguilera *et al*. (2015), which was 0.2 kg CO_2-eq/kg less than the climate impact reported by Roibas *et al*. (2015) about organic banana production in Ecuador.

A test between all fruit types and the three production methods resulted in a significant difference between them (χ^2 = 15.2, P = 0.000). Examining the average climate impact from the different methods, showed that the integrated production method had the smallest impact (median = 0.12 kg CO_2-eq/kg fresh fruit, n = 22). The conventional and organic production methods both had about the same climate impact, which were 0.21 and 0.2 kg CO_2-eq/kg fresh fruit. The integrated production method was used for five types of fruits in this thesis, i.e. apples, grapes, apricots, peaches and kiwi fruits, and for all of them the integrated production method had the smallest climate impact.

The climate impact in this thesis was mass-based, which is yield sensitive. Studies has showed that the magnitude of the effect shift when the climate impact is considered per yield (Cerutti *et al*. 2013; Müller *et al*. 2015; Ribal *et al*. 2017), so if only one production year is studied with a mass-based FU the result may be misleading (Vinyes *et al*. 2015).

When the yield is low, which occurs in organic production and in the unproductive phases, the climate impact rises when mass unit is used (Goossens *et al*. 2017; Ribal *et al*. 2017). This is why the climate impact often is larger for organic production than for conventional production (Keyes *et al*. 2015; Goossens *et al*. 2017).

The climate impact increased when the yield decreased, which may explain why the integrated production method in general had the smallest climate impact, since it had the largest yields (38227 kg/ha).

The yield from organic production method was only 61% of the integrated production methods yields. Analyzing yields from apple production also shows that the integrated production method had the largest average yields, and that the differences between the methods were significant (P = 0.022).

If the climate impact is considered per ha, instead of mass, the climate impact of the organic production is mostly less than that of the conventional production (Keyes *et al*. 2015). However, the integrated production method also practices sustainably agriculture, and when analyzed with a mass-based unit it both shows the largest average yield and the smallest climate impact (EISA, 2012).

4.4 Beyond farm gate

This thesis focused on the climate impact from GHG emission up to farm gate. However, in this section the activities after farm gate will be explored. Post farm gate activities are packing and storage, transportation, distribution centers (DC), ripening centers, retail, consumption and disposal.

To preserve the fruits over long periods of time cold storage is used, which can proceed up to 12 months (Johansson, 2015). The contribution to the climate impact comes from large inputs of energy, though the GHG emissions were lower when stored for 12 months (0.273 kg CO_2-eq/kg apples) in Sweden than it was for the same product when transported from Argentina to Helsingborg (0.296 kg CO_2-eq/kg apples) (Johansson, 2015).

Svanes & Aronsson (2013) reported that transportation of bananas from Costa Rica to Norway represented 67% of the total GHG emission value. The GHG emissions from transportation of bananas from Ecuador to Germany doubled the climate burden according to Iriarte *et al*. (2014). Keyes *et al*. (2015) compared apple transport using trucks and using freight rail. The GHG emissions from using trucks increased the climate impact with more than 40%, which was only an increase of 16% when using freight rail (Keyes *et al*. 2015).

In 2013, the Swedish banana import was 181308 tones, which were almost 100000 more than for any of the other types of fruit (FAOSTAT, 2017). The imported bananas mainly came from Ecuador and Costa Rica (FAOSTAT, 2017), and the GHG emissions reported in this thesis were between 0.291-0.335 kg CO_2-eq/kg banana (Ecuador) and 0.227-0.319 kg CO_2-eq/kg banana (Costa Rica) (Luske, 2010; Svanes & Aronsson, 2013; Iriarte *et al*. 2014; Roibas *et* al. 2015).

The Swedish consumption, in 2015, of fresh apples and pears were 13.4 kg/capita/yr., which showed a decline from 15 kg/capita/yr. in 1990 (Swedish Board of Agriculture, 2017). The consumption of citrus fruits and grapes had instead increased from 16.9 to 20.2 kg/capita/yr. (Swedish Board of Agriculture, 2017). This means that an average Swedish consumer contributes with more than 10 kg CO_2-eq per year from eating citrus fruit and grapes. If one instead chooses to eat apples and pears, the amount of GHG emissions will be 5.5 kg CO_2-eq per year, which is almost a 50% decrease.

Eriksson & Spångberg (2017) explored different end of life situations for fruit, with the scenarios incineration, anaerobic digestion, conversion and donation. The three latter lowered the total emission value.

4.5 Strengths and limitations

Conducting a systematic review brings together results from many studies and provides transparency to the working process, by reporting every step of the process, which make it replicable. There were 55 studies included in this systematic review, which contributed with many data points, especially for apple production and grape production. Nearly all studies followed the same ISO standard for that specific method, which mainly is the same for LCA and CF, and the recommendations of IPCC regarding GHG emissions.

In the search for adequate fruit studies, one thing was made clear; some fruits are more popular than others are. Studies about production of apples and grapes were easily found as stated, though not studies about apricot and pear production. Most studies explored conventional production (Table 11). Even though there were studies from all continents, except Antarctica, many of them were from Europe, which gives a geographical bias.

The data points were not normally distributed, which increase the uncertainty of the result. One reason could be the use of different allocation procedures. Unfortunately, not all studies reported how the climate burden was divided between the different cultivation phases.

This thesis only explored the climate impact with a mass-based FU, and as stated an area-bases FU would give other results, since the latter is not yield sensitive. It was also limited to explore the climate impact of fruit production, which will not give the whole picture of the environmental impact, such as acidification and eutrophication.

5 Conclusions

Fresh fruit productions have generally a small climate impact, which was smallest for apple production. There were differences in climate impact between different types of fruit, and apple productions climate impact differed from peach, apricot, kiwi fruit, banana, small citrus and grapes. Of them, apricot had the largest climate impact, and when grouped into genus, *musa* (banana) had the largest climate impact.

There were no differences in climate impacts between production countries for single fruits. However, there were differences between production countries and continents when all fruit types were included. The result from this data indicates that locally produced food is to be preferred, under the condition that the production is adapted to the local climate.

The inputs and processes of fruit production have different magnitude of climate impact. Fertilization and energy, which both include production and use phase, were the major climate impact hotspots in fruit production. There is a need of strategic decisions and restricted use of fertilization and energy, which should be renewable, in order to mitigate these processes.

There was a significant difference in climate impact between production methods and the climate impact from integrated production method was smallest. However, when tested between single fruits only apple production showed a difference. If more data points on different methods had been, available maybe the result had been different for the other fruits. The average yield was largest from integrated production when all fruits were included and from integrated apple production.

I conclude that integrated fruit production is to be preferred, since the climate impact is the smallest and yields the largest. The integrated production method follows distinctive rules about fertilization, energy use, pest control and more in order to reduce environmental impacts.

I also conclude that apples are the best choice from a global warming perspective, and they should be produced with an integrated production method.

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Appendix I: The studies and data included in the meta-analysis

The included studies and GHG emission values

System boundary: Cradle to farm gate

GWP 100 year

Type of fruit	GHG Kg CO2-eq/kg fresh fruit	Yield Kg/ha/yr	Country	Production method and/or place and/or fruit name	Assessment method, software, databases	Type of article	References
Apple	0.090	55400	France	Intensive Unproductive stages: nursery, orchard creation, orchard establishment, orchard destruction	LCA method SimaPro V7.3.3 Ecoinvent V.2.2 Recipe method. GWP 100 (IPCC, AR4)	Peer-reviewed	Alaphilippe, A., Boissy, J., Simon, S., Godard, C. (2016). Environmental impact of intensive versus semi-extensive apple orchards: use of a specific methodological framework for Life Cycle Assessments (LCA) in perennial crops. Journal of Cleaner Production, 127, pp. 555-561. doi.org/10.1016/j.jclepro.2016.04.03
Apple	0.076	55400	France	Intensive Productive years	LCA method SimaPro V7.3.3 Ecoinvent V.2.2 Recipe method. GWP 100 (IPCC, AR4)	Peer-reviewed	Alaphilippe, A., Boissy, J., Simon, S., Godard, C. (2016). Environmental impact of intensive versus semi-extensive apple orchards: use of a specific methodological framework for Life Cycle Assessments (LCA) in perennial crops. Journal of Cleaner Production, 127, pp. 555-561. doi.org/10.1016/j.jclepro.2016.04.03
Apple	0.075	37800	France	Semi-extensive Unproductive stages: nursery, orchard creation, orchard establishment, orchard destruction)	LCA method SimaPro V7.3.3 Ecoinvent V.2.2 Recipe method. GWP 100 (IPCC, AR4)	Peer-reviewed	Alaphilippe, A., Boissy, J., Simon, S., Godard, C. (2016). Environmental impact of intensive versus semi-extensive apple orchards: use of a specific methodological framework for Life Cycle Assessments (LCA) in perennial crops. Journal of Cleaner Production, 127, pp. 555-561. doi.org/10.1016/j.jclepro.2016.04.03
Apple	0.068	37800	France	Semi-extensive Productive years	LCA method SimaPro V7.3.3 Ecoinvent V.2.2 Recipe method. GWP 100 (IPCC, AR4)	Peer-reviewed	Alaphilippe, A., Boissy, J., Simon, S., Godard, C. (2016). Environmental impact of intensive versus semi-extensive apple orchards: use of a specific methodological framework for Life Cycle Assessments (LCA) in perennial crops. Journal of Cleaner Production, 127, pp. 555-561. doi.org/10.1016/j.jclepro.2016.04.03
Apple	0.381	13130	Peru	Extensive	ISO, 2006 SimaPro 7.3.0 ReCiPe v1.05 GWP 100 (IPCC, AR4)	Peer-reviewed	Bartl, K., Verones, F., and Hellweg, S. (2012). Life Cycle Assessment Based Evaluation of Regional Impacts from Agricultural Production at the Peruvian Coast. Environmental, Science and Technology, 46, pp. 9872–9880. doi.org/10.1021/es301644y
Apple	0.0678	53700	France		ISO, 2006. SimaPro Agribalyse (ReCip-Pe) Ecoinvent v.2 CML 2001 GWP 100 (IPCC, AR4)	Conference Report	Basset-Mens, C., Vannière, H., Grasselly, D., Heitz, H., Braun, A., Payen, S., Koch, P. (2016). Environmental impacts of imported versus locally-grown fruits for the French market as part of the AGRIBALYSE® program. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector.

Apple	0.065	68000	New Zealand	Integrated Central Otago 1	ISO 14040:1997 ISO 14042:2000 ISO 14043:2000 GWP 100	Peer-reviewed	Mila` i Canals, L., Burnip, G.M., Cowell, S.J. (2006). Evaluation of the environmental impacts of apple production using Life Cycle Assessment (LCA): Case study in New Zealand. Agriculture, Ecosystems and Environment, 114, pp. 226–238. doi:10.1016/j.agee.2005.10.023
Apple	0.04	64000	New Zealand	Integrated Hawke´s Bay 1	ISO 14040:1997 ISO 14042:2000 ISO 14043:2000 GWP 100	Peer-reviewed	Mila` i Canals, L., Burnip, G.M., Cowell, S.J. (2006). Evaluation of the environmental impacts of apple production using Life Cycle Assessment (LCA): Case study in New Zealand. Agriculture, Ecosystems and Environment, 114, pp. 226–238. doi:10.1016/j.agee.2005.10.023
Apple	0.042	71000	New Zealand	Integrated Hawke´s Bay 2	ISO 14040:1997 ISO 14042:2000 ISO 14043:2000 GWP 100	Peer-reviewed	Mila` i Canals, L., Burnip, G.M., Cowell, S.J. (2006). Evaluation of the environmental impacts of apple production using Life Cycle Assessment (LCA): Case study in New Zealand. Agriculture, Ecosystems and Environment, 114, pp. 226–238. doi:10.1016/j.agee.2005.10.023
Apple	0.204	25000	Italy	Grigia di torriana	ISO 14040 standard series. EDIP 1997-GabiSoftware GWP 100	Peer-reviewed	Cerutti, A. K., Bruun, S., Donno, D., Beccaro, G. L., Bounous, G., (2013). Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. Journal of Cleaner Production, 52, pp. 245-252. doi.org/10.1016/j.jclepro.2013.03.029
Apple	0.193	23000	Italy	Magnana	ISO 14040 standard series. EDIP 1997-GabiSoftware GWP 100	Peer-reviewed	Cerutti, A. K., Bruun, S., Donno, D., Beccaro, G. L., Bounous, G., (2013). Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. Journal of Cleaner Production, 52, pp. 245-252. doi.org/10.1016/j.jclepro.2013.03.029
Apple	0.196	20000	Italy	Runsé	ISO 14040 standard series. EDIP 1997-GabiSoftware GWP 100	Peer-reviewed	Cerutti, A. K., Bruun, S., Donno, D., Beccaro, G. L., Bounous, G., (2013). Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. Journal of Cleaner Production, 52, pp. 245-252. doi.org/10.1016/j.jclepro.2013.03.029
Apple	0.164	40000	Italy	Golden delicious	ISO 14040 standard series. EDIP 1997-GabiSoftware GWP 100	Peer-reviewed	Cerutti, A. K., Bruun, S., Donno, D., Beccaro, G. L., Bounous, G., (2013). Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. Journal of Cleaner Production, 52, pp. 245-252. doi.org/10.1016/j.jclepro.2013.03.029
Apple	0.104	50000	Portugal	Central Portugal Aa	Carbon footprint GWP 100	Conference Report	Figueiredo, F., Castanheira, É.G., Feliciano, M., Rodrigues, M.Â., Peres, A., Maia, F., Ramos, A., Carneiro, J., Coroama, V.C., Freire, F. (2013). Carbon footprint of apple and pear: orchards, storage and distribution. Energy for Sustainability 2013, Sustainable Cities: Designing for People and the Planet Coimbra, 8 to 10 September 2013
Apple	0.081	29000	Portugal	Northern Portugal B	Carbon footprint GWP 100	Conference Report	Figueiredo, F., Castanheira, É.G., Feliciano, M., Rodrigues, M.Â., Peres, A., Maia, F., Ramos, A., Carneiro, J., Coroama, V.C., Freire, F. (2013). Carbon footprint of apple and pear: orchards, storage and distribution. Energy for Sustainability 2013, Sustainable Cities: Designing for People and the Planet Coimbra, 8 to 10 September 2013
Apple	0.072	50000	Portugal	Northern Portugal C	Carbon footprint GWP 100	Conference Report	Figueiredo, F., Castanheira, É.G., Feliciano, M., Rodrigues, M.Â., Peres, A., Maia, F., Ramos, A., Carneiro, J., Coroama, V.C., Freire, F. (2013). Carbon footprint of apple and pear: orchards, storage and distribution. Energy for Sustainability 2013, Sustainable Cities: Designing for People and the Planet Coimbra, 8 to 10 September 2013

Apple	0.068	37567	Belgium	Conventional (mean)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.06	43100	Belgium	Conventional (full production)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.106	41100	Belgium	Conventional (low ptoduction, old)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.075	28500	Belgium	Conventional (low production, young)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.066	47867	Belgium	Integrated (mean)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.059	53500	Belgium	Integrated (full production)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.057	65100	Belgium	Integrated (low production, old)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.144	25000	Belgium	Integrated (low production, young)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.154	33263	Belgium	Organic (mean)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007

Apple	0.175	48600	Belgium	Organic (full production)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.095	48800	Belgium	Organic (low production, old)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.835	2390	Belgium	Organic (low production, young)	SimaPro 8 ILCD method Ecoinvent v3.2 Agri-footprint 2.0 databases GWP 100	Peer-reviewed	Goossens, Y., Annaert, B., J. De Tavernier, J., Mathijs, E., Keulemans, W., Geeraerd, A. (2017). Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms. Agricultural Systems, 153, pp. 81–93. doi.org/10.1016/j.agsy.2017.01.007
Apple	0.244		Italy	Integrated	ISO 14040 SimaPro 7 Ecoinvent 2015	Master thesis	Johansson, D. (2015). Life cycle assessment (LCA) of apples – A comparison between apples produced in Sweden, Italy and Argentina. Master´s thesis (15 hec). Faculty of Landscape Architecture, Horticulture and Crop Production Science Department of Biosystems and Technology. Swedish University of Agricultural Sciences (SLU). http://stud.epsilon.slu.se
Apple	0.055		Sweden	Integrated	ISO 14040 SimaPro 7 Ecoinvent 2015	Master thesis	Johansson, D. (2015). Life cycle assessment (LCA) of apples – A comparison between apples produced in Sweden, Italy and Argentina. Master´s thesis (15 hec). Faculty of Landscape Architecture, Horticulture and Crop Production Science Department of Biosystems and Technology. Swedish University of Agricultural Sciences (SLU). http://stud.epsilon.slu.se
Apple	1.04		Sweden	Organic	ISO 14040 SimaPro 7 Ecoinvent 2015	Master thesis	Johansson, D. (2015). Life cycle assessment (LCA) of apples – A comparison between apples produced in Sweden, Italy and Argentina. Master´s thesis (15 hec). Faculty of Landscape Architecture, Horticulture and Crop Production Science Department of Biosystems and Technology. Swedish University of Agricultural Sciences (SLU). http://stud.epsilon.slu.se
Apple	0.064	23660	Canada	Conventional	ISO-standardized guidelines (ISO, 2006) SimaPro, version 7.3.3; 'Recipe H' Ecoinvent 2.2	Peer-reviewed	Keyes, S., Tyedmers, P. & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. Journal of Cleaner Production, 104, pp. 40-51. doi.org/10.1016/j.jclepro.2015.05.037
Apple	0.276	23660	Canada	Conventional	ISO-standardized guidelines (ISO, 2006) SimaPro, version 7.3.3; 'Recipe H' Ecoinvent 2.2	Peer-reviewed	Keyes, S., Tyedmers, P. & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. Journal of Cleaner Production, 104, pp. 40-51. doi.org/10.1016/j.jclepro.2015.05.037
Apple	0.073	11880	Canada	Organic	ISO-standardized guidelines (ISO, 2006a) SimaPro, version 7.3.3; 'Recipe H' Ecoinvent 2.2	Peer-reviewed	Keyes, S., Tyedmers, P. & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. Journal of Cleaner Production, 104, pp. 40-51. doi.org/10.1016/j.jclepro.2015.05.037

Apple	0.283	11880	Canada	Organic	ISO-standardized guidelines (ISO, 2006) SimaPro, version 7.3.3; 'Recipe H' Ecoinvent 2.2	Peer-reviewed	Keyes, S., Tyedmers, P. & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. Journal of Cleaner Production, 104, pp. 40-51. doi.org/10.1016/j.jclepro.2015.05.037
Apple	0.38	70000	Italy	Conventional	ISO 14040 (ISO 14040, 2006; ISO 14044, 2006)	Peer-reviewed	Longo, S., Mistretta, M., Guarino, F., Cellura, M. (2017). Life Cycle Assessment of organic and conventional apple supply chains in the North of Italy. Journal of Cleaner Production, 140, pp. 654-663. doi.org/10.1016/j.jclepro.2016.02.049
Apple	0.357	50000	Italy	Organic	ISO 14040 (ISO 14040, 2006; ISO 14044, 2006)	Peer-reviewed	Longo, S., Mistretta, M., Guarino, F., Cellura, M. (2017). Life Cycle Assessment of organic and conventional apple supply chains in the North of Italy. Journal of Cleaner Production, 140, pp. 654-663. doi.org/10.1016/j.jclepro.2016.02.049
Apple	0.083	31400	Switzerland	Integrated	SALCA Version 1.31. Houghton et al. (1995) (GWP 100 yr)	Peer-reviewed	Mouron, P., Nemecek, T., Scholz, R.W., Weber. O. (2006). Management influence on environmental impacts in an apple production system on Swiss fruit farms: Combining life cycle assessment with statistical risk assessment. Agriculture, Ecosystems and Environment, 114, pp. 311–322. doi:10.1016/j.agee.2005.11.020
Apple	0.15 (0.31-0.001)	18102	Global		MEXALCA (Modular EXtraplolation of Agricultural Life Cycle Assessment) method. Ecoinvent database LCA tool SALCAcrop	Peer-reviewed	Nemecek, T., Weiler, K., Plassmann, K., Schnetzer, J., Gaillard, G., Jefferies, D., Garcíae-Suárez, T., King, H., Milà i Canals, L. (2012). Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach. Journal of Cleaner Production, 31, pp. 106-117. doi:10.1016/j.jclepro.2012.03.005
Apple	0.394	54000	New Zealand	Organic (Intensive)	PAS 2050 STELLA Overseer BSI 2008 GWP 100	Peer-reviewed	Page, G., Kelly, T., Minor, M., Cameron, E. (2011). Modeling Carbon Footprints of Organic Orchard Production Systems to Address Carbon Trading: An Approach Based on Life Cycle Assessment. Hortscience, 46(2), pp. 324–327.
Apple	0.525	36000	New Zealand	Organic (Semi-intensive)	PAS 2050 STELLA Overseer BSI 2008 GWP 100	Peer-reviewed	Page, G., Kelly, T., Minor, M., Cameron, E. (2011). Modeling Carbon Footprints of Organic Orchard Production Systems to Address Carbon Trading: An Approach Based on Life Cycle Assessment. Hortscience, 46(2), pp. 324–327.
Apple	0.108		Sweden	Integrated	ISO standards (ISO 2006) GWP 100 (IPCC, 2007)	Master thesis	Sjons, J. (2016). Livscykelanalys av svenskproducerad lingonsylt, hallonsylt och äppelmos. Master's thesis (30 hec). Göteborgs universitet: Institutionen för biologi och miljövetenskap.
Apple	0.088		Hungary	Conventional	ISO standards (ISO 2006) GWP 100 (IPCC, 2007)	Master thesis	Sjons, J. (2016). Livscykelanalys av svenskproducerad lingonsylt, hallonsylt och äppelmos. Master's thesis (30 hec). Göteborgs universitet: Institutionen för biologi och miljövetenskap.
Apple	0.097	53800	Italy	Conventional	SimaPro v.7.3.3 Ecoinvent v.2.2 CML baseline 2 2002 GWP 100 (IPCC, 2007)	Peer-reviewed	Tamburini, E., Pedrini, P., Marchetti, M.G., Fano, E.A., Castaldelli, G. (2015). Life Cycle Based Evaluation of Environmental and Economic Impacts of Agricultural Productions in the Mediterranean Area. Sustainability, 7, pp. 2915-2935. doi:10.3390/su7032915

Apple	0.2	30500	UK		14040 and ISO 14044 (ISO 2006a; ISO 2006b). Ecoinvent database CML methodology GWP 100 (IPCC 2007)	Peer-reviewed	Webb, J., Williams, A.G., Hope, E., Evans, D., Moorhouse, E. (2013). Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK? The International Journal of Life Cycle Assessment, 18, pp. 1325–1343. DOI 10.1007/s11367-013-0576-2
Apple	0.1	63000	New Zealand		14040 and ISO 14044 (ISO 2006a; ISO 2006b). Ecoinvent database CML methodology GWP 100 (IPCC 2007)	Peer-reviewed	Webb, J., Williams, A.G., Hope, E., Evans, D., Moorhouse, E. (2013). Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK? The International Journal of Life Cycle Assessment, 18, pp. 1325–1343. DOI 10.1007/s11367-013-0576-2
Apple	0.188	1652	US, california	Conventional (1)	ISO standards (ISO 2006) PAS 2050:2008 standard FoodCarbonScope (CleanMetrics 2011) CarbonScopeData GWP 100	Peer-reviewed	Venkat, K. (2012): Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. Journal of Sustainable Agriculture, 36:6, pp. 620-649. doi.org/10.1080/10440046.2012.672378
Apple	0.108	7629	US, california	Conventional (2)	ISO standards (ISO 2006) PAS 2050:2008 standard FoodCarbonScope (CleanMetrics 2011) CarbonScopeData GWP 100	Peer-reviewed	Venkat, K. (2012): Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. Journal of Sustainable Agriculture, 36:6, pp. 620-649. doi.org/10.1080/10440046.2012.672378
Apple	0.267	2570	US, california	Organic (1)	ISO standards (ISO 2006) PAS 2050:2008 standard FoodCarbonScope (CleanMetrics 2011) CarbonScopeData GWP 100	Peer-reviewed	Venkat, K. (2012): Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. Journal of Sustainable Agriculture, 36:6, pp. 620-649. doi.org/10.1080/10440046.2012.672378
Apple	0.176	2754	US, california	Organic (2)	ISO standards (ISO 2006) PAS 2050:2008 standard FoodCarbonScope (CleanMetrics 2011) CarbonScopeData GWP 100	Peer-reviewed	Venkat, K. (2012): Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. Journal of Sustainable Agriculture, 36:6, pp. 620-649. doi.org/10.1080/10440046.2012.672378
Apple	0.111	48810	Spain	Integrated	ISO 14040 Simapro 8 Software Ecoinvent database 3.0 Recipe Midpoint (H) GWP 100 (IPCC, 2013)	Peer-reviewed	Vinyes, E., Asin, L., Alegre, S., Muñoz, P., Boschmonart, J., Gasol, C.M. (2017). Life Cycle Assessment of apple and peach production, distribution and consumption in Mediterranean fruit sector. Journal of cleaner production. 149, pp. 313-320. doi:10.1016/j.jclepro.2017.02.102
Apple	0.24±0.04	37000	China	Shanxi (9)	PAS 2050-1 (BSI 2012) GWP 100 (IPCC, 2007)	Peer-reviewed	Yan, M., Cheng, K., Yue, Q., Yu Yan, Y., Rees, R.M., Pan, G. (2016). Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environmental Science Pollution Research, vol. 23, pp. 4681–4691. DOI 10.1007/s11356-015-5670-5
Apple	0.36	29360	China		PAS 2050 protocol GWP 100 (IPCC, 2013)	Peer-reviewed	Yue, Q., Xu, X., Hillier, J., Cheng, K., Pan, G. (2017). Mitigating greenhouse gas emissions in agriculture: From farm production to food consumption. Journal of cleaner production, 149, pp. 1011-1019. doi:10.1016/j.jclepro.2017.02.172

Pear	0.379	15000	China	Conventional (BJ)	ISO standard 14 040 GWP 100 (IPCC, 2007)	Peer-reviewed	Liu, Y., Langer, V., Høgh-Jensen, H., Egelyng, H. (2010). Life Cycle Assessment of fossil energy use and greenhouse gas emissions in Chinese pear production. Journal of Cleaner Production, 18, pp. 1423-1430. doi:10.1016/j.jclepro.2010.05.025
Pear	0.289	18750	China	Conventional (LN)	ISO standard 14 040 GWP 100 (IPCC, 2007)	Peer-reviewed	Liu, Y., Langer, V., Høgh-Jensen, H., Egelyng, H. (2010). Life Cycle Assessment of fossil energy use and greenhouse gas emissions in Chinese pear production. Journal of Cleaner Production, 18, pp. 1423-1430. doi:10.1016/j.jclepro.2010.05.025
Pear	0.056	33000	China	Organic (LN)	ISO standard 14 040 GWP 100 (IPCC, 2007)	Peer-reviewed	Liu, Y., Langer, V., Høgh-Jensen, H., Egelyng, H. (2010). Life Cycle Assessment of fossil energy use and greenhouse gas emissions in Chinese pear production. Journal of Cleaner Production, 18, pp. 1423-1430. doi:10.1016/j.jclepro.2010.05.025
Pear	0.27	16500	China	Organic A (BJ)	ISO standard 14 040 GWP 100 (IPCC, 2007)	Peer-reviewed	Liu, Y., Langer, V., Høgh-Jensen, H., Egelyng, H. (2010). Life Cycle Assessment of fossil energy use and greenhouse gas emissions in Chinese pear production. Journal of Cleaner Production, 18, pp. 1423-1430. doi:10.1016/j.jclepro.2010.05.025
Pear	0.155	19800	China	Organic B (BJ)	ISO standard 14 040 GWP 100 (IPCC, 2007)	Peer-reviewed	Liu, Y., Langer, V., Høgh-Jensen, H., Egelyng, H. (2010). Life Cycle Assessment of fossil energy use and greenhouse gas emissions in Chinese pear production. Journal of Cleaner Production, 18, pp. 1423-1430. doi:10.1016/j.jclepro.2010.05.025
Pear	0.18	48000	China		PAS 2050-1 (BSI 2012) GWP 100 (IPCC, 2007)	Peer-reviewed	Yan, M., Cheng, K., Yue, Q., Yu Yan, Y., Rees, R.M., Pan, G. (2016). Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environmental Science Pollution Research, vol. 23, pp. 4681–4691. DOI 10.1007/s11356-015-5670-5
Pear	0.127	40000	Portugal	Central Portugal Ap		Report	Figueiredo, F., Castanheira, É.G., Feliciano, M., Rodrigues, M.Â., Peres, A., Maia, F., Ramos, A., Carneiro, J., Coroama, V.C., Freire, F. (2013). Carbon footprint of apple and pear: orchards, storage and distribution. Energy for Sustainability 2013, Sustainable Cities: Designing for People and the Planet Coimbra, 8 to 10 September 2013
Pear	0.376	30000	Italy	Organic	SimaPro v.7.3.3	Peer-reviewed	Tamburini, E., Pedrini, P., Marchetti, M.G., Fano, E.A., Castaldelli, G. (2015). Life Cycle Based Evaluation of Environmental and Economic Impacts of Agricultural Productions in the Mediterranean Area. Sustainability, 7, pp. 2915-2935. doi:10.3390/su7032915
Apricot	0.422	20000	Italy	Biodynamic	ISO 14040 series (ISO 2006). SimaPro 8 Ecoinvent 2013	Peer-reviewed	Pergola, M., Persiani, P., Pastore, V., Palese, A.M., Arous, A., Celano, G. (2017). A comprehensive Life Cycle Assessment (LCA) of three apricot orchard systems located in Metapontino area (Southern Italy). Journal of Cleaner Production, 142, pp. 4059-4071. doi.org/10.1016/j.jclepro.2016.10.030
Apricot	0.364	20000	Italy	Integrated (Ninfa)	ISO 14040 series (ISO 2006). SimaPro 8 Ecoinvent 2013	Peer-reviewed	Pergola, M., Persiani, P., Pastore, V., Palese, A.M., Arous, A., Celano, G. (2017). A comprehensive Life Cycle Assessment (LCA) of three apricot orchard systems located in Metapontino area (Southern Italy). Journal of Cleaner Production, 142, pp. 4059-4071. doi.org/10.1016/j.jclepro.2016.10.030
Apricot	0.262	13500	Italy	Integrated (Rubis)	ISO 14040 series (ISO 2006). SimaPro 8 Ecoinvent 2013	Peer-reviewed	Pergola, M., Persiani, P., Pastore, V., Palese, A.M., Arous, A., Celano, G. (2017). A comprehensive Life Cycle Assessment (LCA) of three apricot orchard systems located in Metapontino area (Southern Italy). Journal of Cleaner Production, 142, pp. 4059-4071. doi.org/10.1016/j.jclepro.2016.10.030

Peach	0.591	8420	Peru	Intensive	SimaPro 7.3.0. GWP 100 (IPCC,2007)	Peer-reviewed	Bartl, K., Verones, F., and Hellweg, S. (2012). Life Cycle Assessment Based Evaluation of Regional Impacts from Agricultural Production at the Peruvian Coast. Environmental, Science and Technology, 46, pp. 9872–9880. doi.org/10.1021/es301644y
Peach	0.172		Iran		ISO 14040. SPINE@CPM database	Peer-reviewed	Nikkhaha, A., Royana, M., Khojastehpoura, M., Bacenetti, J. (2017). Environmental impacts modeling of Iranian peach production. *Renewable and Sustainable Energy Reviews*, 75, pp. 677–682. doi.org/10.1016/j.rser.2016.11.041
Peach	0.37	17000	China		PAS 2050-1 (BSI 2012) GWP 100 (IPCC, 2007)	Peer-reviewed	Yan, M., Cheng, K., Yue, Q., Yu Yan, Y., Rees, R.M., Pan, G. (2016). Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environmental Science Pollution Research, vol. 23, pp. 4681–4691. DOI 10.1007/s11356-015-5670-5
Peach	0.17	28000	France		ISO, 2006. SimaPro Agribalyse (ReCip-Pe) Ecoinvent v.2 CML 2001 GWP 100 (IPCC, AR4)	Report	Basset-Mens, C., Vannière, H., Grasselly, D., Heitz, H., Braun, A., Payen, S., Koch, P. (2016). Environmental impacts of imported versus locally-grown fruits for the French market as part of the AGRIBALYSE® program. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector.
Peach	0.138	36780	Spain	Integrated	ISO 14040 Simapro 8 Software Ecoinvent database 3.0 Recipe Midpoint (H).	Peer-reviewed	Vinyes, E., Asin, L., Alegre, S., Muñoz, P., Boschmonart, J., Gasol, C.M. (2017). Life Cycle Assessment of apple and peach production, distribution and consumption in Mediterranean fruit sector. Journal of cleaner production. 149, pp. 313-320. doi:10.1016/j.jclepro.2017.02.102
Peach	0.25	18745	Spain	Integrated	ISO 14040 Simapro 7.3.3 software Ecoinvent database 3.0 Recipe Midpoint H	Peer-reviewed	Vinyes , E., Gasol, C.M., Asin, L., Alegre, S., Muñoz, P. (2015). Life Cycle Assessment of multiyear peach production. Journal of Cleaner Production, 104, pp. 68-79. doi.org/10.1016/j.jclepro.2015.05.041
Peach	0.125	48350	Spain	Integrated	ISO 14040 Simapro 7.3.3 software Ecoinvent database 3.0 Recipe Midpoint H	Peer-reviewed	Vinyes , E., Gasol, C.M., Asin, L., Alegre, S., Muñoz, P. (2015). Life Cycle Assessment of multiyear peach production. Journal of Cleaner Production, 104, pp. 68-79. doi.org/10.1016/j.jclepro.2015.05.041
Peach	0.183	31625	Spain	Integrated	ISO 14040 Simapro 7.3.3 software Ecoinvent database 3.0 Recipe Midpoint H	Peer-reviewed	Vinyes , E., Gasol, C.M., Asin, L., Alegre, S., Muñoz, P. (2015). Life Cycle Assessment of multiyear peach production. Journal of Cleaner Production, 104, pp. 68-79. doi.org/10.1016/j.jclepro.2015.05.041
Peach	0.162	36280	Spain	Integrated	ISO 14040 Simapro 7.3.3 software Ecoinvent database 3.0 Recipe Midpoint H	Peer-reviewed	Vinyes , E., Gasol, C.M., Asin, L., Alegre, S., Muñoz, P. (2015). Life Cycle Assessment of multiyear peach production. Journal of Cleaner Production, 104, pp. 68-79. doi.org/10.1016/j.jclepro.2015.05.041
Peach	0.314 (0.37-0.17)	12990	Global		MEXALCA (Modular EXtraplolation of Agricultural Life Cycle Assessment) Ecoinvent database LCA tool SALCAcrop GWP 100	Peer-reviewed	Nemecek, T., Weiler, K., Plassmann, K., Schnetzer, J., Gaillard, G., Jefferies, D., Garcíae-Suárez, T., King, H., Milà i Canals, L. (2012). Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach. Journal of Cleaner Production, 31, pp. 106-117. doi:10.1016/j.jclepro.2012.03.005

Grapes	0.642	6370	Canada	Conventional 1 bottle (750 ml) = 1.25 kg	ISO 14040 Standard, 2006 SimaPro (version 7.1.6) CML 2 baseline 2000	Peer-reviewed	Point, E., Tyedmers, P., Naugler, C. (2012). Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. Journal of Cleaner Production, vol. 27, pp. 11-20. doi:10.1016/j.jclepro.2011.12.035
Grapes	0.283	4240	Cyprus	Xynisteri	Cool Farm Tool	Peer-reviewed	Litskas, V.D., Irakleous, T., Tzortzakis, N., Stavrinides, M.C. (2017). Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study. Journal of Cleaner Production, 156, pp. 418-425. doi.org/10.1016/j.jclepro.2017.04.057
Grapes	0.572	6800	Cyprus	Cabernet Sauvignon	Cool Farm Tool	Peer-reviewed	Litskas, V.D., Irakleous, T., Tzortzakis, N., Stavrinides, M.C. (2017). Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study. Journal of Cleaner Production, 156, pp. 418-425. doi.org/10.1016/j.jclepro.2017.04.057
Grapes	0.846	11500	Cyprus	Soultanina	Cool Farm Tool	Peer-reviewed	Litskas, V.D., Irakleous, T., Tzortzakis, N., Stavrinides, M.C. (2017). Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study. Journal of Cleaner Production, 156, pp. 418-425. doi.org/10.1016/j.jclepro.2017.04.057
Grapes	0.102	11500	Italy		ISO 14040: 2006 ISO 14067:2013	Peer-reviewed	Cichelli, A., Pattaraa, C., Petrellab, A. (2016). Sustainability in mountain viticulture . The case of the Valle Peligna. Agriculture and Agricultural Science Procedia, 8, pp. 65 – 72. doi: 10.1016/j.aaspro.2016.02.009
Grapes	0.122	8000	Italy		ISO 14040: 2006 ISO 14067:2013	Peer-reviewed	Cichelli, A., Pattaraa, C., Petrellab, A. (2016). Sustainability in mountain viticulture . The case of the Valle Peligna. Agriculture and Agricultural Science Procedia, 8, pp. 65 – 72. doi: 10.1016/j.aaspro.2016.02.009
Grapes	0.099	10000	Italy		ISO 14040: 2006 ISO 14067:2013	Peer-reviewed	Cichelli, A., Pattaraa, C., Petrellab, A. (2016). Sustainability in mountain viticulture . The case of the Valle Peligna. Agriculture and Agricultural Science Procedia, 8, pp. 65 – 72. doi: 10.1016/j.aaspro.2016.02.009
Grapes	0.311	9000	Italy	Grechetto grapes	ISO TS 14067 (2013), ISO 14046 (2014), ISO 14040 (2006) and ISO 14044 (2006) SimaPro GWP 100 (IPCC, 2013)	Peer-reviewed	Bartocci, P., Fantozzi, P., Fantozzi, F. (2017). Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy. Journal of Cleaner Production, 140, pp. 569-580. doi.org/10.1016/j.jclepro.2016.04.090
Grapes	0.47	7000	Italy	Sagrantino grapes	ISO TS 14067 (2013), ISO 14046 (2014), ISO 14040 (2006) and ISO 14044 (2006) SimaPro GWP 100 (IPCC, 2013)	Peer-reviewed	Bartocci, P., Fantozzi, P., Fantozzi, F. (2017). Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy. Journal of Cleaner Production, 140, pp. 569-580. doi.org/10.1016/j.jclepro.2016.04.090
Grapes	0.271		Italy	Conventional (conventional- espalier)	ISO 14040 SimaPro 7.3. IEC (The International EPD Cooperation). GWP 100	Peer-reviewed	Falcone, G., De Luca, A.I., Stillitano, T., Strano, A., Romeo, G., Gulisano, G. (2016). Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. Sustainability, 8, 793. doi:10.3390/su8080793

Grapes	0.3		Italy	Conventional (conventional-gobelet)	ISO 14040 SimaPro 7.3. IEC (The International EPD Cooperation). GWP 100	Peer-reviewed	Falcone, G., De Luca, A.I., Stillitano, T., Strano, A., Romeo, G., Gulisano, G. (2016). Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. Sustainability, 8, 793. doi:10.3390/su8080793
Grapes	0.31		Italy	Organic (organic espalier)	ISO 14040 SimaPro 7.3. IEC (The International EPD Cooperation). GWP 100	Peer-reviewed	Falcone, G., De Luca, A.I., Stillitano, T., Strano, A., Romeo, G., Gulisano, G. (2016). Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. Sustainability, 8, 793. doi:10.3390/su8080793
Grapes	0.329		Italy	Organic (organic-gobelet)	ISO 14040 SimaPro 7.3. IEC (The International EPD Cooperation). GWP 100	Peer-reviewed	Falcone, G., De Luca, A.I., Stillitano, T., Strano, A., Romeo, G., Gulisano, G. (2016). Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. Sustainability, 8, 793. doi:10.3390/su8080793
Grapes	0.154		Italy	750 ml = 1.071 kg	ISO 14040 and 14044 SimaPro CML baseline 2000 method GWP 100	Peer-reviewed	Fusi, A., Guidetti, R., Benedetto, G. (2014). Delving into the environmental aspect of a Sardinian white wine: From partial to total life cycle assessment. Science of the Total Environment, 472, pp. 989–1000. doi.org/10.1016/j.scitotenv.2013.11.148
Grapes	0.158	6370	Spain	Conventional	SimaPro 7.2 GWP 100	Peer-reviewed	Aguilera, E., Guzmán, G., Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35, pp. 725-737. doi:10.1007/s13593-014-0265-y
Grapes	0.172	5790	Spain	Organic	SimaPro 7.2 GWP 100	Peer-reviewed	Aguilera, E., Guzmán, G., Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35, pp. 725-737. doi:10.1007/s13593-014-0265-y
Grapes	0.225	4727	spain	Viticulture 0.7 l/kg grapes	ISO 14040 and 14044 Recipe method	Peer-reviewed	Meneses, M., Torres, C.M., Castells, F. (2016). Sensitivity analysis in a life cycle assessment of an aged red wine production from Catalonia, Spain. Science of the Total Environment, 562, pp. 571–579. doi.org/10.1016/j.scitotenv.2016.04.083
Grapes	0.4206		Spain	750 ml = 1.1 kg	SimaPro 7.3 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Vázquez-Rowe, I., Villanueva-Rey, P,.Iribarren, D., Moreira, M.T., Feijoo, G. (2012). Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rías Baixas appellation (NW Spain). Journal of clean production, 27, pp. 92-102. doi:10.1016/j.jclepro.2011.12.039
Grapes	0.088	3750	Spain	Biodynamic BD 750 ml = 1.1 kg	ISO 14040 and 14044 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production, 65, pp. 330-341. doi.org/10.1016/j.jclepro.2013.08.026
Grapes	0.065	3750	Spain	Biodynamic BD 750 ml = 1.1 kg	ISO 14040 and 14044 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production, 65, pp. 330-341. doi.org/10.1016/j.jclepro.2013.08.026

Grapes	0.134	4490	Spain	Biodynamic-conventional BD-CV 750 ml = 1.1 kg	ISO 14040 and 14044 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production, 65, pp. 330-341. doi.org/10.1016/j.jclepro.2013.08.026
Grapes	0.079	5870	Spain	Biodynamic-conventional BD-CV 750 ml = 1.1 kg	ISO 14040 and 14044 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production, 65, pp. 330-341. doi.org/10.1016/j.jclepro.2013.08.026
Grapes	0.341	8570	Spain	Conventional CV 750 ml = 1.1 kg	ISO 14040 and 14044 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production, 65, pp. 330-341. doi.org/10.1016/j.jclepro.2013.08.026
Grapes	0.257	10860	Spain	Conventional CV 750 ml = 1.1 kg	ISO 14040 and 14044 CML baseline 2000 GWP 100 (IPCC, 1995)	Peer-reviewed	Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. (2014). Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production, 65, pp. 330-341. doi.org/10.1016/j.jclepro.2013.08.026
Grapes	0.457		Spain	750 ml = 1.27 kg	GaBi software CML baseline 2001 GWP 100	Peer-reviewed	Gazulla, C., Raugei, M., Fullana-i-Palmer, P. (2010). Taking a life cycle look at crianza wine production in Spain: where are the bottlenecks? The international Journal of Life Cycle Assessment, 15, pp. 330–337. DOI 10.1007/s11367-010-0173-6
Grapes	0.2		US, california	Conventional L1	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.17		US, california	Conventional L10	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.22		US, california	Conventional L2	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.17		US, california	Conventional L5	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.19		US, california	Conventional L6	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2

Grapes	0.15		US, california	Conventional L7	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.17		US, california	Conventional L8	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.19		US, california	Conventional L9	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.45		US, california	Conventional N1	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.48		US, california	Conventional N2	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.16		US, california	Organic L3	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Grapes	0.2		US, california	Organic L4	Excel Visual Basic macros	Peer-reviewed	Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., Kendall, A. (2015). Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment, 20, pp. 1243–1253. DOI 10.1007/s11367-015-0935-2
Orange	0.12 (0.4-0.001)	20583	Global		MEXALCA (Modular EXtraplolation of Agricultural Life Cycle Assessment) Ecoinvent database LCA tool SALCAcrop	Peer-reviewed	Nemecek, T., Weiler, K., Plassmann, K., Schnetzer, J., Gaillard, G., Jefferies, D., Garcíae-Suárez, T., King, H., Milà i Canals, L. (2012). Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach. Journal of Cleaner Production, 31, pp. 106-117. doi:10.1016/j.jclepro.2012.03.005
Orange	0.13	28600	Italy	Conventional	SimaPro 7.2 Ecoinvent LCA Food DK	Peer-reviewed	Pergola, M., D'Amico, M., Celano, G., Paleseb, A.M., Scuderi, A., Di Vita, G., Pappalardo, G., Inglese, P. (2013). Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis. Journal of environmental management, 128, pp. 674-682. doi:10.1016/j.jenvman.2013.06.007
Orange	0.04	24700	Italy	Organic	SimaPro 7.2 Ecoinvent LCA Food DK	Peer-reviewed	Pergola, M., D'Amico, M., Celano, G., Paleseb, A.M., Scuderi, A., Di Vita, G., Pappalardo, G., Inglese, P. (2013). Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis. Journal of environmental management, 128, pp. 674-682. doi:10.1016/j.jenvman.2013.06.007

Orange and mandarins	0.159	41950	Spain	Conventional	SimaPro 7.2 GWP 100	Peer-reviewed	Aguilera, E., Guzmán, G., Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35, pp. 725-737. doi:10.1007/s13593-014-0265-y
Orange and mandarins	0.154	24260	Spain	Organic	SimaPro 7.2 GWP 100	Peer-reviewed	Aguilera, E., Guzmán, G., Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35, pp. 725-737. doi:10.1007/s13593-014-0265-y
Orange and mandarins	0.311	33352	Spain	Conventional	ISO guidelines (ISO 2006). CML-2001 (2013) Ecoinvent 2.2	Peer-reviewed	Ribal, J., Ramírez-Sanz, C., Estruch, V., Clemente, G., Sanjuán, N. (2017). Organic versus conventional citrus. Impact assessment and variability analysis in the Comunitat Valenciana (Spain). The International Journal of Life Cycle Assessment, 22, pp. 571–586. DOI 10.1007/s11367-016-1048-2
Orange and mandarins	0.101	18326	Spain	Organic	ISO guidelines (ISO 2006). CML-2001 (2013) Ecoinvent 2.2	Peer-reviewed	Ribal, J., Ramírez-Sanz, C., Estruch, V., Clemente, G., Sanjuán, N. (2017). Organic versus conventional citrus. Impact assessment and variability analysis in the Comunitat Valenciana (Spain). The International Journal of Life Cycle Assessment, 22, pp. 571–586. DOI 10.1007/s11367-016-1048-2
Orange	0.14	56000	China		PAS 2050-1 (BSI 2012) GWP 100 (IPCC, 2007)	Peer-reviewed	Yan, M., Cheng, K., Yue, Q., Yu Yan, Y., Rees, R.M., Pan, G. (2016). Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environmental Science Pollution Research, vol. 23, pp. 4681–4691. DOI 10.1007/s11356-015-5670-5
Small citrus	0.269	28000	Morocco		Agribalyse (ReCip-Pe) GWP 100 (IPCC, 2007)	Report	Basset-Mens, C., Vannière, H., Grasselly, D., Heitz, H., Braun, A., Payen, S., Koch, P. (2016). Environmental impacts of imported versus locally-grown fruits for the French market as part of the AGRIBALYSE® program. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector.
Small citrus	0.329	42000	Morocco	Full cycle (incl. non-productive phase (year 1-3)	ISO 14044 SimaPro 7.2 Recipe method 2008 GWP 100 (IPCC, 2007)	Peer-reviewed	Bessou, C., Basset-Mens, C., Cynthia Latunussa, C., Vélu, A., Heitz, H., Vannière, H., Caliman, J-P. (2016). Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. Int J Life Cycle Assess, 21, pp. 297–310. DOI 10.1007/s11367-016-1030-z
Small citrus	0.401	42100	Morocco	Mean year 7-9 (2006-2008). For individual years or the 3-year average model, nursery, tree planting and non-productive years were not included in the studied system.	ISO 14044 SimaPro 7.2 Recipe method 2008 GWP 100 (IPCC, 2007)	Peer-reviewed	Bessou, C., Basset-Mens, C., Cynthia Latunussa, C., Vélu, A., Heitz, H., Vannière, H., Caliman, J-P. (2016). Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. Int J Life Cycle Assess, 21, pp. 297–310. DOI 10.1007/s11367-016-1030-z
Small citrus	0.338	39600	Morocco	year 7 (For individual years or the 3-year average model, nursery, tree planting and non-productive years were not included in the studied system.)	ISO 14044 SimaPro 7.2 Recipe method 2008 GWP 100 (IPCC, 2007)	Peer-reviewed	Bessou, C., Basset-Mens, C., Cynthia Latunussa, C., Vélu, A., Heitz, H., Vannière, H., Caliman, J-P. (2016). Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. Int J Life Cycle Assess, 21, pp. 297–310. DOI 10.1007/s11367-016-1030-z
Small citrus	0.201	66200	Morocco	year 8 (For individual years or the 3-year average model, nursery, tree planting and non-productive years were not included in the studied system.)	ISO 14044 SimaPro 7.2 Recipe method 2008 GWP 100 (IPCC, 2007)	Peer-reviewed	Bessou, C., Basset-Mens, C., Cynthia Latunussa, C., Vélu, A., Heitz, H., Vannière, H., Caliman, J-P. (2016). Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. Int J Life Cycle Assess, 21, pp. 297–310. DOI 10.1007/s11367-016-1030-z

Small citrus	0.663	20500	Morocco	year 9 (For individual years or the 3-year average model, nursery, tree planting and non-productive years were not included in the studied system.)	ISO 14044 SimaPro 7.2 Recipe method 2008 GWP 100 (IPCC, 2007)	Peer-reviewed	Bessou, C., Basset-Mens, C., Cynthia Latunussa, C., Vélu, A., Heitz, H., Vannière, H., Caliman, J-P. (2016). Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. Int J Life Cycle Assess, 21, pp. 297–310. DOI 10.1007/s11367-016-1030-z
Tangerine	0.24	26810	China		PAS 2050 GWP 100 (IPCC, 2013)	Peer-reviewed	Yue, Q., Xu, X., Hillier, J., Cheng, K., Pan, G. (2017). Mitigating greenhouse gas emissions in agriculture: From farm production to food consumption. Journal of cleaner production, 149, pp. 1011-1019. doi:10.1016/j.jclepro.2017.02.172
Citrus	0.31	30500	China		PAS 2050 GWP 100 (IPCC, 2013)	Peer-reviewed	Yue, Q., Xu, X., Hillier, J., Cheng, K., Pan, G. (2017). Mitigating greenhouse gas emissions in agriculture: From farm production to food consumption. Journal of cleaner production, 149, pp. 1011-1019. doi:10.1016/j.jclepro.2017.02.172
Mandarins	0.556	30270	Peru		SimaPro 7.3.0 GWP 100 (IPCC, 2007)	Peer-reviewed	Bartl, K., Verones, F., and Hellweg, S. (2012). Life Cycle Assessment Based Evaluation of Regional Impacts from Agricultural Production at the Peruvian Coast. Environmental, Science and Technology, 46, pp. 9872–9880. doi.org/10.1021/es301644y
Bananas	0.275		Central and South America (Guatemala, Honduras, Panama, and Costa Rica)		Carbon footprint SimaPro. GWP 100 (IPCC, 2007)	Report, working paper	Craig, A.J., Sheffi, Y., Blanco, E.E. (2012). A Supply Chain View of Product Carbon Footprints: Results from the Banana Supply Chain. Massachusetts Institute of Technology, ESD Working Paper Series. ESD-WP-2012-25
Bananas	0.227	51170	Costa Rica		ISO standard 14044 PAS 2050 GWP 100 (IPCC, 2007)	Report	Luske, B. (2010). Comprehensive Carbon Footprint Assessment Dole Bananas. Soil & More International. www.soilandmore.com
Bananas	0.267		Costa Rica		ISO standard 14044 PAS 2050 GWP 100 (IPCC, 2007)	Report	Luske, B. (2010). Comprehensive Carbon Footprint Assessment Dole Bananas. Soil & More International. www.soilandmore.com
Bananas	0.319	45780	Costa Rica		ISO 14067 GHG Protocol (WRI and WBSCD 2011) Ecoinvent database, version 2.2	Peer-reviewed	Svanes, E. & Aronsson, A.K.S. (2013). Carbon footprint of a Cavendish banana supply chain. The International Journal of Life Cycle Assessment, 18, pp. 1450–1464. DOI 10.1007/s11367-013-0602-4
Bananas	0.291	32800 (mean)	Ecuador	Yr 2009	PAS 2050 CCaLC V3.0	Peer-reviewed	Iriarte, A., Almeida, M.G., Villalobos, P. (2014). Carbon footprint of premium quality export bananas: Case study in Ecuador, the world's largest exporter. Science of the Total Environment, 472, pp. 1082–1088. http://dx.doi.org/10.1016/j.scitotenv.2013.11.072
Bananas	0.331	32800 (mean)	Ecuador	Yr 2010	PAS 2050 CCaLC V3.0	Peer-reviewed	Iriarte, A., Almeida, M.G., Villalobos, P. (2014). Carbon footprint of premium quality export bananas: Case study in Ecuador, the world's largest exporter. Science of the Total Environment, 472, pp. 1082–1088. http://dx.doi.org/10.1016/j.scitotenv.2013.11.072

Bananas	0.355	32800 (mean)	Ecuador	Yr 2011	PAS 2050 CCaLC V3.0	Peer-reviewed	Iriarte, A., Almeida, M.G., Villalobos, P. (2014). Carbon footprint of premium quality export bananas: Case study in Ecuador, the world's largest exporter. Science of the Total Environment, 472, pp. 1082–1088. http://dx.doi.org/10.1016/j.scitotenv.2013.11.072
Bananas	0.302		Ecuador	Conventional	ISO 14067 PAS 2050:2011	Peer-reviewed	Roibas, L., Elbehri, A., Hospido, A. (2015). Evaluating the sustainability of Ecuadorian bananas: carbon footprint, water usage and wealth distributon along the supply chain. Sustainable production and consumption, 2, pp. 3-16. Doi.org/10.1016/j.spc.2015.07.006
Bananas	0.249		Ecuador	Organic	ISO 14067 PAS 2050:2011	Peer-reviewed	Roibas, L., Elbehri, A., Hospido, A. (2015). Evaluating the sustainability of Ecuadorian bananas: carbon footprint, water usage and wealth distributon along the supply chain. Sustainable production and consumption, 2, pp. 3-16. Doi.org/10.1016/j.spc.2015.07.006
Bananas	0.25 (0.38-0.08)	23027	Global		MEXALCA (Modular EXtraplolation of Agricultural Life Cycle Assessment) Ecoinvent database LCA tool SALCAcrop	Peer-reviewed	Nemecek, T., Weiler, K., Plassmann, K., Schnetzer, J., Gaillard, G., Jefferies, D., Garcíae-Suárez, T., King, H., Milà i Canals, L. (2012). Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach. Journal of Cleaner Production, 31, pp. 106-117. doi:10.1016/j.jclepro.2012.03.005
Bananas	0.049		Spain	Organic	SimaPro 7.2 GWP 100	Peer-reviewed	Aguilera, E., Guzmán, G., Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35, pp. 725-737. doi:10.1007/s13593-014-0265-y
Bananas	0.641		Spain	Conventional	SimaPro 7.2 GWP 100	Peer-reviewed	Aguilera, E., Guzmán, G., Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35, pp. 725-737. doi:10.1007/s13593-014-0265-y
Bananas	0.27	38000	China		PAS 2050-1 (BSI 2012) GWP 100 (IPCC, 2007)	Peer-reviewed	Yan, M., Cheng, K., Yue, Q., Yu Yan, Y., Rees, R.M., Pan, G. (2016). Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environmental Science Pollution Research, vol. 23, pp. 4681–4691. DOI 10.1007/s11356-015-5670-5
Pineapple	0.058	38153	Colombia		GWP 100 (IPCC, 2007)	Peer-reviewed	Graefe, S., Tapasco, J., Gonzalez, A. (2013). Resource use and GHG emissions of eight tropical fruit species cultivated in Colombia. Fruits, vol. 68, pp. 303–314. Doi:10.1051/fruits/2013075 www.fruits-journal.org
Pineapple	0.234	95358	Costa Rica	Conventional and organic	PAS 2050 Ecoinvent	Peer-reviewed	Ingwersen, W.W. (2012). Life cycle assessment of fresh pineapple from Costa Rica. Journal of Cleaner Production, vol. 35, pp. 152-163. doi.org/10.1016/j.jclepro.2012.05.035
Pineapple	0.407		Ghana		PAS 2050 GWP 100 (IPCC, 1995)	Report	West Africa Fair Fruit (WAFF). (2011). Summary of Studies on Environmental Performance of Fresh Pineapple Produced in Ghana for Export to Europe.
Pineapple	0.21		Mauritius		ISO 14040/44 standards PAS 2050 GWP 100	Report	Brenton, P., Edwards-Jones, G., Jensen, M.F. (2010). Carbon Footprints and Food Systems - Do Current Accounting Methodologies Disadvantage Developing Countries? The International Bank for Reconstruction and Development, the World Bank, Washington D.C. DOI: 10.1596/978-0-8213-8539-5

Pineapple	0.32	31250	Thailand		ISO14067:2013 GWP 100 (IPCC, 2007)	Peer-reviewed	Usubharatana, P., Phungrassami, H. (2017). Evaluation of opportunities to reduce the carbon footprint of fresh and canned pineapple processing in central Thailand. Polish Journal of Environmental Studies, vol. 26, no. 4, pp. 1725-1735. DOI: 10.15244/pjoes/69442
Pineapple	0.165	38238	Thailand		ISO14067:2013 GWP 100 (IPCC, 2007)	Peer-reviewed	Usubharatana, P., Phungrassami, H. (2017). Evaluation of opportunities to reduce the carbon footprint of fresh and canned pineapple processing in central Thailand. Polish Journal of Environmental Studies, vol. 26, no. 4, pp. 1725-1735. DOI: 10.15244/pjoes/69442
Pineapple	0.211	36163	Thailand		ISO14067:2013 GWP 100 (IPCC, 2007)	Peer-reviewed	Usubharatana, P., Phungrassami, H. (2017). Evaluation of opportunities to reduce the carbon footprint of fresh and canned pineapple processing in central Thailand. Polish Journal of Environmental Studies, vol. 26, no. 4, pp. 1725-1735. DOI: 10.15244/pjoes/69442
Kiwi fruit	0.19	10000	Italy	*A. deliciosa* (green) Young phase	ISO 14040 standard series, SimaPro 7.3 Ecoinvent 2.2. GWP 100	Peer-reviewed	Baudino, C., Giuggioli, N.R., Briano, R., Massaglia, S., Peano, C. (2017). Integrated Methodologies (SWOT, TOWS, LCA) for Improving Production Chains and Environmental Sustainability of Kiwifruit and Baby Kiwi in Italy. Sustainability, 9, 1621. doi:10.3390/su9091621 www.mdpi.com/journal/sustainability
Kiwi fruit	0.12	20000	Italy	*A. deliciosa* (green) Full phase	ISO 14040 standard series, SimaPro 7.3 Ecoinvent 2.2. GWP 100	Peer-reviewed	Baudino, C., Giuggioli, N.R., Briano, R., Massaglia, S., Peano, C. (2017). Integrated Methodologies (SWOT, TOWS, LCA) for Improving Production Chains and Environmental Sustainability of Kiwifruit and Baby Kiwi in Italy. Sustainability, 9, 1621. doi:10.3390/su9091621 www.mdpi.com/journal/sustainability
Kiwi fruit	0.13		Italy	*A. deliciosa* (green) Total	ISO 14040 standard series, SimaPro 7.3 Ecoinvent 2.2. GWP 100	Peer-reviewed	Baudino, C., Giuggioli, N.R., Briano, R., Massaglia, S., Peano, C. (2017). Integrated Methodologies (SWOT, TOWS, LCA) for Improving Production Chains and Environmental Sustainability of Kiwifruit and Baby Kiwi in Italy. Sustainability, 9, 1621. doi:10.3390/su9091621 www.mdpi.com/journal/sustainability
Kiwi fruit	0.23	7500	Italy	*A. arguta* (baby kiwi) Young phase	ISO 14040 standard series, SimaPro 7.3 Ecoinvent 2.2. GWP 100	Peer-reviewed	Baudino, C., Giuggioli, N.R., Briano, R., Massaglia, S., Peano, C. (2017). Integrated Methodologies (SWOT, TOWS, LCA) for Improving Production Chains and Environmental Sustainability of Kiwifruit and Baby Kiwi in Italy. Sustainability, 9, 1621. doi:10.3390/su9091621 www.mdpi.com/journal/sustainability
Kiwi fruit	0.15	15000	Italy	*A. arguta* (baby kiwi) Full phase	ISO 14040 standard series, SimaPro 7.3 Ecoinvent 2.2. GWP 100	Peer-reviewed	Baudino, C., Giuggioli, N.R., Briano, R., Massaglia, S., Peano, C. (2017). Integrated Methodologies (SWOT, TOWS, LCA) for Improving Production Chains and Environmental Sustainability of Kiwifruit and Baby Kiwi in Italy. Sustainability, 9, 1621. doi:10.3390/su9091621 www.mdpi.com/journal/sustainability
Kiwi fruit	0.16		Italy	*A. arguta* (baby kiwi) Total	ISO 14040 standard series, SimaPro 7.3 Ecoinvent 2.2. GWP 100	Peer-reviewed	Baudino, C., Giuggioli, N.R., Briano, R., Massaglia, S., Peano, C. (2017). Integrated Methodologies (SWOT, TOWS, LCA) for Improving Production Chains and Environmental Sustainability of Kiwifruit and Baby Kiwi in Italy. Sustainability, 9, 1621. doi:10.3390/su9091621 www.mdpi.com/journal/sustainability
Kiwi fruit	0.21		Korea		ISO standard GWP 100 (IPCC, 2001)	Peer-reviewed	Deurer, M., Clothier, B., Huh, K-Y., Jun, G-III., Kim, I., Kim, D. (2011). Trends and Interpretation of Life Cycle Assessment (LCA) for Carbon Footprinting of Fruit Products: Focused on Kiwifruits in Gyeongnam Region. Kor. J. Hort. Sci. Technol. 29(5), pp. 389-406.

Kiwi fruit	0.178	27687	New Zealand	Gold	ISO 14040 and 14044 PAS 2050 GWP 100 (IPCC, 2001)	Report	Mithraratne, N., Barber, A., McLaren, S.J. (2010). Carbon Footprinting for the Kiwifruit Supply Chain – Report on Methodology and Scoping Study (Final Report). Landcare Research Contract Report: LC0708/156 (Revised Edition) MAF Contract No. GHG0708-A
Kiwi fruit	0.212	20707	New Zealand	Green	ISO 14040 and 14044 PAS 2050 GWP 100 (IPCC, 2001)	Report	Mithraratne, N., Barber, A., McLaren, S.J. (2010). Carbon Footprinting for the Kiwifruit Supply Chain – Report on Methodology and Scoping Study (Final Report). Landcare Research Contract Report: LC0708/156 (Revised Edition) MAF Contract No. GHG0708-A
Kiwi fruit	0.24	17157	New Zealand	Organic Green	ISO 14040 and 14044 PAS 2050 GWP 100 (IPCC, 2001)	Report	Mithraratne, N., Barber, A., McLaren, S.J. (2010). Carbon Footprinting for the Kiwifruit Supply Chain – Report on Methodology and Scoping Study (Final Report). Landcare Research Contract Report: LC0708/156 (Revised Edition) MAF Contract No. GHG0708-A
Kiwi fruit	0.217		New Zealand	Gold	Carbon footprint analysis LCI- databases, by the Swiss Centre, Ecoinvent v.2.2. (2010) GWP 100 (IPCC, 2007)	Peer-viewed	Müller, K., Holmes, A., Deurer, M., Clothier, B. E. (2015). Eco-efficiency as a sustainability measure for kiwifruit production in New Zealand. Journal of Cleaner Production, 106, pp. 333-342. doi.org/10.1016/j.jclepro.2014.07.049
Kiwi fruit	0.135		New Zealand	Green	Carbon footprint analysis LCI- databases, by the Swiss Centre, Ecoinvent v.2.2. (2010) GWP 100 (IPCC, 2007)	Peer-viewed	Müller, K., Holmes, A., Deurer, M., Clothier, B. E. (2015). Eco-efficiency as a sustainability measure for kiwifruit production in New Zealand. Journal of Cleaner Production, 106, pp. 333-342. doi.org/10.1016/j.jclepro.2014.07.049
Kiwi fruit	0.146	36000	New Zealand	Integarted	Carbon footprint analysis LCI- databases, by the Swiss Centre, Ecoinvent v.2.2. (2010) GWP 100 (IPCC, 2007)	Peer-viewed	Müller, K., Holmes, A., Deurer, M., Clothier, B. E. (2015). Eco-efficiency as a sustainability measure for kiwifruit production in New Zealand. Journal of Cleaner Production, 106, pp. 333-342. doi.org/10.1016/j.jclepro.2014.07.049
Kiwi fruit	0.206	26200	New Zealand	Organic	Carbon footprint analysis LCI- databases, by the Swiss Centre, Ecoinvent v.2.2. (2010) GWP 100 (IPCC, 2007)	Peer-viewed	Müller, K., Holmes, A., Deurer, M., Clothier, B. E. (2015). Eco-efficiency as a sustainability measure for kiwifruit production in New Zealand. Journal of Cleaner Production, 106, pp. 333-342. doi.org/10.1016/j.jclepro.2014.07.049
Kiwi fruit	0.819	21000	New Zealand	Organic (500 vines/ha)	STELLA, Carbon Footprint. BSI 2008 GWP 100	Peer-reviewed	Page, G., Kelly, T., Minor, M., Cameron, E. (2011). Modeling Carbon Footprints of Organic Orchard Production Systems to Address Carbon Trading: An Approach Based on Life Cycle Assessment. Hortscience, 46(2), pp. 324–327.
Kiwi fruit	0.152	25281	Iran	Conventional	ISO 14040 SPINE@CPM database GWP 100 (IPCC, 1995)	Peer-reviewed	Nikkhah, A., Emadi, B., Soltanali, H., Firouzi, S., Rosentrater, K.A., Allahyari, M.S. (2016). Integration of life cycle assessment and Cobb-Douglas modeling for the environmental assessment of kiwifruit in Iran. Journal of Cleaner Production, 137, PP. 843-849. doi.org/10.1016/j.jclepro.2016.07.151
Kiwi fruit	0.631		Greece	99 kiwi fruit producers	GWP 100	EPD	Zeus KIWI. (2011). Environmental product declaration for kiwi fruits. EPD PCR 2011:2. UN CPC 01342. Version 1.0 – kiwi fruit