Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Energy and Technology

Assessment of food losses and waste and related greenhouse gas emissions along a fresh apples value chain

Oluwadamilola Omoleye

Master's thesis
Soil, Water and Environment - Master's Programme

Institutionen för Energi och Teknik
Department of Energy and Technology

Examensarbete 2020:11
ISSN 1654-9392
Uppsala 2020

SLU, Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Energy and Technology

Title: Assessment of food losses and waste and related greenhouse gas emissions along a fresh apples value chain
Swedish title: Bedömning av matsvinn, matavfall samt relaterade växthusgasutsläpp i en värdekedja för färska äpplen
Author: Oluwadamilola Omoleye

Supervisor: Techane Bosona, Department of Energy and Technology, SLU
Examiner: Girma Gebresenbet, Department of Energy and Technology, SLU

Course: Master thesis in Environmental science
Course code: EX0897
Credits: 30 hp
Level: Advanced, A2E
Programme/education: Soil, water and environment-Master`s programme

Series title: Examensarbete (Institutionen för energi och teknik, SLU), 2020:11
ISSN: 1654-9392

Uppsala 2020

Keywords: food loss and waste, apple loss, value chain, environmental impacts, GHG, emissions
Online publication: http://stud.epsilon.slu.se

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file.

If you are more than one author, you all need to agree on a decision. You can find more information about publishing and archiving here: https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.

Abstract

Reducing food waste is very important for food security and environmental issues. The aim of this study is to assess potential food losses and waste (FLW) along fresh apples value chain, related environmental impact (emissions), and identify applicable measures to reduce losses and waste. The study covered fresh apple value chain from production to consumption considering agricultural, processing, distribution and consumption stages. Both quantitative and qualitative analyses have been used. For FLW estimation, both primary data and secondary data were used. For greenhouse gas (GHG) emission assessment, secondary data was compiled and used. Considering the total FLW along the whole value chain, FLW became about 42% of the yield. The contribution of processing (post-harvest handling between farm and retail) stage is 42%, followed by the consumption stage (25%), agricultural production (19%), and the distribution (to and from retail and handling at retail) stage (14%). Considering the whole value chain, GHG emissions (organic apple) shows that agricultural production stage contributes 8%, processing 38%, distribution 18% and consumption 36%. Conventional apple emission is the same percentage at processing and distribution stage, 1% increase at agricultural production and consumption each. FLW at the end of the value chain (consumption) causes more emission per unit FLW, because of the large amount of loss at this stage and higher accumulated impacts from agricultural to consumption stages. The major causes of fruit loss ad waste are quality attributes, mechanical injuries, improper harvesting method, improper handling, inadequate storage facilities, over-purchasing, spoilage etc. Strategies to reduce FLW of apple related environmental impact include increasing awareness on FLW, improving post-harvest handling of fruits, reuse and recycle food rather than waste.

Key words: Apple value chain; Food loss; GHG emission; apple loss factors

Table of Contents

List of tables

List of figures

Abbreviations

FLW- Food loss and waste

GHG- Greenhouse gas

FSC- Food supply chain

CO_2 – Carbon dioxide

1. Introduction

1.1 Apple production

There is an increase in food production as a result of an increasing world population Intensive agricultural practices help in food production and have negative impacts on the environment. Use of fertilizers, pesticides contribute to environmental issues, food safety and security(Liu et al, 2013).

Organic farming is a type of farming system which implements the use of natural inputs than synthetic input such as pesticides, fertilizers, chemicals etc. It is like conventional farming in other practices with restrictions on use of synthetic agrochemicals. Organic farming has been on the rise by farmers to protect the environment and improve natural processes.

Fruits are consumed for improved health by humans. Apple (*Malus domestica*) is a sweet, fleshy fruit produced by apple trees. Apples constitute 3% of the total consumer market in the EU followed by dairy products, meat, cereals, crop-based products, vegetables, beverages and pre-prepared meals (Notarnicola et al,2017)

Apples can be grown by conventional and organic methods. Organic apple is a commercial fruit highly cultivated in Sweden. Production of commercial apples ranges between 20000 tonnes per year in which organic is 1-2% (200-400 tonnes) in Sweden. The cost of production of organic apples is higher than conventional apples, despite higher cost of production, organic apples has lower yield. Apple produced can be sold as `organic` if it has been certified by two national organizations responsible for organic farming control; KRAV and Demeter. (FAO,2009)

1.2. Literature review

1.2.1 Apple value chain

Value Chain Analysis (VCA)- is a method used to identify where food loss is the most important along the supply chain. Level of food loss varies along stages of food supply and this depends on food type (cereals, fruits, vegetables, dairy etc), region/country, social and cultural practices. Product value chain is the process involved in production of goods to consumption. Apple value chain consists of a full range of activities and services required to bring the product from farm gate for sales in local and international markets. Addition of value to a product includes production, processing, packaging, storage, transport, marketing and distribution.

1.2.2 Food loss and waste (FLW)

Food loss is important in terms of food production and provision. Food loss is a threat to food security, food safety and quality and the environment. Food losses depend and differ at various stages such as production, storage, processing, marketing, consumption and food practices. According to FAO 2011, food loss can be described as resources wasted such as land, water, energy and inputs, for production of food that will not be consumed.

According to Muth et al, (2019), "food loss and waste (FLW) is defined as food lost at every stage of food supply chain from production to consumption including un-harvested food on the field; food damaged by pest, during transportation and food that were not consumed due to spoilage ,excess preparation and therefore disposed."

Different causes of FLW along the supply chain results in different volumes of waste at each stage. Food waste according to the FAO is estimated at 413 tonnes at the production stage, 293 tonnes at postharvest and storage stage,148 tonnes during processing. 161 tonnes at the distribution stage and 280 tonnes is wasted in consumption(Gustavsson et al,2013). Food types such as fruits, vegetables, poultry, nuts, cereals etc are wasted at different quantities at each stage. Approximately,30% of fruits and vegetables are wasted at the retail and consumption stage,26% of meat, poultry and fish, 15% of nuts and 41% of sugars and sweeteners (Buzby et al,2014). Waste exits for many reasons at different stages, FLW at different stages should be addressed in order to identify the extent of total amount of waste.

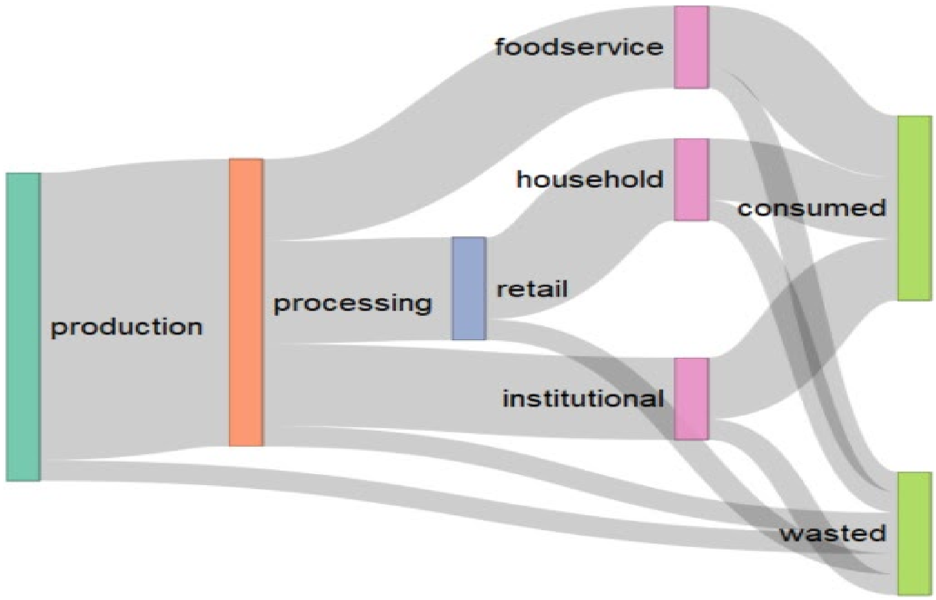

Figure.1. A model showing how food flows through the food supply chain

FLW at all stages; agricultural production, food processing, retail and consumption. Consumption between food service establishments and institutions were distinguished (Read et al., 2019).

Comparisons by various studies between conventional and organic farming systems performed on various agricultural products and at different factors recommends organic farming to be environmentally safe , due to its lower use of fossil fuel energy and less greenhouse gases emission which contributes to global warming (Flessa et al,2002) .Furthermore, products from organic farming are ascertained to be healthier and safer for consumption(Dendler et al., 2016)resulting in high demand due to the benefits especially in developed countries.

This study focuses on the production, consumption and loss of organic apple fruits were evaluated from an environmental perspective. How much fresh apple is lost and wasted along its supply chain and how can such losses be prevented? How waste from organic and conventional apple production impacts the environment? There are not specific answers to these questions as enough attention is not paid to food supply chain losses which are important.

1.2.3 FLW at global level

Food loss and waste is a worldwide issue and food security is a significant concern in all parts of the world however, of utmost concern in developing countries due to expanding population. Decrease of food loss will develop food order productivity. Natural resources such as land, water, fertilizer, and energy utilized in the production of food are lost alongside food waste. Foods that are not consumed contribute to CO_2 outflows just as loss of food monetary level. According to the Swedish Institute for Food Biotechnology:

Types of food losses/waste along food supply chain (Fruit commodities and products)

Agricultural production: losses as a result of mechanical damage during harvest e.g. fruit picking, sorting, crops left in field, animal attack, disease infection etc.

Post-Harvest handling and storage: these are losses that occur during handling, storage and production after harvesting as a result of spillage and degradation, insect infestation.

Processing and Packaging: losses occur at this level during fruit processing such as industrial or domestic processing such as canning, juice production (peeling, slicing of fruits).

Distribution: losses and waste when fruit is being distributed at the market level- wholesalers, retailers, supermarkets. This includes loss during packaging (boxes, crates), transportation to the distributors.

Consumption: losses and waste at domestic and household level during consumption.

1.2.4 Extent of food losses and waste

One-third of edible portions produced for human consumption are wasted worldwide i.e.1.3 billion ton per year (FAO,2011). Food waste occurs from initial production to domestic consumption. The amount of food waste varies by country, in high income countries, at household (consumption stage) food waste is higher than in any supply chain and in low income countries, food waste is mostly at the early stage of supply chain, less is wasted at consumer level.

Food loss in Europe and North America is between 280-300kg/year, in sub- Saharan Africa and South/Southeast Asia is 120-170 kg/year. Per capita food wastage by consumers in Europe and North America is 95-115 kg/year, but only 6-11 kg/year sub-Saharan Africa and South/Southeast Asia.

In countries with low and medium income, agricultural production loss dominates the FSC and losses at post-harvest and distribution are also important.

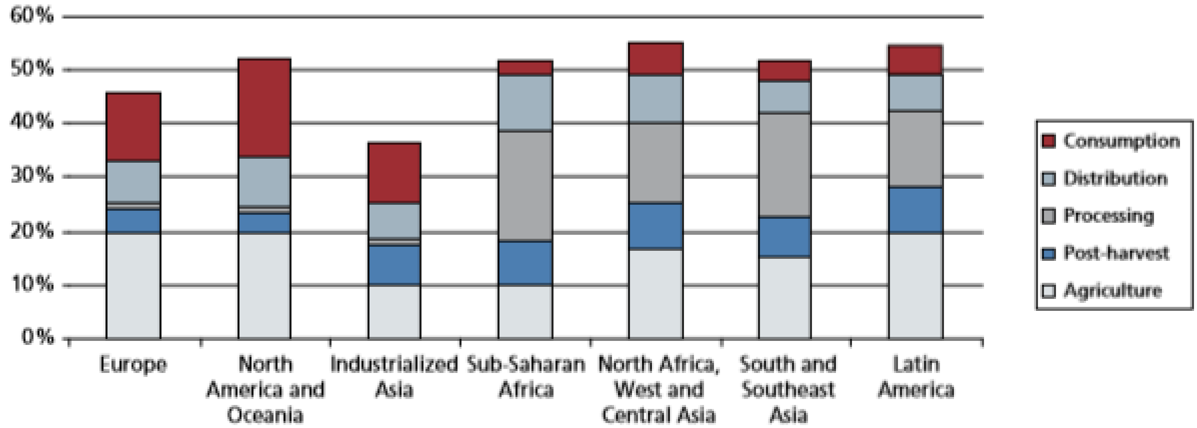

Figure 2. Graph showing Percentage of the initial production lost or wasted at different stages of the FSC for fruits and vegetables in different regions **(**FAOSTAT,2010)

“Agriculture” losses indicate losses during the harvesting process and subsequent sorting and grading. “Post-harvest” indicates losses occurring during processing, transportation and storage immediately after harvest and before processing (FAO,2011). The differences indicate the need to improve fruits and vegetables technology during post-harvest operations in developing countries.

1.2.5 Food loss and waste in Sweden

Due to lack of comprehensive data, food waste generated in Sweden is 1,210,000 tonnes as of 2012 which is equivalent to 127kg per person (Stare et al.,2013). Distributors are supermarkets including wholesalers have been identified but they generate less volume of food waste. Consumers include restaurants, catering facilities and households. According to Jensen et al,2010, data were based on how much food is disposed of in supermarket, restaurant

Despite the availability of facilities to separate food loss thrown as mixed waste, total volume of food waste as mixed waste is greater and the total food waste are calculated as percentage of mixed waste, they also increase. Total volume of food waste is unnecessary food waste and unavoidable food waste, unnecessary food waste in this context is defined as food that would have been consumed assuming it was handled correctly and eaten at some point e.g. bread, food leftovers in plate, unavoidable waste are the food loss during production and cannot be avoided such as peelings, bones, spoilage etc.

1.2.6 Fruits and vegetables losses across the food chain

Fruits and vegetables are of importance and have very short shelf life. This includes (cabbage, carrot, onion) as vegetables and tomato, apple, grapes, berries etc as fruits.

The rate of loss of fruit and vegetables in the agricultural production stage in high income countries is 22% , while in low income countries is 9% (FAO,2011).Reasons for such losses and waste differs widely in each region, according to Global food loss and Waste study, loss is higher in agricultural production in high income countries as a result of overproduction to deliver the right quantity irrespective of adverse weather, losses by producers as a result of market price variation, pest infestation on field, mechanical damage before and during harvest, etc.

Activities in post-harvest handling and storage includes cooling, cleaning, sorting, storage, processing, packing, transportation, and marketing. At post-harvest and storage phase, Losses in high income countries may be due to machinery and additional fruit sorting ,low and medium countries as a result of inadequate facilities such as transport and storage due to temperature and ventilation needed for preserving the fruits and vegetables, resulting to high losses due to degradation ,pest infestation and heat damage during summer to perishable fruit and vegetables (Themen,2014).

Across the value chain, packaging of fruits and vegetables before transportation to market and distribution and processing involves preserving the nutrition to extend the shelf life till it gets to the market. There is low amount of loss and waste during processing in high income countries compared to low income countries (FAOSTAT,2010).Loss is minimal due to accessibility to high technology, while in low income countries use of simpler practices like pickling, salting, poor utility, electricity supply during production etc may contribute to higher amount of loss and waste.

Distribution is a phase in the horticultural value chain from loading the product after packaging, from the farm for sales to consumers In high income countries there is the highest level of loss during this phase in the chain (at 6%) while middle income is less than 6% and low income is less than 4% (FAO,2011) The reason for the loss is due to retailers ordering more than the amount needed so as to ensure varieties of fruit and vegetables, the quantity ends up in excess and rejected by consumers when they become un-fresh. High request of a product by consumers during festivities/celebrations such that the demand goes down after this event resulting in wastage.

Another factor described by the Global Food losses and Waste study is poor refrigeration, products that are sensitive to cold are stored at extremely low temperature and those that require low temperature are stored at high temperatures.

In low and medium countries, the losses during this stage are effective at the consumers stage i.e. at the market. transportation, equipment used in packing, sold openly without refrigeration all contributes to fruit and vegetables loss.

Consumption is the last stage in the value chain, time of purchase by consumers of fresh or processed fruits and vegetables till it is consumed. The loss at high income countries is higher at this stage than in low income countries Above 20% loss in high income countries, 13% in middle income countries and 2% in low income countries(Themen,2014) This is in accordance with the Global Food losses and Waste study. Differences in losses at this stage depends on consumers behaviour such as discarding products 24 hours after purchase, cutting a large part due to degradation etc all these are identified as losses and waste.

1.2.7 Environmental Impacts due to FLW

Food loss comprises waste resources used in production of food and commodity e.g. land, water, inputs and energy. Choice of food is not only important for health; it also affects the environment. Food handling must be sustainable in order to reduce greenhouse gas emissions/ negative implications on the environment. According to FAO (2011), the carbon footprint of wasted food in 2007 is 3.3 billion metric tons equivalent to CO_2 with an estimated economic cost of 750 million U.S dollars. Across the supply chain from initial production of food and product to the final consumers, greenhouse gases (GHG) e.g. carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are produced. (Zhou,2011). Landfills have adverse effects on the environment, produce toxic chemicals and release greenhouse gases (Sonesson, et al 2010) and emissions from burnt incinerators; food waste and other waste products deposited in landfills, bacteria breakdowns the waste which produces gases.

Greenhouse gas emissions (GHGs) are not the only negative environmental impact associated with natural resources / food wastage; other impacts include land occupation, water usage, energy consumption and biodiversity losses, soil erosion, deforestation etc. Plants and animal products have various environmental impacts both negative and positive. However, animal products e.g. milk, eggs , meat etc usually have more negative environmental impacts, negative environmental impacts linked with plant products such as fruits, vegetables, flowers, tubers etc are as a result of emission from soils and from consumption of energy such as fossil fuels etc are also important (Cederberg et al.,2009).

1.3 Aim

The general objective of this study is to assess potential losses and waste along fresh apples value chain, related environmental impact (emissions) and identify applicable measures to reduce losses and waste. The study is specifically aimed to:

- identify and map apple value chain
- assess potential loss/waste along the apple value chain and related environmental impact.
- identify factors causing FLW along apple value chain
- identify and describe available technologies (methods) for loss reduction and reuse of waste products.

2. Materials and Methodology

2.1 Scope of the study

The focus of this study is on FLW along fresh apples supply chain and GHG emissions due to this apple loss and waste. The study covers whole chain including agricultural production, processing, distribution, and consumption stages. GHG emissions is the only environmental impact category assessed in the study, focusing on GHG emission due to FLW along fresh apple supply chain.

2.2 Data Collection

In this study, both primary and secondary data have been collected and used. The primary data survey was conducted to collect data on FLW along apple value chain. Secondary data was collected to enrich the FLW data and create data base for the assessment of GHG emission due to FLW.

2.2.1 Data survey of FLW along apple value chain

For collection of primary data, there different categories of questionnaire were designed; questionnaire targeting apple processor, retailers and consumers. Questions include in each questionnaire are provided in Appendix A. A google format was created for each questionnaire and sent out to all targeted groups. For consumers, an online survey was conducted targeting consumers in Sweden in spring 2020. In this case, the google-format based questionnaire distributed via email and social media platforms to university different networks and student networks. For processors and retails, the questionnaires were distributed to a processor, selected retails.

2.2.2. Secondary data of losses and waste along apple value chain

This is based on literature study (reviews articles, project and reports) All literature used in this paper is properly referred to in the text (including figures and graphs) This study is focused on fresh apple value chain including agricultural production, processing, distribution retail , and consumption stages. Secondary data sources include mainly research reports and published scientific papers. Data collection was conducted between March and May 2020. Selected search words for this study were “apple loss and waste”, “organic apple value chain”, “environmental impact of apple value chain”, , LCA and apple”, and “carbon footprint and apple”. The major Databases were Google scholar, and Web of Science (all databases). In some cases, reference list from articles were also used to find more relevant data source.

2.2.3. Secondary data of environmental impact along value chain

Emission data obtained from different reports, with focus on developed countries. After identification of relevant papers, 14 papers with 17 supply chains were used as source of emission data along fresh apple supply chain. Organic and conventional apple value chains were considered separately to identify the differences between the two supply chains. Data from integrated agricultural production of apple was categorized as organic in this study.

2.3. FLW estimation along apple value chain

In order to estimate FLW, firstly, the supply chain was determined to be agricultural production, processing (including transport to processing facility, storing, and packaging), distribution (handling at retail), and consumption levels. Accordingly, 10 apple value chains were identified from relevant peer reviewed papers and trusted documents. Secondly, FLW at each stage of the 10 value chains was extracted carefully at each stage of each apple value chain. Initially, FLW data was estimated (extracted) as percentage of the apple amount entering each stage of the value chain. Then, FLW was quantified in weight corresponding to 1 ton (after reducing all losses) of fresh apple finally consumed. This increases our understanding on characteristics of FLW along apple value chain. All unit conversions were done carefully, because different studies presented their results in different units. This conversion of unit enables us to have uniform database for analysis in this study.

2.4. GHG emission estimation along apple value chain

To estimate GHG emission, firstly data on emission due to activities each stage of value chain (agricultural production, processing, distribution, and consumption) was extracted from the 17 apple value chains (see section 2.3). Then the data is carefully edited to maintain the uniformity of unit, and supply chain structure. This is important as different papers (data sources) used different units and different supply chain structure. Therefore, the extracted GHG emission values were provided in kg CO2 equivalent (kg CO2 eq) per 1-ton fresh apple handled at each stage. Using this redefined unit of emission and the quantity of FLW along apple value chain (see section 2.3), GHG emission corresponding FLW at each stage was calculated.

In the estimation of FLW and related GHG emission values, Excel Spreadsheet was used. Mainly, descriptive statistics such as, minimum, maximum, and average values are used to describe and present the results along with Tables, graphs, and charts.

Level of food loss varies along stages of food supply and this depends on food type (cereals, fruits, vegetables, dairy etc), region/country, social and cultural practices.

2.5. Assumptions and limitations

In this study, the following major assumptions were made:

- The amount of FLW does vary between Organic and conventional apple value chain.
- Except the agricultural production stage, GHG emission at processing, distribution, and consumption levels does not vary between organic and conventional apple value chains.

- FLW characteristics and related emission along apple value chain do not vary much between different developed countries.
- In order to describe, the FLW and related GHG emission in quantitative value (weight), 1 ton of consumed (after reducing all FLW values along the chain) fresh apple was considered as reference (functional unit) for final analysis.

This study has also some limitations:

- Processed apple such as dried and apple juice product value chains were not studied in detail.
- Except GHG emission, other environmental impacts categories such as energy use, land use, eutrophication, acidification etc are not considered.

3. Results

3.1 Mapping apple value chain

Loss and waste of fruit occurs in all stages along the value chain. The reason for this is fruits are delicate and have a short shelf life i.e. cannot be kept for so long without effective preservation measures. Loss of fruits vary considerably from one product to another because the fruits and vegetables sector are heterogeneous; fruit products varies as some can withstand certain treatment and temperatures while some products are sensitive to rough handling and incorrect temperature (Mattsson,2014). For this reason, the major activities along apple supply chain have been mapped out (see Figure 3).

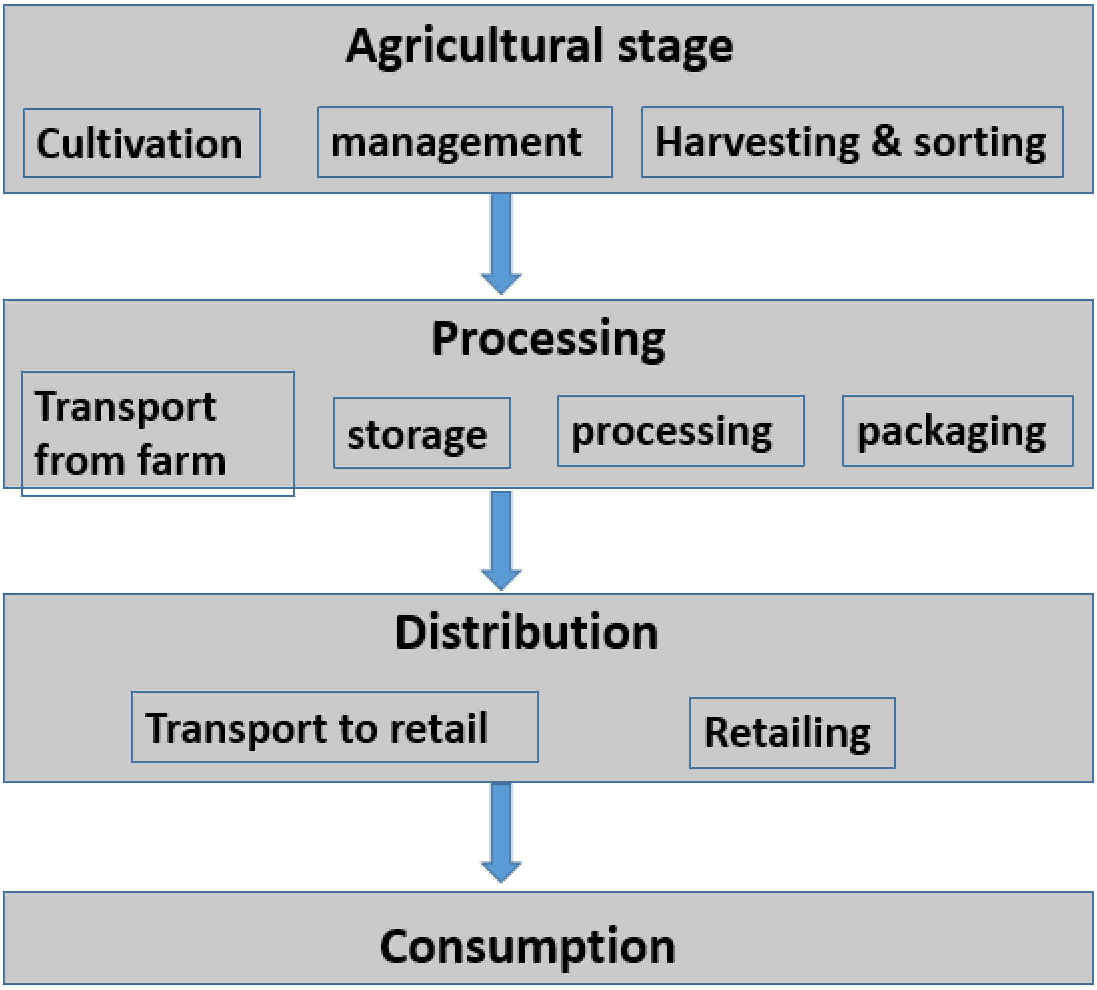

Figure 3: Main activities along the apple value chain as identified in this study - from production at the farm level to the final consumers

3.2. Background characteristics of survey participants and related data

From the online survey of consumers, 91 respondents were registered. Out of this about 50 % were female and 50% were male (see Table 1). Regarding the causes of FLW, spoilage (56% of respondents), over purchase (27), bad taste (9%) and other factors (9%) are the major factors contributing to FLW along apple value chain (see Table 2).

Table 1: response regarding gender

Gender	Frequency (number of respondents)	Percentage (i.e. percentage of total respondents)
Female	45	50
Male	45	50
Total	90	100

Table 2(a): responses of respondents regarding FLW at consumption level

Loss (%)	frequency (no of respondents	Percentage (%)
0-1%	43	47.25
1-2%	6	6.59
2-3%	13	14.29
3-5%	8	8.79
5-10%	8	8.79
10-20%	7	7.7
20-30%	5	5.5
30-40%	1	1.1
40-50%	na	na
>50%	na	na
Total	91	100

Table 2(b): Response regarding factors causing loss

Factor	Frequency (number of respondents)	Percentage (i.e. percentage of total respondents)
Bad taste	8	8.9
Spoilage	50	55.6
Over purchase	24	26.7
Other factor	8	8.9
Total	90	100

Table 3: Response regarding purchase habit of apple

Product type	Frequency (number of respondents)	Percentage (i.e. percentage of total respondents)
Organic	26	28.6
conventional	29	31.9
both	36	39.6
Total	91	100

Consumers are also assessed in the survey in terms of their consumption type and fruit selection. Regarding the purchasing behaviour of respondents, 28% purchase only organic apple, 32% purchase only conventional, and 40%, purchase both organic and conventional apple. Amount of fresh apple loss and waste indicated by the consumers in their household's ranges between 0%-40%. About 47% of respondents indicated that the FLW of apple at consumption level is less than 1% of apple purchased. In general, from result of survey, the average FLW value at consumption level was 4.6% of purchased amount. Main reasons for losses and waste in the homes are bad taste, spoilage, over-purchase and other factors. Most prominent cause of loss and waste is spoilage, followed by over-purchase and bad taste respectively. The survey indicated also that most consumers purchase apple juice rather than dried apple.

Primary data was also acquired from an apple processing company in Sweden. The company receives from farmers and perform activities such as storing, sorting, packaging and marketing. Storage of apple at the facility is between 3 to 4 months, with temperature at 1- 4°C.Activities at the facility include washing, sorting, packaging, before distribution to the retailers. Apple loss and waste at this stage is estimated at 10-20 percent. Cause of losses at the supply chain occurs during storage, packaging, transportation to retailers, truck loading and unloading.

Primary data was also obtained from 4 retailing stores, where both conventional and organic apples are sold as fresh and dried product and in processed form such as apple juice, apple chips. Two of the stores indicated the amount of loss at their facility (2% and 3-5%) while the other two retails did not specify the exact amount of loss. Causes of loss stated at the facility include bruises, impacted injuries etc.

3.3 Estimated FLW values based on primary and secondary data

Collection of data was done from 10 published reports on the amount of FLW at each stage of apple supply chain. Data is not obtained from each stage because some reports do not contain agricultural to consumption stages i.e. some reports cover only one of the stages and some have one of the stages. (agricultural, processing, distribution and consumption). Packaging, sorting was added to processing, transportation to retail, supermarkets, stores was included under distribution stage for the datasets to be more consistent. The collected data is organized and presented in Appendix-B.

Table 4 describes that considering the apple amount entering each stage, the average FLW values were estimated to be 8%, 19%, 8%, and 15% at agriculture, processing, distribution, and consumption levels respectively. This average value has included both the data obtained from primary and secondary sources. The findings of this study indicated that processing and consumption levels contributes much to the FLW along apple value chain (see Table 4).

Table 4 also indicates that when 1 ton of consumed apple is considered, the agricultural yield before loss was estimated to be 1.716 ton while FLW values were 137 kg, 300 kg, 102 kg, and 177 kg at agriculture, processing, distribution, and consumption level respectively.

Table 4: Summary of loss and waste estimation data along apple fruit value chain

	Before loss	**Mean FLW**	**Mean FLW**	**Quantity remaining after loss**
Value chain stage	Ton	% of amount entering each stage	Ton	Ton
Agriculture	1.716	8	0.137	1.579
Processing	1.579	19	0.300	1.279
Distribution	1.279	8	0.102	1.177
Consumption	1.177	15	0.177	1
Total			0.716	

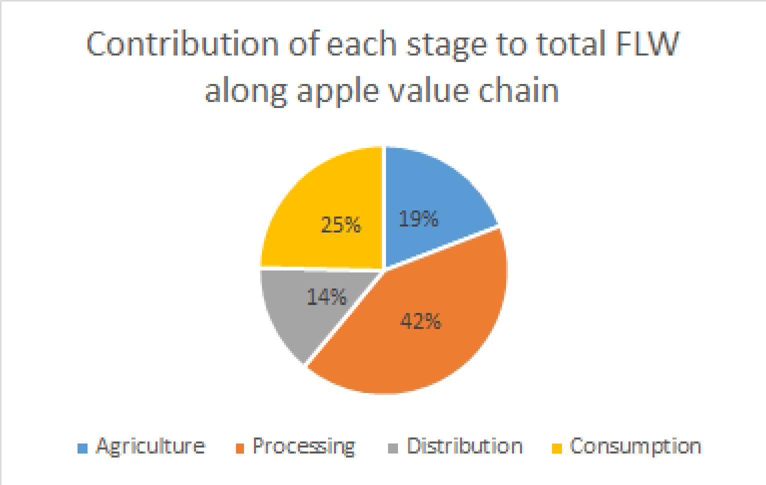

Figure 4: Pie chart showing calculated estimates of FLW along the supply chain

Figure 4 shows the percentage contribution of each stage to the total FLW (716 kg per 1 ton consumed fresh apple) along the value chain. Processing stage has the highest amount of loss (42%), followed by consumption stage (25%), agriculture stage (19%), with the lowest amount at the distribution phase (14%).

3.4 Environmental Impacts (GHG emissions) produced by apple loss and waste

The detailed data base created from secondary data sources is presented in Appendix C.

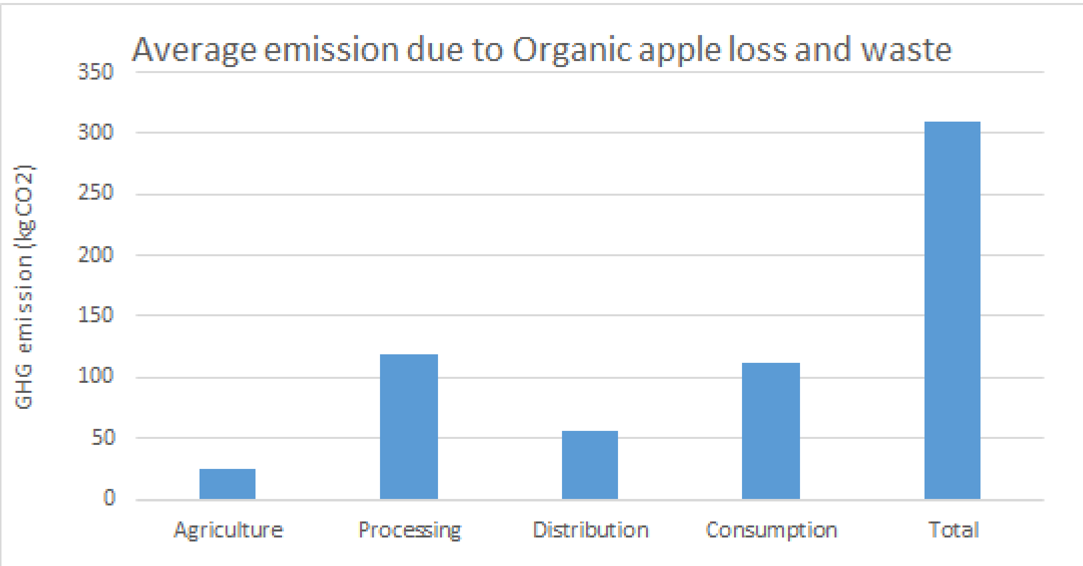

Figure 5(a): Average GHG emissions from organic apple loss and waste

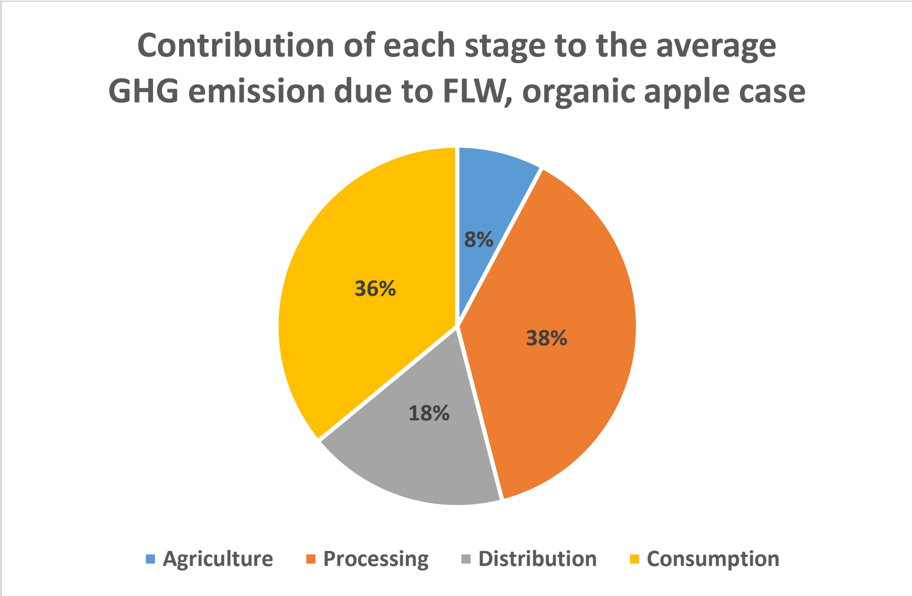

Figure 5(b): Average GHG emissions showing each stage in percentage (%)

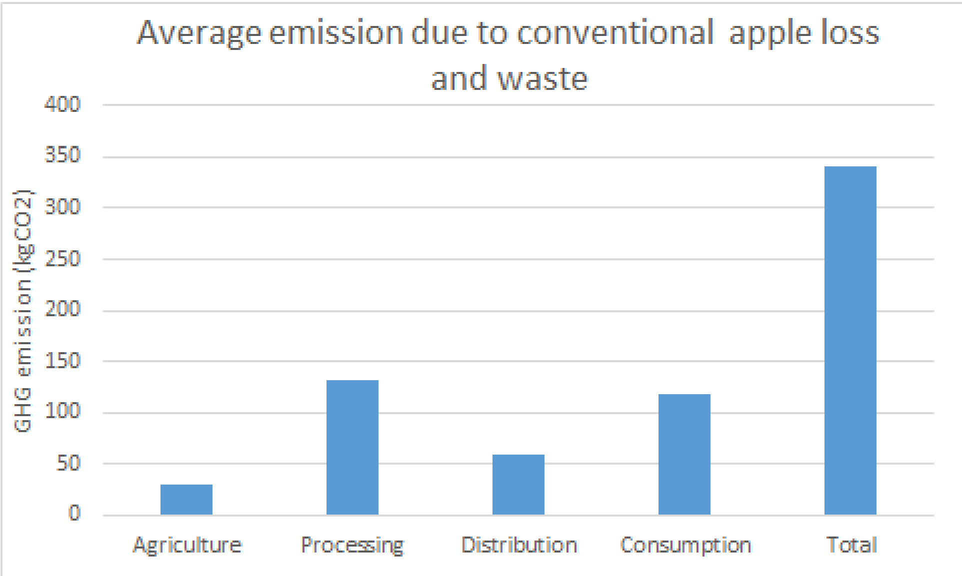

Figure 6(a): Average GHG emissions from conventional apple loss and waste.

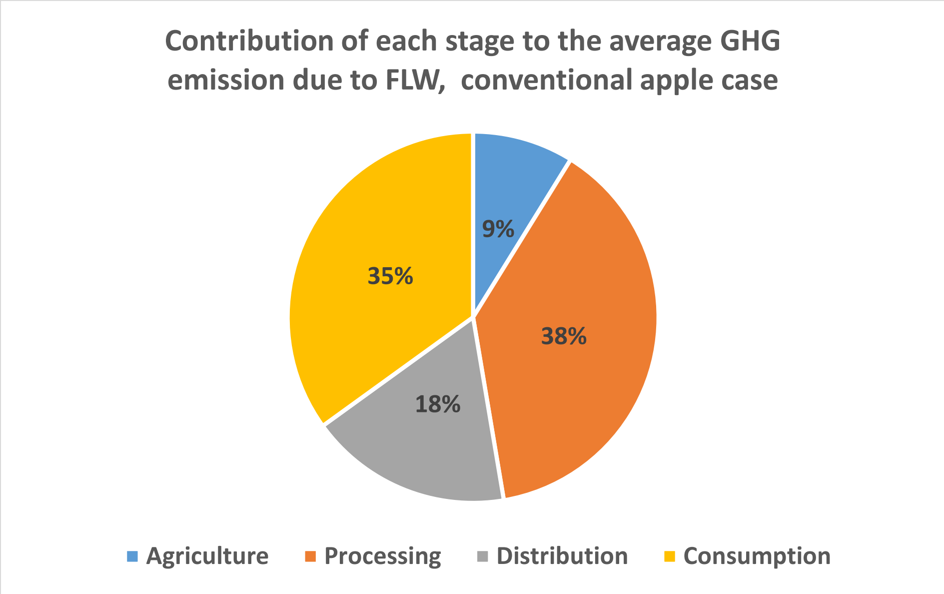

Figure 6(b): Average GHG emissions showing each stage in percentage conventional apple loss and waste

Figure 5 and 6 shows emission rates from organic and conventional apples along the supply chain. Regarding GHG emission from organic apple, GHG values are agricultural stage (24kgCO_{2eq}/ton of apple),processing(118kgCO_{2eq}), distribution (56kgCO_{2eq}) and consumption stage (111kgCO_{2eq}). Regarding GHG emission from conventional apple, the GHG values are at agricultural stage (30kgCO_{2eq}/ton of apple),processing(131kgCO_{2eq}), distribution (60kgCO_{2eq}) and consumption stage (119kgCO_{2eq}).

4. Discussion

The purpose of this study is to identify the potential FLW along the apple value chain, the environmental impact (emissions) due to FLW, and steps to reduce FLW. There has been particularly limited research on a specific fruit (apple) loss and waste across the supply chain. Most reports are usually focus on fruit and vegetables or just one or two stages of the apple supply chain.

In this study, post-harvest handling activities such as storage, packaging, cooling, washing, grading etc are classified as processing stage. In the case of primary data, only 1 processor has participated. It was difficult to get more data from other processors. Distribution stage consisted of transportation to retailer and handling, at wholesalers/retailers, wholesalers/retailers. In the survey 4 retailers participated.

Regarding consumer survey, 91 participants were recorded. About 55.7% of the consumers responded that spoilage is a major factor contributing to apple loss,26.7% as over purchasing and 8.9% respondents chose bad taste and other factors. In the primary survey, the responses reflect the characteristics of individual or household consumption. On the other hand, data at consumption stage from literature review consisted of large households, restaurants, and this influenced the loss and waste amount.

4.1 Differences in apple loss and waste along the supply chain.

The first research question is to estimate loss and waste along its supply chain. Stages considered in this study are agricultural production, processing and consumption Assessment showed that the largest loss from both organic and conventional apple came from the processing stage and smallest loss occurred at distribution stage. Second largest loss occurred at consumption stage followed by agriculture stage . Previous research has conducted fruit losses and waste using value chain analysis and other methodologies (Porat et al 2018;Meyer et al 2018;Erikkson 2012;Burzby et al;2016).

In general, results regarding FLW show a similarity with results from previous studies, however there are also differences. One reason is that in this study, limited data sources consisted of all the supply chain i.e. no available data for processing stage compared to the consumption stage. Porat et al (2018) has similar results with the study in terms of loss and waste across the supply chain except at the processing stage.

In contrast, FAO, (2011) calculated fruits and vegetables loss in Europe and indicated that more loss occurred at the agricultural stage (20%), followed consumption stage (14%) with the least at distribution and processing stage. Reason for this difference could be as a result of FAO (2011) did not calculate only for apple but for all fruits and vegetables.

4.1. Apple loss and waste along its supply chain

4.1.2. During growth and harvest

Waste at this stage varies a lot as it depends on the variety (type) being harvested and conditions of the fruit during harvest. Various diseases, pests, physiological disorders etc can affect apples on the field. (Tarabay et al,2018). Disorders are described as complications in the fruit that are not pathogen related. Stress caused by temperature, humidity, light, handling etc, (Masood,2011)

Quality attributes such as size, shape, colour and absence of blemishes etc is important along the supply chain (Nissen, et al 2018). Grower plays a big role in this aspect as they decide on the quality limit the buyers want (Mattsson,2014). Decision made during production and distribution chain to some extent may depend on financial considerations such as product price.

Harvesting can be done manually or mechanically. Hand harvesting is done for products that are vulnerable to physical injury such as apples (Wills et al,2007), though harvesting is done with care, spoilage can still occur. Determining the maturity stage for various varieties of apple is difficult. Choice of harvesting date- too early harvesting and late harvesting has an impact on the fruit firmness, colour, skin colour, seed colour, production of flavour and odour. Apples harvested too early may be sour, harsh and badly coloured, and if harvested when they are too mature result in spoilage and improper storage (IALC,2006).

Different picking dates of apples during the harvesting period may also affect the fruit quality. Water quantity is reduced in apples harvested early due to waxy surfaces not fully formed. Surface in a storage unit of early harvested apple fruits is larger because transpiration depends on the fruit surface area, making small fruits smaller in weight. Structure of fruit cuticle is another factor contributing to water evaporation from fruits, the cuticle is not fully developed in apple fruit harvested early (Mitcham et al ,2002, Kvikliene et al,2009). The cuticle is the first obstacle that pathogens must challenge (Kvikliene et al.2009).

In summary, causes of losses during harvesting are mechanical injuries by dropping, throwing etc, immature or over-mature harvesting, weather impact on fruit e.g. frost sun, improper harvesting method, late transportation to storage/markets. Lack of communication among producers, distributors as well as consumers' meal plan all further increases food wastage. (Sonosson et al,2010). Interest in food waste and loss has developed over the years, fruits have high diets and are important classes of food for consumers, amount of fruit waste and loss needs to be evaluated along the value chain.

4.1.3 Processing

In this case, processing includes sorting ,grading and packaging. Harvested products need to be protected; this is done by packaging. **Packaging** is essential in terms of the product quantity, the market and customers' needs. Different materials, shapes, sizes are used for packing horticultural products. Packaging helps to prevent damage during distribution and for maintenance (Thompson and Mitchel,2002). It is important to use a good package to protect the fruit and reduce the large amount of damage sustained by fruits. (Fadiji et al.,2016)

Apples not properly packed can result in losses of the product and cause physical injuries to the product. Most observable cuts, bruises punctures on apple fruits occur during packaging and distribution. Bruising is caused by dropping the fruits on a hard substance and this causes impact damages on the fruit (Kafashan et al,2007). Large amounts of fruits are wasted due to damage caused by bruising.

Sorting is performed to distinguish the product by colour, size and grade (Thompson, Mitcham and Mitchell,2002). **Grading** is done to reduce handling losses during transportation and to increase uniformity. Grading is done according to size, weight , colour and/or combination of all the features(Wills et al.,2007).Inadequate cleaning and sanitation, inappropriate grading and packaging , mounting crates containing fruits, dropping of fruit from a long distance, damage by improper handling e.g. long fingernails all cause post-harvest losses of fruits (IALC,2006).

4.1.4 Distribution

This includes transportation to wholesalers, retailers and final consumers. Horticultural products such as apples are highly susceptible to damage during transportation and post-harvest handling (Sittipod et al.,2009, Eissa et al.,2012). It is important to avoid blemishes, cuts, bruises etc to meet consumers' wants and requirements. Waste can occur due to misconception of fruit been ripe and then kept into storage or defects on the fruit are not detected which affects the quality of the apple fruit (Mattson,2014)

Temperature during transportation is not always maintained i.e. optimal temperature needed for fruits is difficult to attain affecting the quality of the damage. Different types of fruit require different temperature, separating the fruits may not be possible. Optimal temperature of 8-19 degrees Celsius is considered ideal for all fruits and vegetables. (Mattson,2014). Ideal temperature for apple fruit is 2-2.5degrees Celsius with relative humidity at about 90-92%(USAID,2008). It is also stated that apples can be kept for a long time in a cool storage area (3^{o}C, well ventilated space, dark and slightly humid) (Masood,2011).

Wholesalers check the quality of product delivered. The quality, class, size, colour etc is checked with agreement in the contract. Error during transportation and handling (deteriorated fruits) is returned to the sender. The longer the product is being transported, more chances the quality reduces. (Mattson,2014). Sometimes deteriorated products are packed e.g. fruits affected by green mould are sold in the criteria of less quality product. Problem with this is that some of the products which previously was not affected by the mould may become mouldy either in the store or after purchase by consumers. In the situation whereby over purchased is done by wholesalers, storage facilities may not be enough for all the excess products, resulting in damage and increased waste.

After products are dispatched from wholesalers to retailers, wastes arise as a result of improper handling or by ordering too much. At this level, improper handling of fruit boxes can result in bruised products; bruising is not visible instantly but may develop later after purchase by consumers. Wrong storage procedure such as the use of inappropriate temperature. The fresh products are chosen first by the consumers, while some products remain on the shelves for a long time and then deteriorate. Products returned by retailers to the wholesalers are not concluded as waste as some of these products are sold to another buyer who finds it suitable for their quality requirement (Mattson,2014).

4.1.5 Consumption

Along the food supply chain, the consumer stage includes preparation processes according to the consumers' wants and consumption in the home. Amount of fruits wasted at home is not always accounted for nevertheless there is a significant amount of waste with the consumers. Consumers´ waste includes wastes at industrial, household, restaurants, hotels. Factors contributing to loss and waste at this level includes lack of storage facilities, inappropriate handling, poor portion control, over-purchasing, poor food safety and food quality controls. (CEC,2019).

4.2 Impact assessment

Considering 1 ton of consumed apple as a reference, GHG due to FLW of organic and conventional apples are 310kgCO_{2eq}/ton and 340 kgCO_{2eq}/ton respectively. The difference between these two production types is lower than 10%. In case of organic apple ,consumption contributes about 36% of the total mission per 1 ton of apple consumed and in conventional case, the consumption stage contributes 35% of total emission per ton of apple. The main contributor is the processing stage accounting for 38% of the total GHG emission for both conventional and organic apples. Second to the processing stage is the consumption stage which is 1% lower than conventional. Distribution stage accounts for 18% of total GHG for both organic and conventional, the agricultural stage contributes 8% and 9% of total GHG for organic and conventional apples respectively. This indicates that not much difference is observed between the two production types. Corresponding with these findings, Longo et al(2017) studied life cycle assessment of organic and conventional apple supply chains in Italy and indicated that packaging has a major impact during the post-harvest, about 71.5% for both organic and conventional apples step due to high electricity consumption of cold storage ,washing and sorting of apples.

Considering the entire phases of a food product value chain, more impact occurs at the production phase. Nevertheless, each phase of food production i.e. production to consumption has additional environmental impacts. The more food product is wasted along the supply chain, the higher its environmental impacts This shows as the supply chain goes down (consumption), the higher the food wastage footprint. (FAO,2013). More wastage occurred at the Processing stage and consumption stage in this study therefore higher impact is observed.

For example, some studies have assessed and discussed the environmental impact of food waste. Notarnicola et al (2017) inquired into the environmental impact of most food types consumed in the Europe countries and indicated that food is wasted at agricultural, industrial and domestic phases. Katarina Scholz (2013) examined the carbon footprint of food wastes from retailer's store, which accounted for 46% of the total CO_2 effect of fruit and vegetable waste.

Purchase of locally produced apple have less environmental impact compared to imported apples, with transportation as the primary cause of impacts (Stadig, 1997; Jones, 2002; Blanke and Burdick, 2005; Sim et al., 2007).Stadig(1997) found out that consuming apples produced and stored in Sweden resulted in less environmental impacts than importing them from New Zealand.

Organic apple is characterized by lower impacts for all supply chain categories. Environmental impact during cultivation of organic apples is mainly caused by irrigation, fertilization and harvest, diesel consumption during irrigation and use of manures /vegetable matter. After harvest, activities such as storage, packaging, transportation have similar impacts for organic and conventional apples.

Certain impacts have a global effect while some occur essentially at local scale. Methane (CH_4) emissions from landfills, N_2O emissions as a result of agricultural practices have global warming potential which contributes to climate change on a global scale, with eutrophication on a local scale due to nutrient losses from food waste along the food supply chain.

Resource inputs and emissions for food items vary with food items and geographical regions, various practices along the supply chain contribute to differences in environmental impacts. (Frankowska et al,2019) Variability as a result of economic and management conditions, crop type, energy requirement etc contributes to environmental implications (Muth et al,2019). Carbon impact of the same food section varies with countries for instance carbon footprint of cereals in Asia is higher than wasted volume, while cereals in Europe have lesser carbon usage than Asia, due to differences in types of cereal planted in both regions (FAO,2013)

Production of some food products consume more natural resources than some others. Not all food commodities are wasted in similar contents and the same amount of natural resources are used for production i.e. certain products are less intensive than the others (FAO,2013). Volumes of products and methods of production influence GHG emissions, the emissions from wasted fruit and vegetables is lesser than emission from dairy products and meat due to the production method and other activities along the value chains. This is similar with water use, land use, energy consumption etc.

4.3 Factors Influencing Food loss and Waste

Causes of food losses and waste can be attributed to various reasons. Studies on FLW described a wide range of various causes of FLW that have evolved from pre-existing factors. The pre-existing factors are considered and depend on the product, stage of food supply chain observed i.e. from production to consumption and the context. Causes of FLW along the supply chain are often similar. A problem at one stage of the product chain can affect the entire chain e.g. bruise/mechanical damage at the early stage of production may render the product unmarketable. To determine the causes and effective ways to reduce them, all the stages of the food supply chain need to be considered. (Themen,2014)
According to research conducted by OECD (2011), producers, wholesalers/retailers, consumers behaviour contributes to FLW. Consumers preferences, prices by retailers, amounts of food produced is sometimes in excess resulting in wastage by individuals and companies.

Factors determining FLW can be divided into 2 main factors: loss along the food supply chain and loss as a result of the surroundings of the food supply chain (Kowalska.,2017).

Loss along the food supply chain: These can be explained as steps and procedures along the supply chain such as machines, materials, management practices, methods used and People carrying out such operations also contribute to losses/waste.

People: knowledge and Attitude of people participating in the food supply chain determines a level of food losses and waste. Inaccuracies on the part of producers/staff can cause a great deal of loss. People are the most important as they contribute to FLW in every aspect. Extra care needs to be taken in production, processing, distribution etc. Consumers should limit the loss of food at household level, consumers are often aware of the impact of food waste on the environment, economic implication but this does not influence their decision and behaviour on food wastage.

Management: Quality management practices should be ensured in supply chains. Good hygienic and manufacturing practices that are significant for food safety can reduce FLW. EU food law committed to hygiene of foodstuffs in the food industry identifies, evaluate and control hazard to reduce food wastage and losses contributing to food security (Kołożyn-Krajewska, et al 2010; Kowalski 2010). Effective risk management may improve the food supply chain performance.

Methods: Technologies used postharvest such as packaging method, processing method, storage method plays an important role along the food supply chain. Packaging, storage methods that can extend the shelf-life of products and prevent food loss should be implemented. In low and medium countries, lack of skills, inadequate market facilities, poor packaging, processing and storage contributes to high FLW in this region. (Eli et al,2018)

Value chain actors to take a position in improved technologies and practises; or from policy failure for instance the absence of legal and regulatory environments encouraging such investments (Themen.,2014).

Machines: Management of food loss and waste requires advanced technology and more machines is important. During agricultural production and food processing, technology use is essential. Improved methods combined with advanced technology will reduce FLW to a certain extent. In low- and medium-income countries, one major cause of food loss at the production and processing stage is the use of old machinery and inadequate technical support of the new machines. Recurring breakdowns, bad condition, basic amenities necessary such as electricity may result in avoidable losses in raw materials and final products. Maintenance and servicing of machinery should be carried out frequently (Kowalska,2017).

Loss as a result of the surroundings of the food supply chain: factors influencing FLW from surroundings food supply chain includes policies, regulations, political issues, consumer trends, consumers education, food market development, funds and support for operators, training and education. Awareness on food waste and supply chain to consumers may influence the rend and behaviour of the consumers. Nowadays, the food supply chain has become longer as there is an increase in the organizational structure of supply chain. Preventing food loss and waste may be a challenge in a long food supply chain.

4.4 Strategies to reduce fruits and vegetables losses and waste (environmentally friendly)

The concept of waste hierarchy is to identify steps that protect the environment with the resources and energy consumption i.e. prioritizing efficient use of natural resources. (EPA,2017) The waste hierarchy is the three R's -Reduce, Reuse, recycle helps with sustainable life. This is implemented by reducing the amount of waste, so lesser quantity goes to the landfill thereby reducing carbon footprint (FAO,2013).

Reduce: The effect of food production on natural resources cannot be overemphasized and it rises while the food moves on the food value chain. Reduction of food wastage means reducing the impact on natural resources. The focus is to maximize efficiency and stay away from unnecessary consumption. Less waste will result to less to recycle and reuse.

Raising awareness for food wastage: Less data is available for amount of wastage due to lack of report on food wastage data. It is important to create awareness and campaigns programmes on the importance of reducing wastage across the supply chain. It is important to understand about the environmental impact of food wastage. Assumptions such as organic food waste does not cause any harm to the environment is a misconception as natural resources used for production are wasted. Unconsumed food that ends up in landfill constitutes a large percentage of methane emission. Therefore, it is important to understand for food wastage across the supply chain. Such understanding helps to reduce FLW.

Communication along the supply chain: Efficient communication between producers, distributors, wholesalers/retailers is paramount to meet the supply and demand of the consumers. For instance, farmers need to find sellers for their product , retailers need to know the quantity of product that can be sold. Consumers can play a role by not over-purchasing product. All individuals and stakeholders across the supply chain need to be involved in a communication channel for reducing food wastage.

Improving food harvest, storage and transportation practices: Proper harvesting techniques, harvesting containers and tools can help to reduce FLW. Optimized harvest time and maturity period should be considered. After harvesting, temperature is another storage factor that can extend fruit shelf life and reduce postharvest losses. Transportation method for fruits and vegetables depends on distance, perishability and value of the product being transported (Elik,2019). Storage needs to be done to prevent deterioration for a certain period. Storage structure should be of high quality and needs to be kept cool for effectiveness. (Kiaya,2014).Shelf life of product depends solely on temperature variations during transport and storage, temperature influences the quality of product due to high effect on rates of biological reactions.(Hertog et al,2014)Harvesting technique, optimal temperature suitable for product storage and transportation should be considered for postharvest to reduce losses and waste .

Packaging method: This is important in reducing food waste along the supply chain. Fresh fruits and vegetables packaging require appropriate and smarter means of packaging to keep food fresher for a longer period. Smart packaging should promote environmental impacts reduction and the packaging should be eligible for recycling and biodegradability (FAO,2013). Packaging solutions such as retainers, individual wrapping and cushioning during transportation, smaller packaging in the markets for consumers etc will reduces wastage at consumers level (Elik,2019).

In order to reduce the environmental, social and economic impacts of food wastage, avoiding food wastage is more beneficial due to production resources conservation than improving food wastage after its occurrence (FAO,2013)

Reuse: To recover resources used during production is important when reducing waste seems to be possible. Recovered resources do not require further processing and more energy is not consumed. In a situation, where excess food is produced is it is important to keep it within the human food chain(FAO,2013).For instance, food that are no longer fit for human consumption can be diverted for livestock feed, therefore conserving resources that should have used to produce animal feeds (EPA,2017).Various ways for reusing food wastage are as follows:

- Creating markets for products not present in the food chain: Food items may not make it to the market due to failure to meet the retailing product standards due to overproduction on the field in high income countries, inaccessibility to market and poor planning in low income countries etc (Themen,2014). Food left in the field can be purchased at lower price thus producing a new food value chain. This is beneficial to the farmers and the environment at large. Food perfectly for sales and consumption out of the value chain can also be as a result of more supply with less demand.
- Distribution of surplus food to needy: As a substitute of edible food to be discarded, it is better for food industry along the supply chain to donate surplus food. Recently, the amount of food being donated is negligible compared to the amount of available edible foods worldwide (FAO,2013). For this to be effective, public and private collaborators need to participate in this process.
- Food not fit for consumption should be fed to livestock: Best use of food not fit for consumption such as fruit and vegetable peelings can be used as animal feed thus replacing energy and resources for producing animal feed. Food waste can be fed directly or treated(processed)to animals. Environmental impact such as GHG emissions, energy and water use) will depend on the type of treatment observed and procedure, feeding food waste to animals is environmentally beneficial than the cost of production for new feedstuff. According to Kawashima (2004), it is important to be less dependent on imported feed products while reducing their GHG emissions.

Recycle/Recover: Waste materials are re-processed to assemble the same or different products. Food products are transformed into a raw material which in turn can be formed into another/new food product. Option for by-product recycling includes composting, anaerobic digestion, recreating food from by-products and food waste etc. Recycling has a higher advantage over landfills (FAO,2013) This process benefits the environment by reducing use of raw materials and waste generation. Greenhouse gases emitted are used in anaerobic digestion replaces conventional fossil fuel thereby reducing carbon emissions.

FLW interventions should be observed by federal, state and local governments, both private and public companies such as food manufacturers, processors, technology developers etc (Muth et al.,2019)

4.5 FLW reduction and sustainability

The Sustainable development goals aim to eradicate poverty, protect the environment and promote prosperity and well-being. Goal 12 aims to “halve global per capita food waste at the retail and consumer levels and reduce food losses along production and supply chains by 2030”. (UNDP,2015). Maximizing the extent of terrestrial land to absorb CO_2 emissions and reducing land use is important for sustainability, feeding the global population, and minimizing the negative effects of climate change (IPCC,2019).Reducing FLW along a supply chain has the prospective to diminish the food production, limit pressure off agricultural land and reduce GHG emissions of the food system. In addition, a food system barely with built-in waste is more sustainable and adaptable, moderating food production from adverse effects of global change. (Schipanski et al.,2016) High losses of crop is said to increase the rate of global warming (Gaupp et al,2019).

5. Conclusions

Food waste is produced along the supply chain from production to final consumers. Ensuring that food systems are both resource and energy efficient is important to minimize the environmental impacts caused by waste. The study focused on assessing the environmental impacts of organic apples in order to understand how loss and waste contributes to the environment by collection of primary and secondary data of apple waste through surveys and published reports. Agricultural production included activities on field till harvest, processing stage included post-harvest handling, distribution stage-(transportation to retailers, stores and to the consumers) and consumption stage. Considering the total FLW along the whole value chain, FLW became about 42% of the total yield. The contribution of the processing stage (42%), followed by the consumption stage(25%), agricultural production (19%) and the distribution stage (14%). Major causes of FLW are quality attributes requirement, mechanical injuries, improper harvesting method, improper handling, inadequate storage facilities, over-purchasing, spoilage etc.

In terms of GHG emissions due to FLW, it was estimated to be 310kgCO_{2eq} per 1 ton apple consumed, for organic apple out of this each stage has its contribution: agricultural production (8%), processing (38%) distribution (18%) and consumption (36%) .Regarding conventional apple, the estimated value was 340kgCO_{2eq} per ton of apple consumed with contribution of each stage- agricultural stage (9%), processing stage(38%), distribution (18%) and consumption stage (35%). Entire supply chain irrespective of production type (organic and conventional) has environmental impact, however, total emission generated form organic apple was lower than conventional apple. Processing and consumption stage had most losses and more environmental impact with the least at agricultural and distribution stage.

Strategies were suggested with the aim of reducing loss and environmental impact of apple supply chains. These include increasing awareness on FLW, reducing over purchase, improving post-harvest handling of fruits, reuse and recycle food rather than waste. Consumers attitude towards food waste can be changed through education on environmental impacts and by encouraging consumers to waste less

Acknowledgement

I would like to express my gratitude to my supervisor Techane Bosona at the Department of Energy and Technology, Swedish University of Agricultural Sciences, Uppsala. I deeply appreciate your support and guidance throughout the project.

I would like to thank my family ,Monisola Omoleye,Olabisi Omoleye and Gbemisola Omoleye for their prayers, love , sacrifices for educating me and preparing me for my future . I owe special thanks to Adebisi Garba for his friendship and support.

6. References

Annika,E. Karlsson (2017) Climate Impact from fresh fruit production-a systematic review and meta-analysis. Master Thesis, Department of Biological and Environmental Sciences, University of Gothenburg.

Beretta C, Stucki M, Hellweg, S(2017) Environmental impacts and hotspots of food losses: value chain analysis of Swiss food consumption. Environ.SciTechnol,51,11165-11173.https://pubs.acs.org/doi/10.1021/acs.est.6b06179.

Blanke, M., Burdick, B., (2005) Food (miles) for thought: energy balance for locally grown versus imported apple fruit. Environ. Sci. Pollute. Res. 12 (3), 125-127.

Buzby J.C,Hyman J,Stewart H,Wells H.F (2011)The value of Retail and Consumer-Level Fruit and vegetable losses in the United States. The Journal of Consumer Affairs. Volume 45 No 3 pages 492-515.

Buzby, J.C., Farah-Wells, H., Hyman, J., (2014)The estimated amount, value, and calories of postharvest food losses at the retail and consumer levels in the United States. SSRN Electron. J.Available on https://doi.org/10.2139/ssrn.2501659. (Accessed 08/03/2020).

Buzby, J.C., Padera, B., Bentley, J.T., Campuzano, J., Ammon, C., (2016) Updated Supermarket Shrink Estimates for Fresh Foods and Their Use in ERS Loss-adjusted Food Availability Data. U.S. Department of Agriculture, Economic Research Service. EIB-155, 40 pp. https://www.ers.usda.gov/publications/pub-details/?pubid=44309 (Accessed June 2020).

CEC. (2019)Technical Report: Quantifying Food Loss and Waste and Its Impacts. Montreal, Canada: Commission for Environmental Cooperation. page 129.

Cederberg,C,Sonesson,U, Henriksson,M, Sund,V and Davis,J.(2009)Greenhouse Gas Emissions from Swedish Production of Meat, Milk and Eggs. Uppsala: SIK-Institutet för livsmedel och bioteknik.Chapter 27, Postharvest Handling Systems: Pome Fruits. University of California, Agriculture and Natural Resources.

Cerutti A.K, Galizia D, Bruun S , Mellano G.M ,Beccaro G.L , Bounous G.(2011)Assessing environmental sustainability of different apple supply chains in Northern Italy. Department of Arboriculture, University of Torino. pages 1-8.

Clune,S, Crossin,E,Verghese K (2017) Systematic review of greenhouse gas emissions for different fresh food categories.J.Clean.Prod.140 (Part 2), pages 766-783.

Davida Johansson (2015) Life cycle assessment (LCA) of apples- a comparison between apples produced in Sweden, Italy and Argentina. Master's Thesis in Biology, SLU Alnarp. http://stud.epsilon.slu.se pg. 9-12.

Dendla ,L,Cheng Y,Martin F, He, X., Yuhui Q, Yuexian L,.(2016)Environmental impact assessment of organic and conventional tomato production in urban greenhouses of Beijing city, China, Journal of Cleaner Production.

Eberle U,Fels J(2016)Environmental impacts of German food consumption and food losses.Int J Life Cycle Assess 21,pg 759–772

Eissa,A.A.H., Gamaa,G.R,Gomaa,F.R.,Azam,M.M (2012)Comparison of package cushioning materials to protect vibration damage to golden delicious apples .Int.J. Latest Trends Agric.Food Sci.2 (1),36-57.

Elik A, Yanik D.K,Istanbullu,Y,Guzelsoy N.A,Yavuz, A,Gogus,F(2019) Strategies to reduce Post harvest losses for fruits and Vegetables. InternationalJournal of Scientific and Technological Research. ISSN 2422-8702 (Online), DOI: 10.7176/JSTR/5-3-04 Vol.5, No.3.
EPA(2017) The waste Hierarchy. Available at https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/warr-strategy/the-waste-hierarchy.Accessed on 13th May,2020.

Eriksson M.(2012) Retail Food wastage-a case study approach to quantities and causes. Licentiate thesis 045 Swedish University of Agricultural Sciences ISSN 1654-9406 ISBN 978-91-576-9107-1.

Eriksson,M, Strid I, Hansson,P-A(2012) Food losses in six Swedish retail stores: wastage of fruit and vegetables in relation to quantities delivered. *Resources, Conservation and Recycling* 68,pg 14–20.

Eurostat News Release (2016) Production of fruit and vegetables. Available at www.ec.europa.eu/Eurostat/ (Accessed on 9th March,2020).

Fadiji,T. Coetzee C, Chen L, Chukwu O,Opara,U.L (2016) Susceptibility of apples to bruising inside ventilated corrugated paperboard packages during simulated transport damage. Post-Harvest and Technology 118, pages 111-119.

FAO (2013) Reducing the food wastage footprint, Natural Resources management and Environment Department pages 15-119.

FAO (2009) Sweden Available at http://www.fao.org/3/y1669e/y1669e0d.htm.(Accessed on 13th of Feb, 2020).

FAO (2011)Global food losses and food waste – Extent, causes and prevention. Rome.
FAOSTAT. (2010). FAO Statistical Yearbook 2009 - Agricultural Production, Available at: : http://www.fao.org/economic/ess/publications-studies/statistical-yearbook/fao-statistical-yearbook-2009/b-agriculturalproduction/en/ FAOSTAT. (Accessed on 13th February,2020).

Frankowska A, Jewsani H.K, Azapegic Adisa(2019) Life cycle environmental impacts of fruit consumption in the UK. Journal of Environmental Management 248 109111 page 2-13.

Gaupp,FHall,J,Hochrainer-Stigler,S,Dadson,S,(2019)Changing risks of simultaneous global breadbasket failure.Nat.Clim.Change.,1-4 https://www.nature.com/articles/s41558-019-0600z.

Ghinea Cristina (2017) Assessment of Environmental Impact of Food Waste: A case study Apple fruits.Journal homepage:_www.fia.usv.ro/fiajournal Journal of Faculty of Food Engineering, Ştefan cel Mare University of Suceava, Romania Volume XVI, Issue 1, page. 21 - 28 .

Goossens, Yanne & Annaert, Bernd & Tavernier, Johan & Mathijs, Erik & Keulemans, Wannes & Geeraerd, Annemie. (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. 81-93. 10.1016/j.agsy.2017.01.007.

Gustavvson,J,Stage,J(2011)Retail Waste horticultural products in Sweden.*Resources,Conservation and Recycling* 55, pg 554-556.

H.Flessa,R,Ruser,P Dörsch,TKamp,M.A Jimenez,J.C Munch, F.Beese(2002)Integrated evaluation of greenhouse gas emissions (CO2, CH4, N2O) from two farming systems in southern Germany.Agro System Enviro. Volume 91, Issues 1–3, Pages 175-189.

He, X., Yuhui Q, Yuexian L,leonie D,Cheng Y,Martin F(2016) Environmental impact assessment of organic and conventional tomato production in urban greenhouses of Beijing city, China, Journal of Cleaner Production Available at http://dx.doi.org/10.1016/j.jclepro.2015.12.004. (Accessed on 14th February,2020)

Hertog, M.L., Uysal, I., McCarthy, U., Verlinden, B.M., & Nicolaï, B.M. (2014) Shelf life modelling for first-expired-first-out warehouse management. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 372, 20130306.

IALC (2006)Post-harvest Management of Fruits and Vegetables. Training Manual, Volume V-E. University of Illinois at Urbana-Champaign, USA. International Arid Lands Consortium and NWFP Agriculture University Peshawar.

IPCC,(2019)Climate change and Land: An IPCC special report on Climate change, Desertification, Land degradation, Sustainable Land Management, Food security and Greenhouse gas fluxes in Terrestrial Ecosystems.

J. Gustavsson, C. Cederberg, U. Sonesson (2013)The Methodology of the FAO Study: “Global Food Losses and Food Waste - Extent, Causes and Prevention,210, FAO, p. 70.

J.C. Buzby, H. Farah-Wells, J. Hyman (2014) The estimated amount, value, and calories of postharvest food losses at the retail and consumer levels in the United States SSRN Electron. J. Available on https://doi.org/10.2139/ssrn.2501659.. (Accessed on 14th February,2020).

Jensen Carl, Stenmarck Åsa, Sörme Louise, Dunsö Olof (2011) Matavfall från jord till bord [Food waste from field to fork], SMED Report no. 99.

Jones, A., (2002)An environmental assessment of food supply chains: a case study on dessert apples. Environ. Manag. 30 (4), 560-567.

Kafashan, J, Zeebroeck, M.V, Sadrnia, H, Moshou, D, Baerdemaeker, J.D, Nicolai, B, Ramon, H, Tijskens, B, (2007)Effects of Impact Locations on Mechanical and Dynamical Properties of Fruits. Division of Mechatronics, Biostatistics and Sensors(MeBioS) [pdf] Available at: http://pooya.um.ac.ir/ResearchDocuments/papers/1007829.pdf (Accessed 16th March,2020).

Kawashima, T. (2004)The Use of Food Waste as a Protein Source for Animal Feed - Current Status and Technological Development in Japan In Protein Sources for the Animal Feed Industry, FAO. (Available at http://www.bvsde.paho.org/bvsacd/cd43/jfood.pdf).

Keyes, S., et al.,(2015) Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment, Journal of Cleaner Production http://dx.doi.org/10.1016/j.jclepro.2015.05.037.

Kiaya, V (2014) Post-harvest losses and strategies to reduce them. Technical Paper on Postharvest Losses, Action Contre la Faim (ACF).

KołożynKrajewska, D., Sikora, T(2010)Food safety management. Theory and practice,C.H. Beck, Warsaw.

Kowalska A.,(2017)The issue of food losses and waste and its determinants. Log Forum 13 (1), 7-18,.Available from: https://www.researchgate.net/publication/315713593 (Accessed Feb 25 2020).

Kvikliene. N, Valiuskaite. A, (2009)Influence of Maturity Stage on Fruit Quality During Storage of Apples. Lithuanian Institute of Horticulture. [pdf] Available at: http://www.lsdi.lt/straipsniai/28-3/16_Kvikliene.pdf (Accessed 16th March, 2020).

Liu Rongduo,Zuzanna Pieniak, Wim Verbeke(2013)Consumers' attitudes and behaviour towards safe food in China: A review Volume 33, Issue 1, pages 93-104.

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, 654-663.

Martin M,Oliveira F,Dahlgren L,Thornéus J (2016)Environmental implications of Swedish food consumption and dietary choices. Swedish Environmental Research Institute IVL-rapport 181 pg. 13-21.

Masood,M.(2011) An assessment of apple post-harvest losses -the case of Nerkh District, Afghanistan. Van Hall Larenstein University of Applied Sciences Part of Wageningen University Forum-Gebouw 102 pg. 5-10.

Mattson K. (2014) Why do we throw away edible fruit and vegetables? Division of Trade and Markets, Rapport by Jordsbruksverket Available on www.jordbruksverket.se. Accessed on 6th March,2020.

Mattsson L, Williams H, Jonas Bergherl (2018)Waste of fresh fruit and vegetables at retailers in Sweden- a calculation of mass, economic cost and climate impact. *Resources, Conservation and Recycling* 130,pg 118-126.

Meyer,C.H,Frieling D,Hamer M,Oertzen G (2017) Food Losses in Supply Chains for Fruits, Vegetables and Potatoes between Field and Retail Shelf in North-Rhine Westphalia, Germany.Available online http://dx.doi.org/10.18461/pfsd.2017.1704 Accessed on June 2020 .

Mitcham. E.J and Mitchell. F.G, (2002)Postharvest Technology of Horticultural Crops,3rd edition.

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 Volume 114, Issues 2-4 pages 311-322.

Muth,K.M,Birney C,Cuellar A,Finn S,Freeman M,Galloway J.N, Gee I, Gephart J,Jones K,Low, L,Meyer M,Read Q,Smith T,Weitz K,Zoubek,S.(2019) A systems approach to assessing environmental and economic effects of food loss and waste in the United States. Science of The Total Environment. 685. 10.1016/j.scitotenv.2019.06.230pages 1240-1254 .

Nissen R, Sally B., Rajendra A.Ian C,(2018) Factors affecting postharvest management of apples: a guide to optimising quality. National Library of Australia Cataloguing-in-Publication entry pg. 15-21.

Notarnicola B,Tassielli G, Renzulli P.A, Castellani V., Sala.(2017) Environmental impacts of food consumption in Europe, Journal of Cleaner Production, 140: 753765.

OECD Joint Working Party on Agriculture and the Environment (2011) A green growth strategy for food and agriculture (preliminary report).

OECD Working Party on Agricultural Policies and Markets (2011) Waste management in the food chain: scoping paper.

Porat R,Lichter A, Terry L.A, Harker R, Buzby J,(2018) Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention .Postharvest Biology and Technology 139 ,135–149.

Read, Quentin D ,Samuel Brown,Amanda D.Cuéllar Steven M.Finn,Jessica A.Gephart,Landon T.Marston,Ellen Meyer,Keith A.Weitz,Mary K.Muth(2019) Assessing the environmental impacts of halving food loss and waste along the food supply chain. volume 712, page 2-3.

Schipanski,M.E,MacDonald,G.K,RosenzweigS,Chappell,M.J,Bernett,E.M,Kerr,R.B.,Blesh,J, Crews T, Drinkwater L,Lundgren, J.G,Schnarr,C.(2016) Realizing resilient food systems.BioScience 66,600-610,https://doi.org/10.1093/biosci/biw052.Smith.

Scholz, Katharina(2013) Carbon footprint of retail food wastage ,Uppsala.

SEPA (2008)Svinn I livsmedelskedjan – möjligheter till minskade mängder. Swedish Environmental Protection Agency, Bromma, Sweden, ISBN 978-91-620-5885-2.

Sim, S., Barry, M., Clift, R., Cowell, S.J., (2007) The relative importance of transport in determining an appropriate sustainability strategy for food Sourcing. Int. J. Life Cycle Assess. 12 (6), 422-431.

Sittipod S., Swasdee, D., Singh, S.P, Singh, J., (2009) Effect of truck vibration during shipments in Thailand ,J.Appl.Package.Rs 3(1),27-38.

Sonesson U, Davis J, Ziegler F,(2010) Food production and emissions of greenhouse gases. SIK Report 802.Gothenburg: Swedish Institute for Food and Biotechnology.

Sonesson, U., J. Davis and F.Ziegler.(2010) Food production and Emissions of Greenhouse Gases.Uppsala:The Swedish Institute for Food and Biotechnology.

Stadig, M., (1997)Life Cycle Assessment of Apple Production e Case Studies for Sweden, New Zealand and France. SIK, Gothenburg, Sweden. SIK report 630 1997.

Stare Malin, Johansson Malin, Dunsö Olof, Stenmarck Åsa, Sörme Louise, Jensen Carl, (2013) Förbättrade matavfall faktorer för verksamheter [Better food waste factors for businesses and organizations], SMED Report no. 117 .

Stenmarck Åsa (2007) Biologiskt avfall från livsmedelsbutiker – faktorer för returer från butiker till grossist [Biological waste from supermarkets – factors for returned goods from stores to wholesaler], SMED Report no. 13.

Stenmarck Åsa, Gottberg Annika (2009) Utredning: Animaliskt och vegetabiliskt avfall [Investigation: Animal and vegetable waste], SMED Report no. 29 .

Stenmarck Åsa, Jensen Carl, Sundqvist Jan-Olov, Sörme Louise, Szudy Mikael (2011) Förslag på metodik för förbättrade matavfall data från tjänstesektorn och hushåll [Proposal for methodology to improve food waste data from the services sector and households], SMED Report no. 48 .

Swedish Environmental Protection Agency SEPA (2011) Food waste volumes in Sweden Available at http://www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Avfall/ Avfallsforebyggande-program/ (Accessed on 24/02/2020).

Swedish Institute of Food and Biotechnology (2011) Global food losses and food waste. Extent causes and prevention.

Tarabay,A. P.,Chahine-Tsouvakis H., Tohme,S.T,Nemer,N, Wassim H,(2018) Reduction of food losses in Lebanese apples through good harvesting and postharvest practices. Annals of Agricultural Sciences Volume 63, Issue 2,pages 207-213.

Techane Bosona(2017)LCA of fresh and dried organic apple fruits produced in Sweden.Kungl. Tekniska Högskolan (KTH) pg 8-17.

Themen Daniel (2014) Reduction of food loss and waste in Europe and Central Asia for improved food security and agri food chain efficiency pg.16-55.

Thompson. J.F, Mitchel. F.G, (2002) Postharvest Technology of Horticultural Crops. 3rd ed. Chapter 10, Packages for Horticultural Crops. University of California, Agriculture and Natural Resources.

Thompson. J.F, Mitcham. E.J, Mitchell. FG. (2002) Postharvest Technology of Horticultural Crops. Third Edition. Chapter 8, Preparation for Fresh Market. University of California, Agriculture and Natural Resources.

Ulrika F, Hanna H,Lisbeth M,Erik S (2016) Food losses and waste in primary production ; Data collection in the Nordic countries.

United Nations Development Programme (2015)Sustainable Development Goals .Available on https://www.undp.org/content/undp/en/home/sustainable-development-goals.html.Accessed on (11/06/2020).

Vinyes E,Asin L, Alegre S, Munoz 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 pages 313-320.

Wills, R.B.H.; McGlasson, W.B.; Graham, D.; and Joyce, D.C, (2007)Post-harvest. An introduction to the physiology and handling of fruit, vegetables and ornamentals, 5th ed. UNSW press.

Zhenni Zhou (2015) Food Waste in Retailing stores in Sweden- a welfare simulation analysis master's degree project in Economics Graduate school pg. 9-12.

Appendix

Appendix A: Questionnaires

Appendix A1: Questionnaire for Apple processor

1. Do you process organic apple? If yes, ____% is organic apple.

2. How long do you store (organic or conventional) apple at your facility?

3. What is the best temperature (degree C) to store apple

4. What are main activities at your facility? Washing? Sorting? Packaging? Processing into juice? Drying? Distribution?

5. Estimated total apple loss (as waste for instance) at your facility ?

6. Causes of loss at your facility?

7. Additional comment if any

Appendix A2: Questionnaire for retailers

1.Do you sell fresh organic apple?

2.Do you sell organic apple juice?

3.Do you sell dried organic Apple?

4. Do you sell apple juice produced in Sweden or imported?

5. Is there any loss or waste ? If yes, what percentage %?

6.What are causes of loss ?

7. Retail name (optional).

Appendix A3: Questionnaire for retailers

1) When you purchase fruits, which one do you prefer?
   - □ Organic
   - □ Conventional
   - □ both

2) If you purchase apple fruits, which one do you prefer?
   - □ Conventional
   - □ Organic
   - □ both

3) What percentage (of amount purchased) fresh apple is wasted at home?
   - □ 0-1%
   - □ 1-2%
   - □ 2-3%
   - □ 3-5%

4) Main reasons for waste? :
   - □ Bad taste
   - □ Spoilage
   - □ Over purchase (more than needed)
   - □ Other factor

5) If you purchase processed apple, which one do you purchase often?
   - □ Apple juice
   - □ Dried apple (apple chips)
   - □ both

6) Your age groups
   - □ <20 years old
   - □ 20-30 years old
   - □ 31-40 years old
   - □ >40 years old

7) Your Gender
   - □ Female
   - □ Male

8) Where do you live currently?
   - □ Sweden
   - □ Outside Sweden (Europe)
   - □ Outside Europe

Appendix B- Summary of FLW data along apple value chain

	FLW data in % of amount entering each stage													
Reference*	1	2	3	4	5	6	7	8	9	10	11	Average	Minimum	Maximum
Agriculture	0	0	10	3	0	2	0	0	16	0	0	8	2	16
Processing	0	0	0	0	0	18	0	0	24	0	15	19	15	24
Distribution	4	4	0	0	2	20	9	20	3	0	5	8	2	20
Consumption	0	0	0	0	0	0	0	9	0	30	5	15	5	30

*-List of references in the above Table

1. Erikkson (2012); Sweden
2. Gustavvsson (2011); Sweden
3. Ulrika et al (2016), Nordic countries
4. Eurostat (2016), Sweden
5. Mattsson et al (2018), Sweden
6. Meyer et al (2017), Germany
7. Burzby et al(2016), USA
8. Burzby et al (2011), USA
9. Porat (2018), UK
10. Eberle (2016), Germany
11. Own Survey (2020), Sweden

Appendix C- Greenhouse gas emissions data along fresh apple supply chain. The values are in kg CO2 eq per 1ton fresh apple handled at each stage.

Reference	Data source	Product	Agricultural Production	Processing	Distribution	Consumption
Bosona (2017)	Ref 1	Organic apple	34	150	105	na
Clune et al (2017)	Ref 2	Organic apple	na	na	290	na
Johansson (2015)/ sweden	Ref 3	IP Apples	49	234	41	na
Johansson (2015)/ sweden	Ref3	Organic apple	271	na	na	na
Johansson (2015)/Italy	Ref 7 (Ref3?)	Conventional apples	244	na	na	na
Keyes et al(2015)	Ref 4	Conventional apples	64	197	15	na

	Ref4	Organic apples	73	195	15	na
Frankowska et al(2019	Ref 5	Conventional apples	322	504	509	na
Annika (2017)	Ref 6	Conventional apples	185	na	na	na
(Beretta et al,2017)	Ref 8	Conventional apples	300	150	150	100
Cerutti et al (2011)	Ref 9	Conventional apples	62	96	122	na
Longo et al,2017	Ref 10	Organic apples	588	na	na	na
"	Ref10	Conventional apples	612	na	na	na
Vinyes et al (2017)	Ref 11	Conventional apples	112	na	118	69
Goosens et al (2017)	Ref 12	Organic apples	154	na	na	na
"	Ref12	Conventional apples	68	na	na	na
"	Ref12	IP Apples	66	na	na	na
	Average	Total (organic and conventional)	200	218	152	85
	Average	Organic (including IP)	176	218	152	85
	Average	conventional	219	218	152	85

Appendix D: Summary of FLW and GHG emission data: minimum, maximum and average values

Value chain stage	FLW in % of weight			GHG emission in kgCO2 eq/t of fresh organic apple handled at each chain stage			GHG emission in kgCO2 eq/t of fresh conventional apple handled at each chain stage		
	Minimum	Maximum	Average	min	max	Average	min	max	Average
Agriculture	2	16	8	34	588	176	62	612	219
Processing	15	24	19	96	504	218	96	504	218
Distribution	2	20	8	15	509	152	15	509	152
Consumption	5	30	15	69	100	85	69	100	85

Sveriges Lantbruksuniversitet
Institutionen för energi och teknik
Box 7032
750 07 UPPSALA
http://www.slu.se/institutioner/energi-teknik/

Swedish University of Agricultural Sciences
Department of Energy and Technology
P. O. Box 7032
SE-750 07 UPPSALA
SWEDEN
www.slu.se/en/departments/energy-technology/