LCA of Fresh and Dried organic apple fruits produced in Sweden

December 2016

KTH - Kungl. Tekniska Högskolan
LCA course project report (draft)
Course number: AG2800

Group 14

Techane Bosona

ABSTRACT

Agricultural sector contributes significantly to environmental impacts and LCA studies are important at each agricultural product category. The goal of the current study was to assess the environmental burdens of organic apples fruits produced in Sweden and supplied as Fresh Apple and Dried Apple fruits with intention of investigating the influence of apple drying process on the environmental impact of apple fruit using life cycle assessment (LCA) method. It was modelled as two product systems: Fresh Apple and Dried Apple fruits. The system boundary starts from agricultural production and ends at gate of consumer. The functional unit was 1 ton of fresh apple at farm gate and transported to processing facility. The analysis was done by modelling the two product cases in SimaPro (version 8.2) LCA software. The drying process was introduced at processing-facility. In both cases the product life cycle consists of three major stages: agricultural production (farming), post-harvest process, and transport activities. Three product transport segments have been considered: from farm-to-processing facility (80 km), from processing facility to retailer (50 km), and from retailer to consumer (5 km).

In this LCA, cumulative energy demand (CED) method was used for assessment of energy demand, and Europe ReCiPe (H) midpoint method was used to assess different environmental impact categories such as climate change and fossil depletion. Sensitivity analysis was used to understand the influence of varying apple distribution distance (from processing facility to retailer).

The results indicated that apple drying process reduced cumulative energy demand by 36% i.e. from 6.11 GJ for Fresh Apple product to 3.9 GJ for Dried Apple product case. It was found that Post-harvest stage consumes more energy in both Fresh Apple (54.5%) and Dried Apple (41.10%) cases.

The drying process reduced the quantified values of in most of impact categories. For instance, the quantified climate change impact values were 265.08 kg CO2 eq and 141.34 kg CO2 eq in Fresh Apple and Dried Apple cases respectively. Post-harvest and transport stages are found to be major contributors to climate change in both Fresh Apple and Dried Apple cases.

In general, the CED and ReCiPe method analysis pointed out that post-harvest and transport stages are major contributors to energy demand and climate change impacts. This indicates that in the fruit supply chains, improving post-harvest processes and product distribution systems can leads to reduction of environmental impacts and sustainability of fruit product supply chains.

Key words: Organic apple fruit; Life cycle assessment; Fresh apple; Dried Apple; SimaPro; Sweden

Contents

Abbreviations

DA	Dried Apple
ELCD	European life cycle database
FA	Fresh Apple
FU	Functional unit
GJ	Giga joule
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle inventory analysis
MJ	Mega joule
CED	Cumulative energy demand
tkm	Ton-kilometre

1. INTRODUCTION

1.2. Apple cultivation

Apple has high moisture content of 80–85% (in wet base) and it is exposed for losses under unappropriated preservation and storage methods could results in product losses which ranges from 10% to 30% (Antal, 2015). Apple fruits are produced in Sweden in different methods: Conventional growing (CG), Integrated fruit production (IFP) and organic growing methods (Jönsson, 2007, Johansson, 2015). Studies in Sweden indicated that, apple tree starts producing fruit with full capacity after 5 years and production continues on average for 15 years without decreasing productivity while it decreases after about 15 years as indicated in Figure 1 (Stadig, 1997; Jönsson, 2007; Ascard et al., 2010). Yearly about 16000 tons of apple fruits are produced in Sweden which is about 0.13% of total production in EU28 (http://www.wapa-association.org/docs/2014/European_apple_and_pear_crop_forecast_2014_-_Summary.pdf).

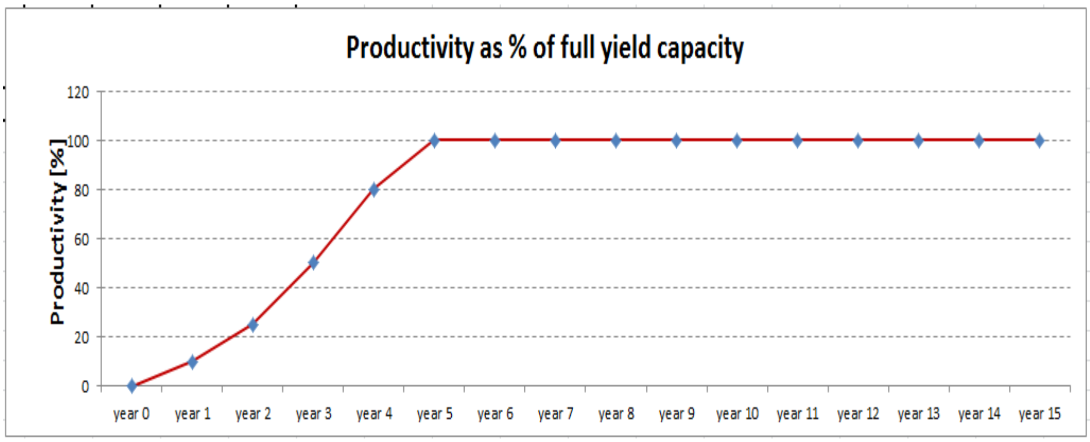

Figure 1: Apple productivity over its entire production period. Source: Authors description based on data from Ascard et al (2010).

1.1. Organic Farming System

In food sector, organic label is an indication of certain methods of how the food is produced. All organic production methods has restriction on the use of: synthetic fertilizers and pesticides in crop and fodder production; synthetic health care products, growth promoters and hormones in livestock production; synthetic preservatives and irradiation in post-harvest handling; and GMOs at all stages in the food chain (http://www.fao.org/docrep/005/y4137e/y4137e03.htm). Organic farms have lower yields, especially during conversion from conventional to organic farm system. However, organic products have higher output prices as well as lower input costs (http://www.fao.org/docrep/005/y4137e/y4137e03.htm).

Although there is increased demand of organic apple in Sweden, the production in Sweden doesn't satisfy the demand (Jönsson, 2007). In Sweden, there are requirements for organic farming which is mainly issued by KRAV. KRAV is an incorporated association with stakeholders representing farmers, processors, consumer, and firms with environmental and animal welfare interests (http://www.krav.se/about-krav; Jönsson, 2007). The Organic apple farms in southern Sweden that are considered in this study are certified according to KRAV regulations and they supply their fresh apple fruits to a company which processes and distribute all over Sweden. KRAV regulations include use mechanical weed controlling method and avoiding chemical pesticides (www.krav.se).

1.2. Apple fruit drying

Drying is one of the oldest food preserving method in which the moisture is reduced extending shelf life. In this technique, reducing the energy consumption and the apple water content to the desired level is a challenge. There should not be substantial loss of color, appearance, flavor, taste and chemical components of apple fruit during drying process (Antal, 2015).

There are standards for dried apple produces. Dried apples intended for direct consumption can be presented as (UN, 1998): Whole and not peeled, Whole and peeled, Whole with core, Whole without core, Halved and peeled, Halved and not peeled, Rings, Sliced, and In pieces. In this study, apple dried in form of sliced form are considered. It is also assumed that the dried organic apples are not treated with preserving agents.

In supply of dried apple produces, there are requirements regarding quality of produce (UN, 1998). For example, dried apple must be sound and free from deterioration; prepared from ripe fruit; free from visible foreign matter and living insects; free from fermentation and foreign smell and/or taste. It should not be also over dried. Such dried apple must be able to withstand transport and handling conditions and arrive consumers' destination in satisfactory condition.

Hot air drying (HAD) is employed most commonly for drying fruits such as apple. In this technique, convection enables the transfer of heat from the hot air to the product and water to the air (Dikbasan, 2007; Antal, 2015). On the other hand, long drying time of HAD could compromise food quality.

1.3. LCA in agricultural sector

Life cycle assessment (LCA) is a tool developed to study the environmental impacts of different activities. LCA is “The compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 1440:2006).

Agricultural sector contributes significantly to environmental impacts like global warming, eutrophication, and acidification (Berggen et al., 2012; Notarnicola et al., 2015; Longo et al., 2017). Agriculture affects environment in its contribution to greenhouse gas emission, land degradation, emission to water, and water depletion (Longo et al., 2017). Gases emitted from agricultural production consist primarily of Carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are gases primarily emitted from food production (Johansson, 2015). However, the assessment on LCA studies by Notarnicola et al. (2015) indicated that fruits have less environmental impacts in comparison to other food diets. The complexity of orchard systems affects implementation of LCA based studies.

Organic food products vary when evaluated on basis of production area and product unit i.e. the impacts are higher when evaluated per product unit when compared to conventional farming (Longo et al., 2017). This is due to lower yields of organic farming per land area used. Studies indicate that in Sweden the apple fruit yield varies mainly between 10 t/ha to 40t/ha (Johansson, 2015; stadig 1997; Jönsson, 2007). In the current study, from the primary data on 4 organic apple farms, the average yield is found to be 12.5t/ha and this amount is used in this study. This is reasonable as the yield of organic fruit is less than conventional farming systems (Longo et al., 2017).

Locally produced and consumed apple fruits in Sweden results in about 80 kg CO2 per ton of fresh apple fruit while imported from France could results in about 235 kg per 1 ton of fruit (http://www.appelriket.se/kvalitet-och-miljo/). Study by Notarnicola et al. (2015) indicated that LCA approach is applied to some extent on production of citrus-based products, essential oil, natural juice, and concentrated juice. To my knowledge, there is no LCA report on apple drying. There are also only few LCA studies on Apple fruit in Sweden and more studies are required particularly on organic apple.

2. GOAL OF THE STUDY

The goal of the study is to assess the environmental burdens of organic apples fruits produced in Sweden. This study is a comparative and change-oriented LCA in which supply of fresh apple fruit is compared with supply of dried apple fruit. It is change-oriented as fresh apple is subjected to drying process to investigate the effect of drying on environmental impact of apple fruit production and supply. Accordingly the main objective is to address the following research questions:

-What is the environmental impact of locally produced Organic apple fruit in Sweden?

-How apple drying process influences the environmental impacts?

-What are the environmentally hot-spot stages of apple fruit product life cycle?

First the LCA of fresh consumption will be conducted. Then the drying process will be introduced and analysed as consequential LCA. It is intended to understand the environmental impacts of organic apples when consumed as fresh and how it changes when it is supplied in dried form. The drying process could be important process to improve preserving methods of organic apple. However, its environmental impact should be assessed properly. The study enables to understand the influence of the apple drying process on energy consumption and environmental impacts of organic apple supply.

This study contributes to the LCA study data base on organic foods in general and organic apples in Sweden in particular. The study results could be useful database that benefit also the farmers and food processors to understand the environmentally hotspot areas in their production processes and introduce improvements.

3. SCOPE OF THE STUDY

3.1. Functional unit

Studies indicated that environmental impacts of fruit production and supply can be influenced heavily by functional unit (FU) chosen during LCA study (Notarnicola et al. 2015; Longo et al., 2017). Therefore, choosing appropriate functional unit is essential in LCA studies of fruits. Therefore, explanation and documentation of every assumption made during LCA on fruits is very essential. In this study, the FU is 1 ton of fresh apple at the farm gate: (i) 1 ton of fresh apple ready to be transported to processing facility where apple will be stored, treated, packed and delivered to retailer as fresh apple fruit; (ii) 1 ton of fresh apple ready to be transported to processing unit where it will be stored, treated, dried, and delivered to retailer as Dried Apple fruit. It should be noted that, downstream the supply chain, the products reduces from 1 ton at farm due to product loss along the chain. In addition to product losses, there is weight reduction in dried apple after drying process. These have been accounted carefully in this LCA study (see Figures 5 and 6).

3.2. System boundaries

3.2.1. Time boundaries

Although apple trees can produces continuously for about 15 years, this study considers only one time harvesting season i.e. production of 1 ton during production season of a year is considered.

3.2.2. Geographic boundaries

The apple fruits are assumed to be consumed within Sweden. It is assumed that both fresh and dried apples are cultivated in the same area. Although the company that processes and distributes organic apple produced in southern Sweden, distributes apple fruit all over Sweden and export to some countries like Norway and Finland, this LCA study is limited only to the case of local distribution. From processing facility, the apple will be distributed, via about 5 wholesalers, all over Sweden. Also the apple will be sold via about 10 small size distributors and local boutiques (Csaki and Rudolfsson, 2005). For this study, food distribution via a local distributor within an average distance of 50 km is considered in basic analysis scenarios (although up to 150 km is considered in sensitivity analyses).

3.2.3. Material and natural system boundaries

This LCA study starts from apple cultivation (agricultural production) and ends at consumer gate. It includes the materials and processing systems throughout the apple supply chain. The agricultural phase includes cultivation (tractoring) and apple tree planting, organic fertilizer supply and application, pruning of apple tree, irrigation, and harvesting and related material and energy inputs from LCA perspective. Transporting harvested apple fruits to processing facility, from the facility to retailer, and from retailer to consumer are included. Apple treatment (washing and sorting), storing and cooling, and packaging activities at processing facility are considered. In this case it is assumed that at the processing facility the apple can be packed as fresh apple or processed (dried) and packed. The study considered the production and supply of packaging materials. Simplified representation of the boundary system is given in Figure 2.

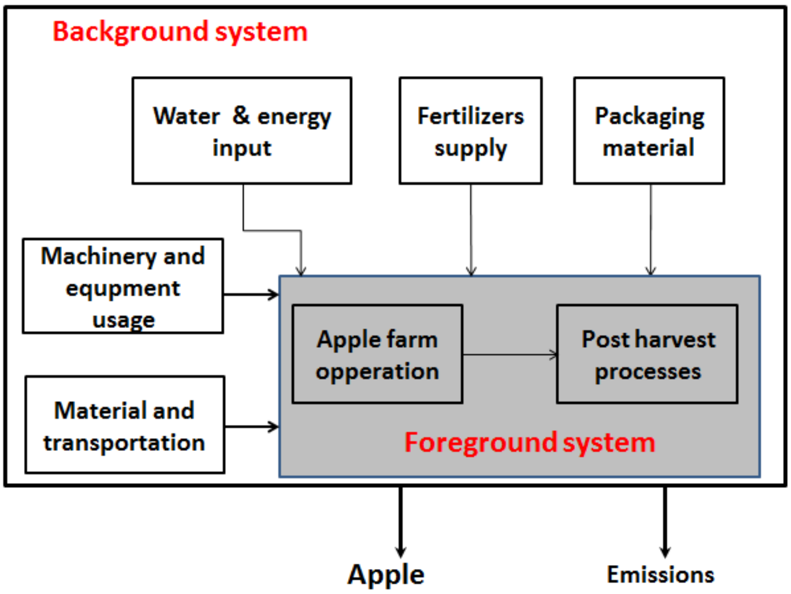

Figure 2: Initial flow chart describing the Background and Foreground systems for both fresh and dried apple supply cases.

3.2.4. Cut-off criteria

In this LCA study, production and supply of machineries and equipment (tractor, apple drying machine) are not considered, but only the use of them has been considered. Similarly, necessary farm building and infrastructures could be there but not included in this study. Although the packaging materials (and packaging process) at processing facility have been considered, the container (wooden or plastic) for transporting fresh apple from farm to processing unit has been omitted in this study, since enough data was not obtained regarding its production and use time and if the container was used only for apple or for different products.

For organic farming, chemical pesticides are not applied. However natural pest controlling and mechanical weed controlling methods are used. Such activities could use some energy and resource utilization. However, such detail data on such activities are not gathered and pest and weed controlling activities are omitted in this LCA. At consumption level, although there is less need of food preparation for fruit, food preservation and related activities could be considered. However consumer (household) level is excluded from this study in both Fresh Apple and Dried Apple systems. The waste treatment part is also outside of the system boundary of this study.

3.2.5. Allocation procedures

Some data from apple farms refers to input to farm operations which include the farm operation other than apple farm where there is multiple farming systems e.g. apple orchard and animal farming. In such cases allocation problems arise in LCA study on apple orchards. In this study, such allocation problems were avoided by considering literature based data that required for only apple production related farm activities. For example apple yield per hectare, irrigation water requirement, diesel and electric power required for apple orchard related activities were carefully compiled literature (Stadig, 1997; Jönsson, 2007; Ascard et al., 2010).

3.3. Assumptions and limitations

3.3.1. Assumptions

In this study, the following major assumptions were made:

- Apple drying process is assumed to be done at the apple processing facility and it is not based on actual drying process at the facility. Therefore, the data used in relation to drying process is based on literature on similar studies. For example, energy use for apple drying was estimated based on the assumption that apple drying could be similar to what described in study by Antal (2015) regarding hot air combined freezing dryer (HAD-FD) of apple fruits.
- Organic fertilizer is assumed to be the same as organic fertilizer described (as Horn meal {GLO}| market for | Alloc Def, S) in ecoinvent v3 data base (Wernet et al., 2016)

- In the case of local apple distribution from processing facility (which is the case in this study), 50 km distribution distance was assumed in both fresh apple and dried apple cases. This assumption has been further analyzed using sensitivity analysis (see section 3.4.2.2).
- Only apple loaded single trip (not round trip) has been considered in each transport segments assuming that the trucks can be used for transporting other goods on return trip.
- In all cases where electric energy was considered, electricity production in Sweden with medium voltage was assumed and applied from Ecoinvent v3 in SimaPro 8.2.
- Duration of storage cooling at processing facility was assumed to be only 20 days while 10 days were considered for retailer level.

3.3.2. Limitations

This study also didn't consider the food quality characteristics that could be affected due to drying process of organic apple fruits. The apple slicing and drying machine and related data were compiled from different sources and these data may not describe well the case of drying apple at company level.

3.4. Impact categories and impact assessment method

3.4.1. Impact categories

The focus of this study is to investigate Energy Use, Global warming potential, and resource depletion (water and fossil depletion) since Energy use and global warming are commonly investigated impacts. However, using ReCipe (H) impact assessment method used in SimaPro (Version 8.2; Pré Consultants, 2015) includes many impact categories: Ozone depletion; Terrestrial acidification; Freshwater eutrophication; Marine eutrophication; Human toxicity; Photochemical oxidant formation; Particulate matter formation; Terrestrial ecotoxicity; Freshwater ecotoxicity; Marine ecotoxicity; Ionising radiation ; Agricultural land occupation; Urban land occupation; Natural land transformation; and Metal depletion.

3.4.2. Impact assessment methods

3.4.2.1 Cumulative energy demand (CED) method

Energy demand assessment was done using cumulative energy demand (CED) V1.09 method described in ecoinvent v2.0 and available in SimaPro data base (Version 8.2; Pré Consultants, 2015). Cumulative energy demand, also called ‘primary energy consumption’ (Frischknecht et al., 2015) method, is used to evaluate the energy consumption by different part of apple supply chain such as farming operation, processing stage (post-harvest) and transport activities. It was used to evaluate Fresh Apple and Dried Apple product cases as well as comparing the two product systems. Figures 3 presents example of SimaPro modeling used to analyze the energy demand and different impact categories at different stages of product life cycle.

3.4.2.2 ReCiPe Midpoint (Hierarchist) method

In this study, ReCiPe Midpoint, which is one of many impact assessment methods in SimaPro (Version 8.2; Pré Consultants, 2015), has been used. Specifically, Europe ReCiPe Midpoint (H) which refers to the normalization values of Europe as described in (Wernet, 2016) has been applied in this LCA study. The Europe Recipe (H) method enables to analyze the inventory results and present the environmental impacts as a fraction of the yearly average emission of a European citizen. The analyses are done including long term effects such as in case of freshwater exotoxicity and marine water ecotoxicity. Figure 4 presents example of SimaPro modeling used to analyze the different impact categories at different stages of product life cycle.

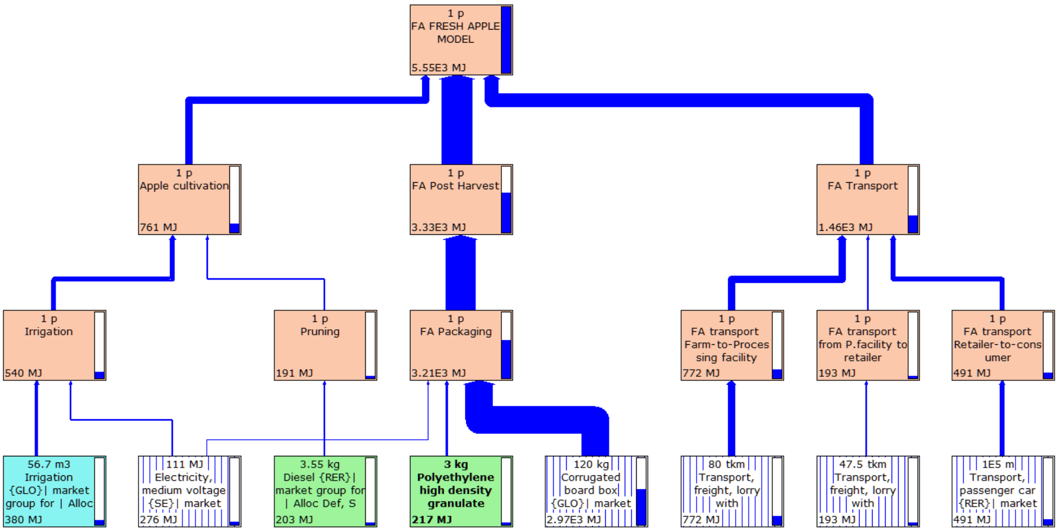

Figure 3: Network for Fresh Apple model: CED analysis

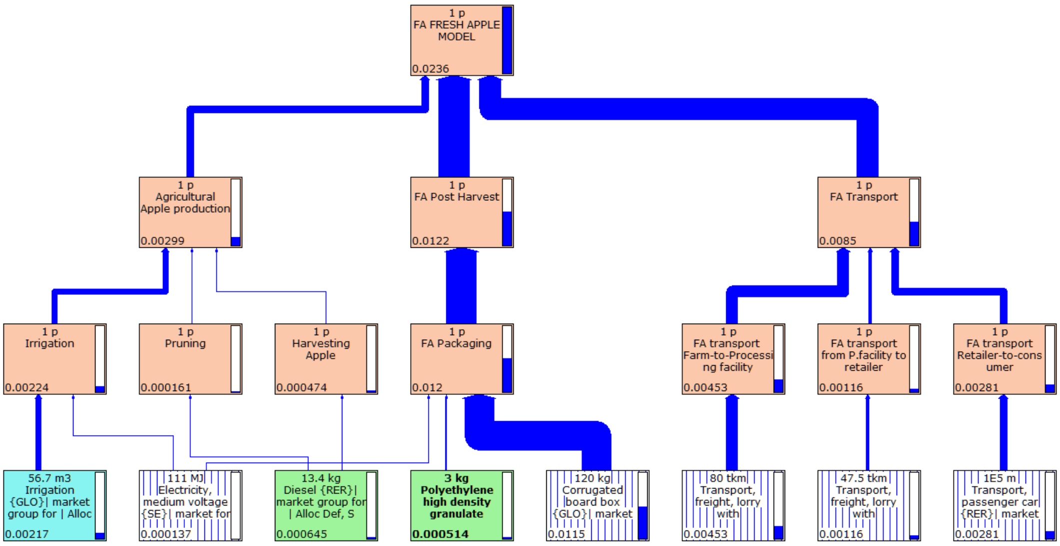

Figure 4: Example of SimaPro modeling: Network (at 0.5% cut-off) for Fresh Apple model for environmental impact analysis

3.4.2.3. Sensitivity analysis

In this LCA study, the transport distances for distribution of fresh apple fruit and dried apple fruit (from processing unit to retailers) were estimated to be within 50 km radius. However, since this distance can vary in reality and it has influence on energy consumption and other environmental impact categories, sensitivity analysis was done for better understanding. For this analysis, 3 scenarios have been set (for each Fresh Apple model and Dried Apple model) by varying the distribution distance (expressed in terms of tkm) from apple processing facility to local retailers. Transport distances from farm-to-processing facility and transport distances from retailers to household (consumer's shopping distance) have been kept constant i.e. 80km and 5 km respectively. The scenarios were implemented in SimaPro V8.2 using parameters. The parameters were defined in SimaPro as indicated in Table 1.

Table 1: Scenarios for sensitivity analysis parameter: distribution distance from processing facility to local retailer

	Scenario1		Scenario2		Scenario3	
Fresh Apple model	50 km	47.5 tkm	100 km	95 tkm	150 km	142.5 tkm
Dried Apple model	50 km	14.5 tkm	100 km	29 tkm	150 km	43.5 tkm

3.5. Normalisation and single score analysis

Both normalization and single score approaches are used in this study. Single score based analysis was used to assess the energy demand using CED method (CED version 1.09) as implemented in SimaPro 8.2. Normalization approach was applied to evaluate the environmental impacts indicated in section 3.4.1. The Normalization approach was used to identify which impact categories should get more attention during result interpretation and for recommending more detailed future studies that can investigate these identified focus areas.

4. LIFE CYCLE INVENTORY ANALYSIS

4.1. Process flowchart

The two product systems in this LCA study are modeled in SimaPro as Fresh Apple Model and Dried Apple Model. The process flow charts describing these two cases are depicted in Figure 5 and Figure 6 respectively.

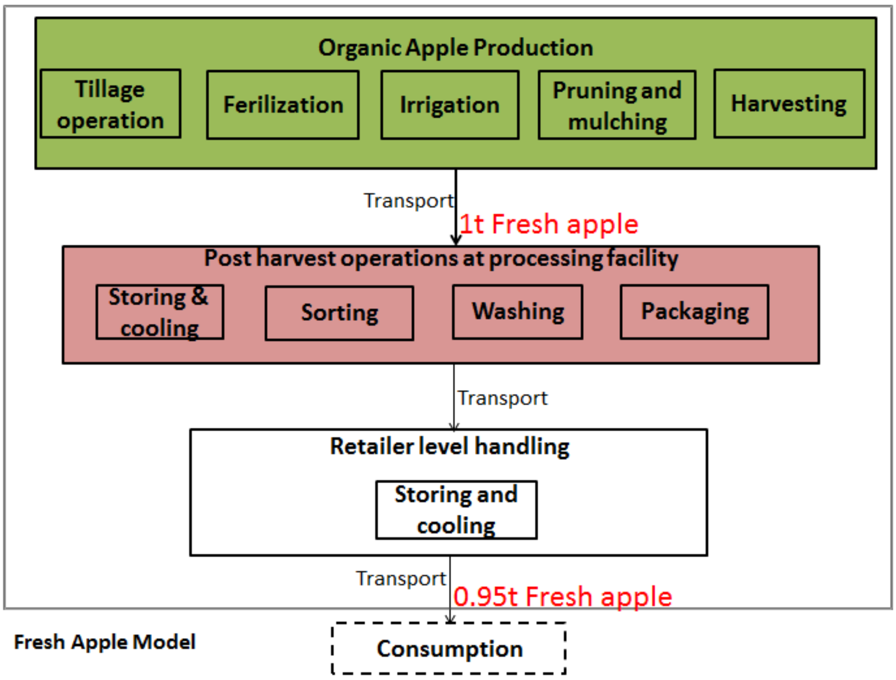

Figure 5: Flow chart describing detailed processes at different stages of **Fresh Apple** supply system

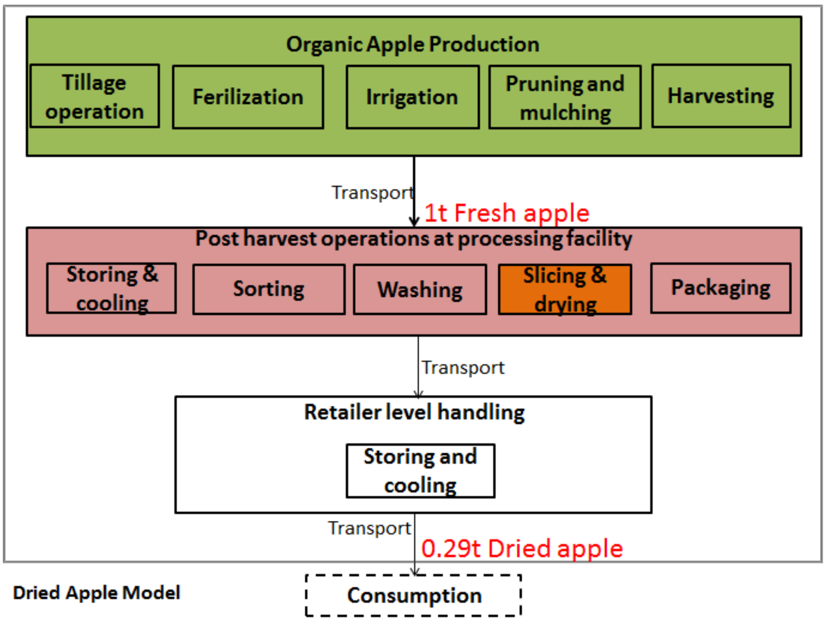

Figure 6: Flow chart describing detailed processes at different stages of Dried Apple supply system

4.2. Description of different stages

4.2.1. Organic Apple Production (Farming stage)

At agricultural production level farm operation such as ploughing (including harrowing and planting apple trees), fertilizing, pruning, irrigation and harvesting have been considered (see Table 3 and Figures 5 and 6). Diesel and electric based energy supply have been used for such operations as described in Table 3 and Table B-1 in Appendix. Diesel estimated for pruning activities includes crushing/mulching of pruned leaves and branches. The harvesting was considered to be done by hand but assisted by two tractors and a light vehicle. This doesn't include transport to processing facility (where treatment and processing like drying is done). The estimated diesel requirement for tillage, pruning, and harvesting operations is 0.21 kg, 3.34 kg, and 9.83 kg respectively per FU. Figure 7 depicts such typical activities at apple orchard.

Figure 7: Pictures describing different on farm activities at apple orchard: plowed furrow for planting of apple tree (top-left); Pruning activity (top-right); field management before harvesting (bottom-left); and manual harvesting (bottom-right). Source: http://www.appelriket.se/bildbank-frukt-i-odling/ , accessed on Dec 7-2016).

4.2.2. Post-harvest operations at processing facility

Operations at processing facility also require energy and water and packaging materials. For sorting and washing (to improve the quality of apple fruit), 5.33 MJ of electric energy and 2.9 t of water per FU are estimated as input in both Fresh Apple and Dried Apple modelling cases. For storage cooling 34.4 MJ per FU is estimated considering only 20days storage duration. The processing facility uses Controlled Atmosphere (CA) and Ultra Low Oxygen

(ULO) cooling techniques (Csaki D., Rudolfsson A. 2005). Cold storage reduces the ripping of fruits while increasing the shelf life. CA technique regulates the levels of oxygen and carbon dioxide i.e. by reducing oxygen and increasing carbon dioxide http://www.unido.org/ fileadmin/import/32113_20ControlledAtmosphereStorage.2.pdf; http:// www.vanamerongen.com/EN/Controlled-Atmosphere_20_34_6.html).

The Fresh Apple and Dried Apple models requires different amount of packaging materials and energy for packaging as the weight of dried apple reduces due to dehydration. During drying process, the weight reduces as moisture content reduces. The moisture content reduces from about 82% for fresh apple to about 11% for dried apple (Dikbasan, 2007). This indicates that the weight of 1t fresh apple will reduce to about 0.29t when dried (including the product loss of 5% at processing facility). Therefore 0.29t dried apple is considered per FU of this study (see Figures 5 and 6).

Appropriate packaging is important for fruit supply chains. During transporting fruits, bruise damage could occur and this could compromise the food quality and appearance of fruits (Fadiji et al., 2016). This leads to food losses or influences the purchasing decision of consumers. In this study, it was assumed that apple fruit will be packaged in plastic bags which will put in carton boxes. The quantity of cardboard and plastic required per FU (in both Fresh Apple and Dried Apple models) was estimated based on study by Longo et al (2017) (see Table 2). For Dried Apple case, the weight reduction due to dehydration of apple has been taken into consideration. In this study, 3 kg of plastic packaging and 120 kg of cardboard packaging were estimated per FU for Fresh Apple model respectively and 0.87 kg plastic and 35 kg cardboard for Dried Apple model respectively.

Figure 8: Example of apple packaging using plastic bags and cardboard. Source: adapted from Fadiji et al. (2016).

For Dried Apple model, the energy input for apple slicing was estimated by considering automatic commercial apple chips cutting machine which has a capacity of slicing about 1.5 t fresh apples per 2 kwh energy consumption (https://www.alibaba.com/product-detail/automatic-apple-chips-cutting-machine-banana_60520517697.html). Accordingly, the energy for apple slicing per FU was estimated to be 1.3 kwh. The energy input for apple drying was estimated based on study by Antal (2015) regarding hot air combined freezing dryer (HAD-FD) technique. Accordingly electric energy of 60 kwh per FU is estimated in this LCA study.

4.2.3. Retailer level handling

The energy requirement for retail cooling is estimated based on study by Stadig (1997) and assuming 10 days duration for apple in retailer. Accordingly, 17.2 MJ and 5 MJ of electric energy were considered per FU for Fresh Apple model and Dried Apple model respectively.

4.2.4. Transporting apple fruit

In both Fresh Apple and Dried Apple models, three segments of transporting apple fruit have been considered within defined radius (See Figure 9): Transport from farm-to-processing facility (80 km); Transport from processing facility-to-retailer (50 km); and Transport from retailer-to-household (5 km). In this study only one way transport (not round trip) is considered with the assumption that these transport activities can be coordinated with transporting other goods or purposes instead of running empty. The Apple processing facility is considered as collection and distribution centre as shown in figure 9. The ton-kilometer (tkm) values as modelled in SimaPro are provided in Table B-1 in Appendix.

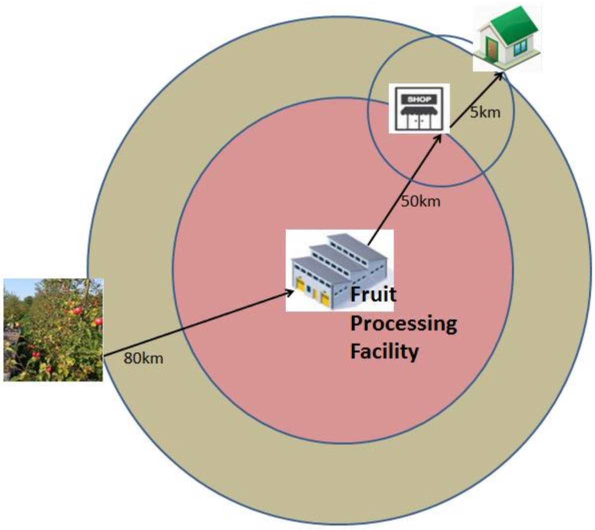

Figure 9: Author's Description of transport distances in cases of apple collection (80 km), distribution (50 km), and shopping (5 km) as modelled in SimaPro for Fresh Apple and Dried Apple models.

4.2. Data

In order to collect and document important data for this LCA study, the major environmental factors at different stages (processes) of apple supply chain were identified (see Table 2) based on literature (Assomela, 2012). In this study, useful data was acquired from primary sources, literature, and literature based estimation. All data used as input in this LCA study has been documented in Table 3. Detailed description of implementation of these data as material and process inputs has been provided in Table B-1 in Appendix.

At the farming stage, some operations needed only at the first year of the apple production life span which is about 15 years on average (see section 1.2). For instance, ploughing and planting apple trees are activities at the beginning year while its contribution is for all production years (15 years). This factor was taken into consideration when estimating the energy required per FU.

Table 2: Major environmental factors at diiferent stages along apple supply chain

Process	Farming (Apple production)	Storage	Processing	Packaging	Transport
Major environmental factor	Consumption of diesel oil, water and electric energy for irrigation	Consumption of electric energy	Consumption of electric energy and water	Production and use of packaging material, energy for packaging process	Diesel oil for trucks and small car (for shopping)

Table 3: Input data at different stages of apple fruit product cycle, per FU

Description	Unit	quantity	Data source
Farming stage (Agricultural production)			
Diesel for Plowing, harrowing, and planting	kg	0.21	Stadig (1997)
Organic fertilizer	kg	12	Longo et al (2017)
Fertilizer transport distance	km	50	Assumption
Water for irrigation	kg	54000	Estimated based on study by Stadig (1997)
Electricity for irrigation	MJ	64.42	
Energy for pruning (including crushing/mulching)	kg	3.34	Estimated based on study by Stadig (1997)
Energy (diesel) for harvesting activities	kg	9,83	Stadig (1997) but assumed it was diesel used instead of benzine
Post-harvest process			
Energy for storing (cooling)	MJ	34.4	Stadig 1997
Water (washing etc)	kg	2900	Longo et al (2017)
Energy for sorting	MJ	5.33	Stadig 1997
Plastic Packaging for fresh apple (polyethylene)	kg	3	Estimated based on packaging of 12 pices in a plastic bag of about 3gram. 1 apple is about 0.085 kg
Cardboard for packing fresh apple	kg	120	Longo et al. (2017)
Energy for Packaging process	MJ	7.17	Stadig (1997)

Packaging material delivery (both plastic and cardboard)	km	10	Assumed shopping available within 10 km
Electricity for apple slicing	kwh	1.3	Estimated as explained in section 4.2.2
Electricity for drying	kwh	60	Antal (2015)
Energy for Packaging process	MJ	2.08	Estimated based on Stadig (1997)
Dried apple weight (per FU)	ton	0.29	Estimated based on study by Dikbasan (2007)
Packaging plastic for dried apple (polyethylene)	kg	0.87	
Packaging carton for dried apple	kg	35	Estimated based on Longo et al. (2017)
Retailer			
Electricity for cooling at retailer for fresh apple	MJ	17.2	Estimated based on Stadig 1997
Electricity cooling at retailer for dried apple	MJ	5	
Transport			
Transport from farm to processing facility	km	80	Primary data and google map
Transport from processing facility to retailer	km	50	Csaki and Rudolfsson (2005).
Transport from retailer to consumer	km	5	Assumption

5. LIFE CYCLE INTERPRETATION

5.1. Results

5.1.1. Energy demand analysis using CED method

From characterization and single score analysis results (see Figure 10 and Table 4), it is understood that Post-harvest stage consumes more energy in both Fresh Apple and Dried Apple cases. This stage consumes about 54.5% and 41.10% of total CED in Fresh Apple and Dried Apple products respectively. The contribution of farming activities, post-harvest, and transport processes to the total energy demand (6.11 GJ per FU) for Fresh Apple case is 21.67%, 54.49%, and 23.84% respectively (see Figure 10 and Table 4). Similarly, for Dried Apple case (with total energy use of 3.9 GJ per FU), these values became 33.94%, 41.10%, and 24.96% respectively.

The characterization results (see Figures 10 and 11) also depicts that agricultural apple production and apple transport activities consumes more non-renewable energy while post-harvest processes consumes more non-renewable and renewable biomass energy sources mainly due to packaging material production and uses.

The single score results points out that, there is energy demand reduction at post-harvest (by 51.85%) and transport stages (by 33.16%) for Dried Apple product case when compared to Fresh Apple product. There is no difference in energy demand at farming stage since the difference between the two product systems is the drying process introduced at post-harvest stage. The overall reduction in energy demand is 36.16% under the basic scenarios of this LCA study. This indicates that there is high potential of reducing energy consumption by introducing such fruit drying techniques in the fruit supply chains. However, such studies should be supplemented with studies on the consequences of fruit drying on food nutrition and quality.

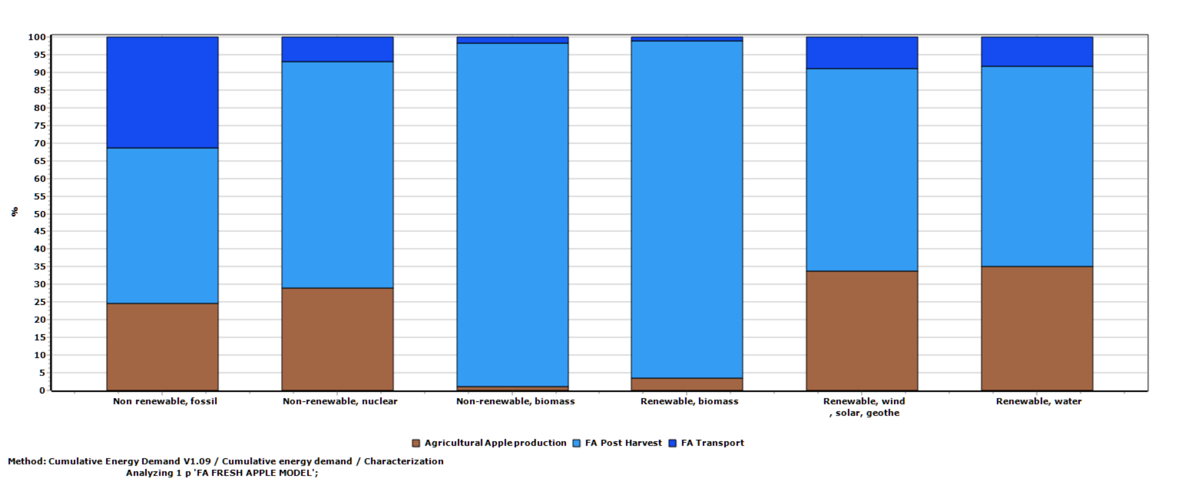

Figure 10: Characterization result of CED analysis for Fresh Apple model

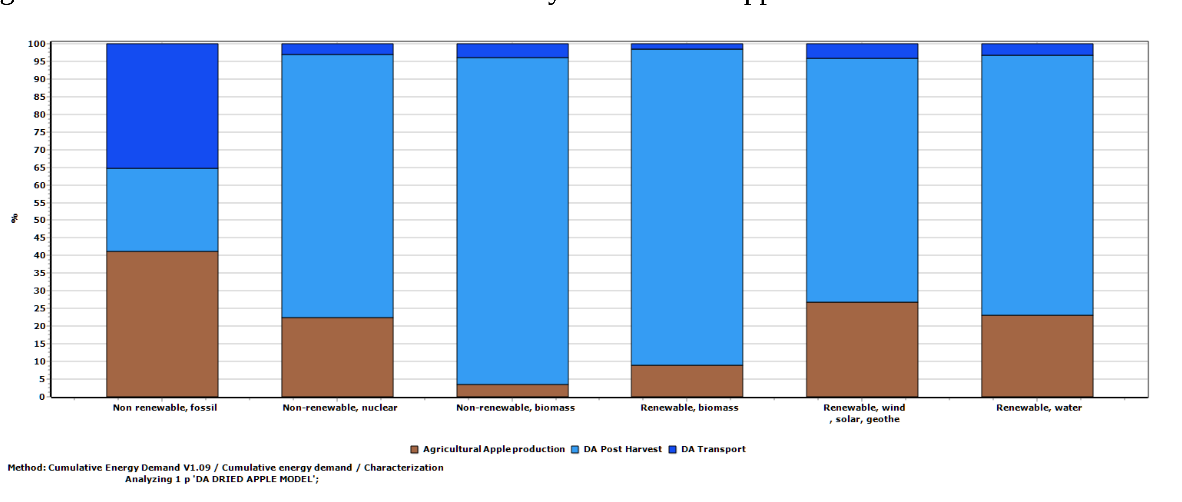

Figure 11: Characterization result of CED analysis for Dried Apple model

Table 4: Single score results - cumulative energy demand for Fresh Apple model per FU

Impact category	Unit	Total	Agricultural Apple production	FA Post Harvest	FA Transport
Total	MJ	6109,93	1323,90	3329,56	1456,47
Non-renewable, fossil	MJ	4471,02	1097,59	1972,93	1400,51
Non-renewable, nuclear	MJ	456,29	131,94	293,01	31,34
Non-renewable, biomass	MJ	2,17	0,02	2,10	0,04
Renewable, biomass	MJ	1014,60	36,32	967,54	10,73
Renewable, wind, solar, geothe	MJ	18,04	6,11	10,32	1,61
Renewable, water	MJ	147,81	51,90	83,67	12,24

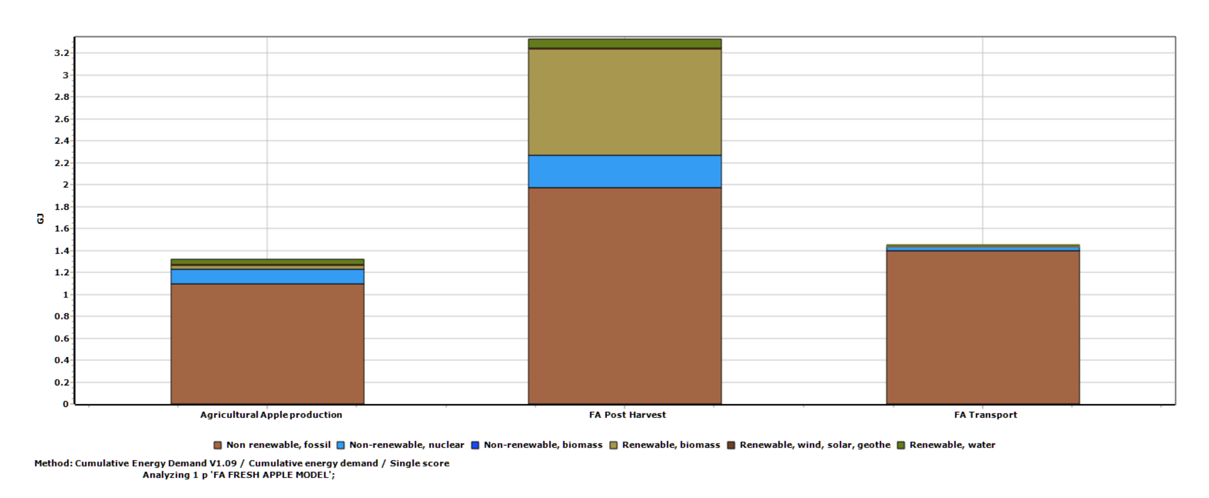

Figure 12: Single score result of CED analysis for Fresh Apple model

Table 5: Quantified cumulative energy demand for Dried Apple model

Impact category	Unit	Total	Agricultural Apple production	DA Post Harvest	DA Transport
Total	MJ	3900.63	1323.90	1603.30	973.44
Non-renewable, fossil	MJ	2658.58	1097.59	620.91	940.08
Non-renewable, nuclear	MJ	590.47	131.94	439.97	18.56
Non-renewable, biomass	MJ	0.68	0.02	0.63	0.03
Renewable, biomass	MJ	403.85	36.32	360.99	6.54
Renewable, wind, solar, geothe	MJ	22.90	6.11	15.82	0.97
Renewable, water	MJ	224.16	51.90	164.98	7.27

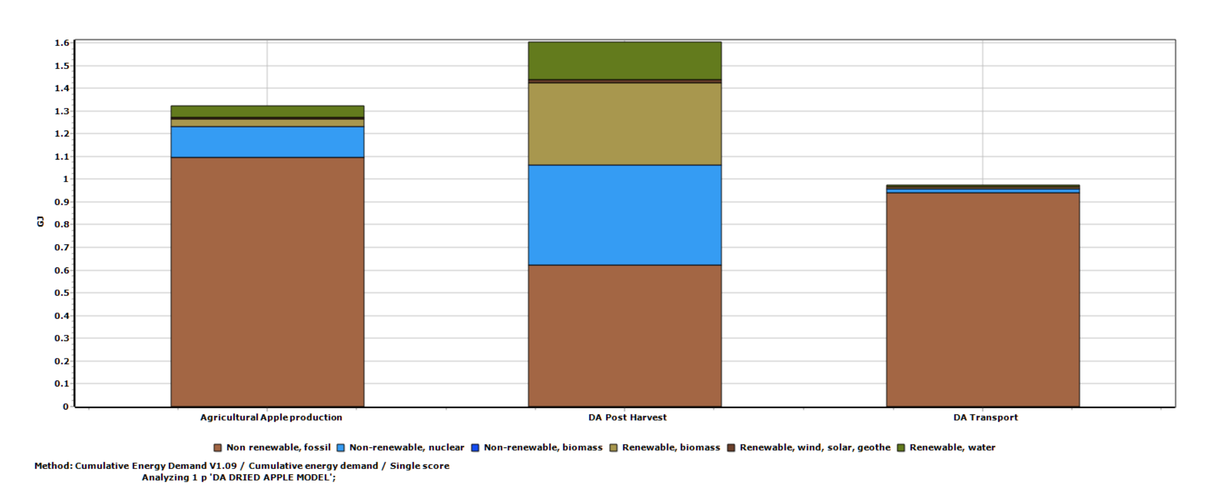

Figure 13: Single score result of CED analysis for Dried Apple model

5.1.2. Comparison analysis for energy demand

As indicated above (see section 5.1.2), the result of analysis using CED method indicated that Fresh Apple product case has more energy demand than Dried Apple product. The total energy demand by Fresh Apple and Dried Apple products are 6.11 GJ and 3.9 GJ respectively per FU (see Table 6 and Figure 15). The value for Fresh Apple case is reasonable when compared to previous studies on fruit. For instance the energy consumption of fruits is about 5MJ per kg of in-season fruit in case of western diets (Notarnicola et al., 2015).

The comparison analysis indicated that the energy demand in Dried Apple model is reduced by 36% when compared to energy demand in Fresh Apple model (see Table 6 and Figure 15). The reduction of energy demand in Dried Apple case is due to reduced packaging material and related packaging processes as well as the reduced transport activity and related fossil fuel use. This points out that the energy required for apple slicing and drying processes was relatively lower than the energy saved due to reduced packaging material and packaging process in Dried Apple model.

Table 6: Quantified energy demand per FU for both Fresh Apple and Dried apple models

Impact category	Unit	DA DRIED APPLE MODEL	FA FRESH APPLE MODEL
Total	MJ	3900.65	6109.93
Non-renewable, fossil	MJ	2658.58	4471.02
Non-renewable, nuclear	MJ	590.47	456.29
Non-renewable, biomass	MJ	0.68	2.17
Renewable, biomass	MJ	403.85	1014.60
Renewable, wind, solar, geothe	MJ	22.90	18.04
Renewable, water	MJ	224.16	147.81

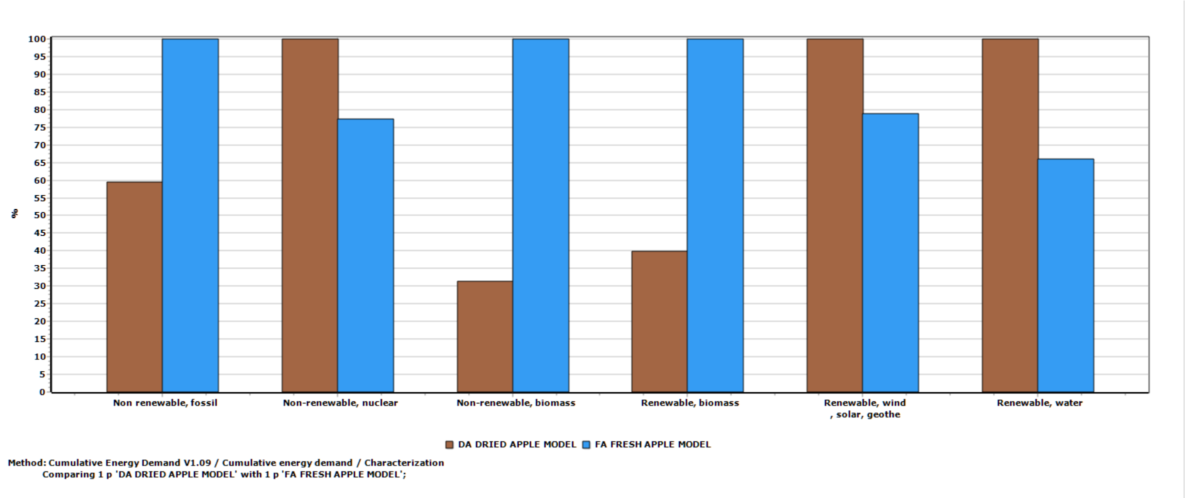

Figure 14: Comparison analysis-Characterization of CED

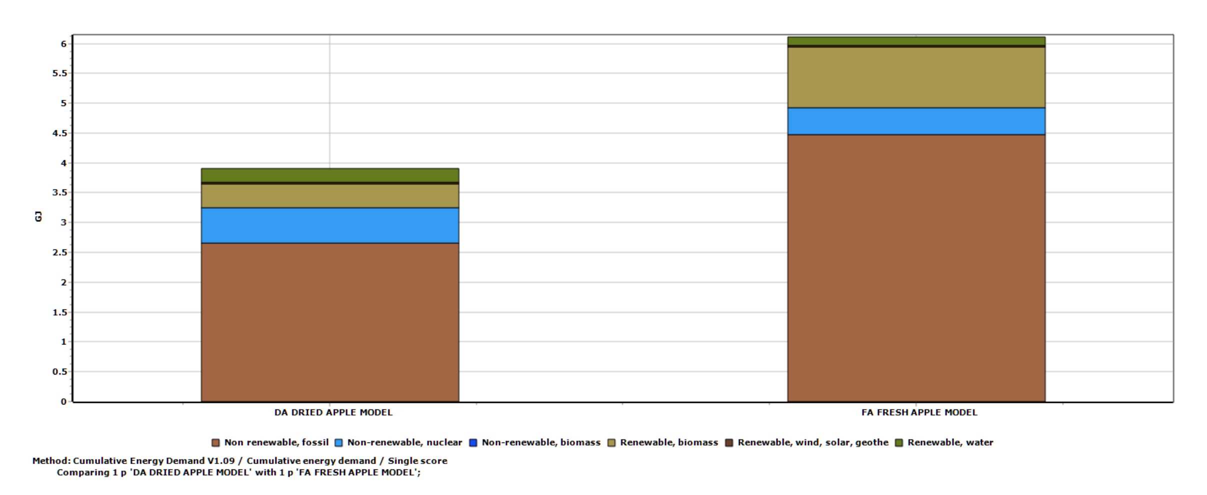

Figure 15: Comparison analysis (Single Score): Cumulative energy demand in GJ for Fresh Apple and Dried Apple models

5.1.3. Environmental impact analysis using ReCiPe (H) method

5.1.3.1. Characterization results

Analysis using Europe ReCiPe Midpoint (H) depicts that, in Fresh Apple case, post-harvest has more contribution to environmental burdens followed by transport stage (see Figure 4). Similarly, in Dried Apple model, transport has more contribution followed by post-harvest stage (see Figure A-2 in Appendix). Agricultural production (farming) stage has more impact on Agricultural land utilization and Water depletion in both Fresh Apple model (more than 85%) and Dried Apple (about 95%) model (see Figure 16 and 17). Similarly, Post-harvest processing stage has more impact on fresh water eutrophication, marine eutrophication, and terrestrial ecotoxicity in the case of Fresh Apple model, while it has more impact on marine eutrophication and ionising radiation in case of Dried Apple product.

In both Fresh Apple and Dried Apple models, the transport stage has relatively more impact on Ozone depletion, fresh water ecotoxicity, and marine ecotoxicity (see Figures 16 and 17) while it has also relatively more impact on terrestrial exotocity, urban land occupation and climate change in Dried Apple product case (see Figure 17).

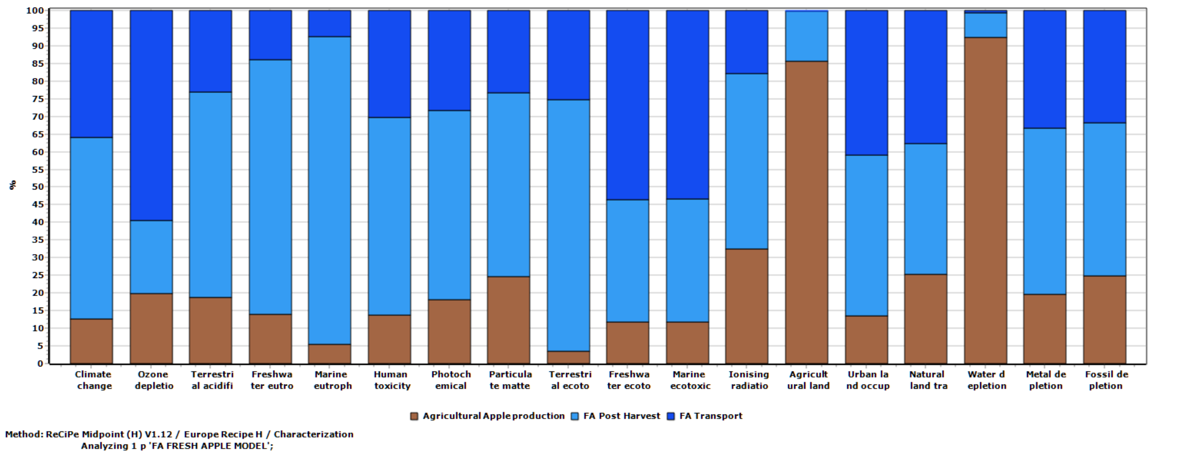

Figure 16: Characterization result illustrating the impacts of different stages along Fresh Apple product chain: Agricultural Apple Production, Post-harvest, and Transport stages.

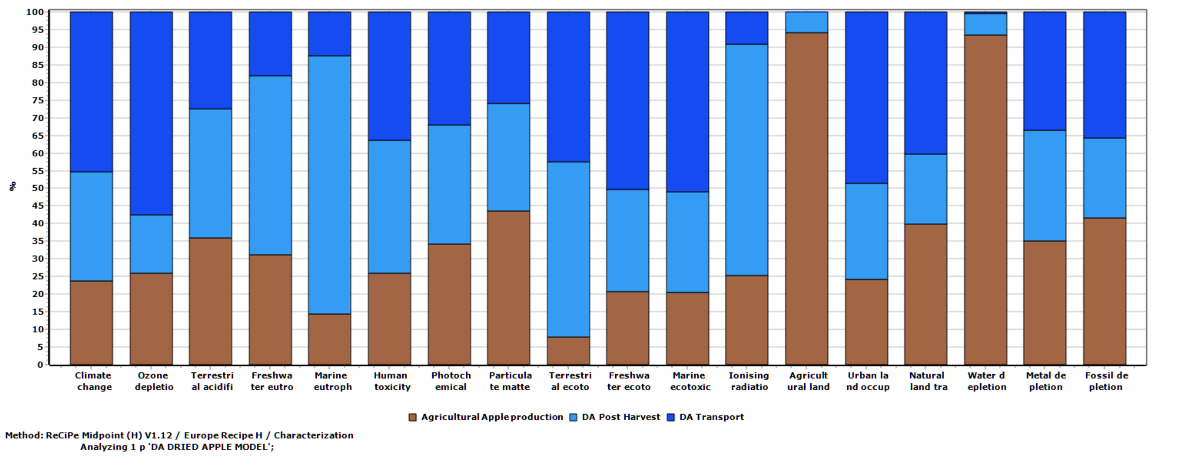

Figure 17: Characterization result illustrating the impacts of different stages along Dried Apple product chain: Agricultural Apple Production, Post-harvest, and Transport stages

5.1.3.2. Selected impact categories

Impact categories identified as focus area are presented in Table 7. Regarding water depletion and land use impacts, agricultural production stage is the major contributor in both Fresh Apple and Dried Apple product systems. In Fresh Apple product case, post-harvest and transport stages contributes more to fossil depletion. However, in Dried Apple it is agricultural production stage that contributes more to fossil depletion due to reduction in packaging material and diesel fuel needed for packing and distributing dried apple products.

Climate change impact values were quantified as 265.08 kg CO2 eq and 141.34 kg CO2 eq in Fresh Apple and Dried Apple cases respectively. Similarly, fossil depletion was found to be 99.68 kg-oil-eq and 59.63 kg-oil-eq in Fresh Apple and Dried Apple products respectively. The major contributor to climate change impact is Post-harvest stage followed by Transport stage in Fresh Apple model case (see Table 7). In the Dried Apple case, transport stage is the major contributor to climate change followed by post-harvest stage (see Table 8). This indicates that in the fruit supply chains, improving post-harvest processes and product distribution systems can leads to reduction of environmental impacts and improvement of sustainability of fruit product supply chains.

Table 7: quantified results of selected ipact categories for Fresh Apple model (per FU)

Impact category	Unit	Total	Agricultural Apple production	FA Post Harvest	FA Transport
Climate change	kg CO2 eq	265,0801	33,54465	136,2276	95,30786
Agricultural land occupation	m2a	941,2261	805,3385	134,4459	1,441698
Urban land occupation	m2a	6,646268	0,898108	3,031034	2,717127
Water depletion	m3	61,82319	57,11954	4,328439	0,375213
Fossil depletion	kg oil eq	99,67451	24,77243	43,22273	31,67934

Table 8: quantified results of selected ipact categories for Dried Apple model (per FU)

Impact category	Unit	Total	Agricultural Apple production	DA Post Harvest	DA Transport
Climate change	kg CO2 eq	141,377	33,54465	43,91749	63,91487
Agricultural land occupation	m2a	856,2453	805,3385	50,02361	0,883164
Urban land occupation	m2a	3,720889	0,898108	1,014511	1,808271
Water depletion	m3	61,13732	57,11954	3,786585	0,2312
Fossil depletion	kg oil eq	59,62508	24,77243	13,58276	21,26988

5.1.3.2. Normalization results

Although the focus of this study is on energy demand, climate change, water and resource depletion, the overall normalization results has been presented here to understand the impact categories on which the apple fruit products have more impact. This normalization results include long term impacts. From normalization results, it is understood that both Fresh Apple and Dried Apple product cases have more impact on fresh and marine ecotoxicity, natural land transformation, agricultural land occupation and fresh water eutrophication (see Figures 18 and 19).

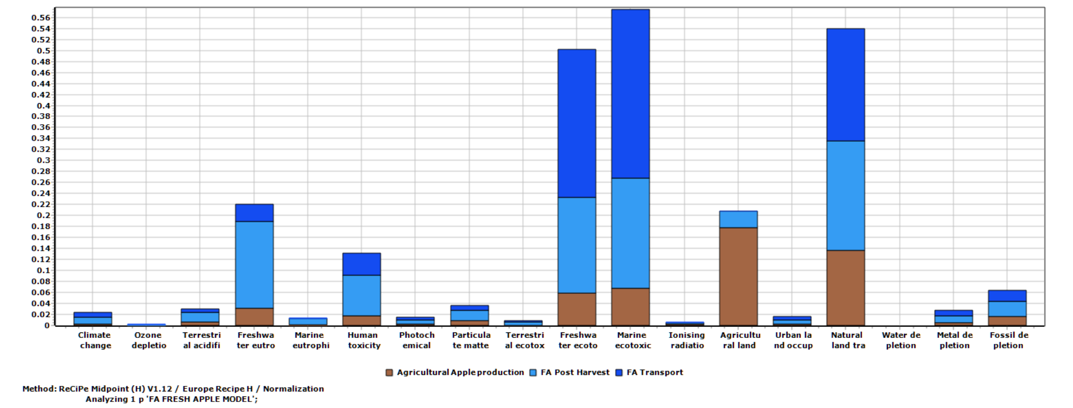

Figure 18: Normalization result illustrating the impacts of different stages along Fresh Apple product chain: Agricultural Apple Production, Post-harvest, and Transport stages.

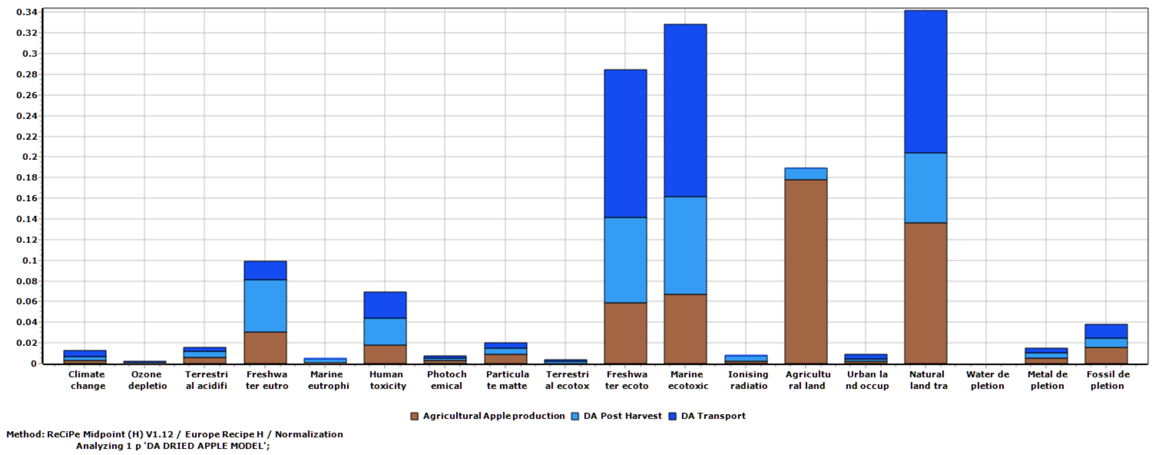

Figure 19: Normalization result illustrating the impacts of different stages along Dried Apple product chain: Agricultural Apple Production, Post-harvest, and Transport stages.

5.1.3.3 Comparison analysis

Table 9 summarizes the comparison of quantified results of impact categories. The reduction of values due to drying process is presented as %. Climate change reduced by about 47% while urban land occupation and fossil depletion reduced by 44% and 40% respectively. Regarding other impact categories, higher reduction was noticed for marine eutrophication (by 63%), terrestrial ecotoxicity (by 56%), and fresh water eutrophication (by 55%) as presented in Table 9. However, Ionising radiation was increased by 29% (see Table 9 and Figures 20 and 21).

Table 9: Comparison of Fresh and Dried apple models per FU

Impact category	Unit	DA DRIED APPLE MODEL	FA FRESH APPLE MODEL	Reduction due to drying [%]
Climate change	kg CO2 eq	141,377	265,0801	46,67
Ozone depletion	kg CFC-11 eq	4,34E-05	5,68E-05	23,59
Terrestrial acidification	kg SO2 eq	0,549114	1,050669	47,74
Freshwater eutrophication	kg P eq	0,041133	0,091192	54,89
Marine eutrophication	kg N eq	0,050392	0,136089	62,97
Human toxicity	kg 1,4-DB eq	43,69279	82,64093	47,13
Photochemical oxidant formation	kg NMVOC	0,437504	0,827441	47,13
Particulate matter formation	kg PM10 eq	0,300682	0,533328	43,62
Terrestrial ecotoxicity	kg 1,4-DB eq	0,032187	0,07273	55,74
Freshwater ecotoxicity	kg 1,4-DB eq	3,131371	5,524422	43,32
Marine ecotoxicity	kg 1,4-DB eq	2,856575	4,997188	42,84
Ionising radiation	kBq U235 eq	49,08595	38,065	-28,95
Agricultural land occupation	m2a	856,2453	941,2261	9,03
Urban land occupation	m2a	3,720889	6,646268	44,02
Natural land transformation	m2	0,055214	0,087115	36,62
Water depletion	m3	61,13732	61,82319	1,11
Metal depletion	kg Fe eq	10,83041	19,40977	44,20
Fossil depletion	kg oil eq	59,62508	99,67451	40,18

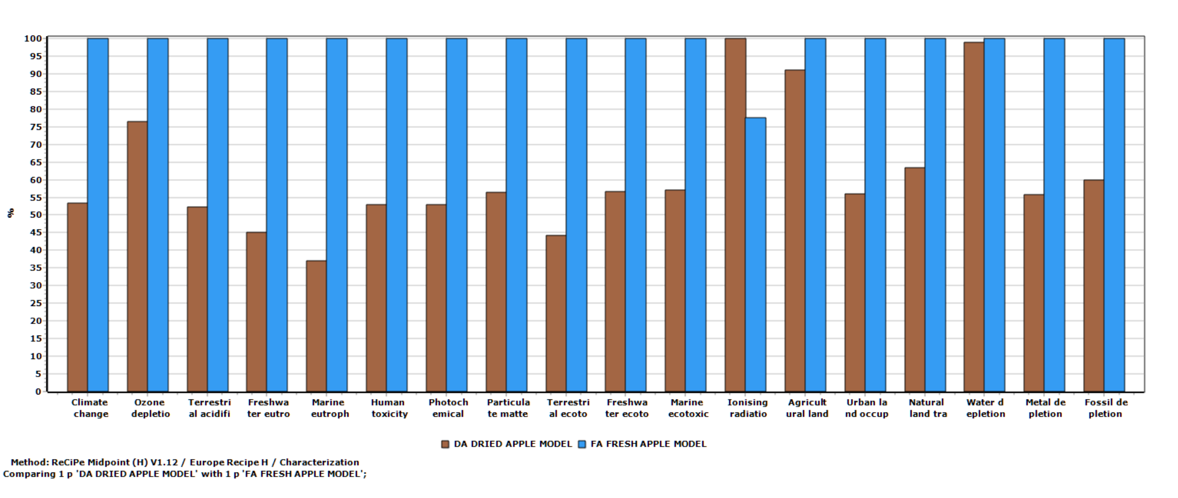

Figure 20: Comparision analysis- Characterization result of Fresh Apple and Dried Apple model

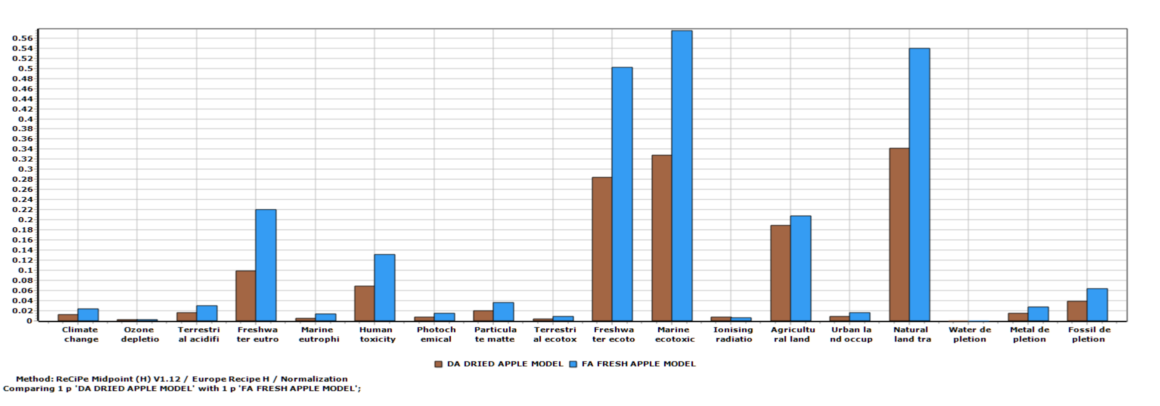

Figure 21: Comparison analysis- Normalized result of Fresh Apple and Dried Apple model using Europe ReCipe Midpoint (H).

5.1.4. Sensitivity analysis

5.1.4.1.Sensitivity analysis on energy demand

From sensitivity analysis results the energy demand increased by 6.38 % (in Fresh Apple case) and 3.08% (in Dried Apple case) when distribution distance increased from 50km to 150 km. In both Fresh Apple and Dried Apple models (see Tables 10 and 11), increasing distribution distance increases the use of non-renewable fossil fuel and this is the main contributor to increased energy consumption as transport distance increases.

Table 10- Sensitivity analysis results for Fresh Apple model

Impact category	Unit	Scenario1:50km	Scenario2:100km	Scenario3:150km
Total	**GJ**	**6,11**	**6,30**	**6,50**
Non-renewable, fossil	GJ	4,47	4,66	4,85
Non-renewable, nuclear	GJ	0,46	0,46	0,46
Non-renewable, biomass	GJ	0,00	0,00	0,00
Renewable, biomass	GJ	1,01	1,02	1,02
Renewable, wind, solar, geothe	GJ	0,02	0,02	0,02
Renewable, water	GJ	0,15	0,15	0,15

Table 11- Sensitivity analysis results for Dried Apple model

Impact category	Unit	Scenario1:50km	cenario2:100km	Scenario3:150km
Total	**GJ**	**3,90**	**3,96**	**4,02**
Non-renewable, fossil	GJ	2,66	2,72	2,77
Non-renewable, nuclear	GJ	0,59	0,59	0,59
Non-renewable, biomass	GJ	0,00	0,00	0,00
Renewable, biomass	GJ	0,40	0,40	0,40
Renewable, wind, solar, geothe	GJ	0,02	0,02	0,02
Renewable, water	GJ	0,22	0,22	0,22

5.1.4.2 Sensitivity analysis with ReCiPe midpoint (H) method

The characterization results from sensitivity analysis (See Figure 22 and 23) indicate that increased apple distribution distance has relatively more impact on some impact categories such as climate change, ozone depletion, urban land occupation, natural land transformation, and fossil depletion. From Tables 12 and 13, it is known that when distribution distance increased from 50km to 150 km, the climate change increased by 9.77% and 5.59% for Fresh Apple and Dried Apple cases respectively while for fossil depletion the % became 8.52% (for Fresh Apple product) and 4.35% (for Dried Apple product).

In comparison to all impact categories listed in Tables 12 and 13, Ozone depletion showed the highest increase with 25.88% in Fresh Apple case and 10.37% in Dried Apple case followed by urban land occupation and natural land transformation impacts relatively.

Table 12: Sensitivity analysis results for Fresh Apple model (per FU)

Impact category	Unit	Scenario1: 50 km	Scenario2: 100 km	Scenario3: 150 km	Increase from Scenario1 to 3 [%]
Climate change	kg CO2 eq	265,0801	278,0304	290,9808	9,77
Ozone depletion	kg CFC-11 eq	5,68E-05	6,41E-05	7,15E-05	25,88
Terrestrial acidification	kg SO2 eq	1,050669	1,078012	1,105355	5,20
Freshwater eutrophication	kg P eq	0,091192	0,092282	0,093371	2,39
Marine eutrophication	kg N eq	0,136089	0,13716	0,138231	1,57
Human toxicity	kg 1,4-DB eq	82,64093	85,03003	87,41913	5,78
Photochemical oxidant formation	kg NMVOC	0,827441	0,853317	0,879193	6,25
Particulate matter formation	kg PM10 eq	0,533328	0,54717	0,561013	5,19
Terrestrial ecotoxicity	kg 1,4-DB eq	0,07273	0,074997	0,077263	6,23
Freshwater ecotoxicity	kg 1,4-DB eq	5,524422	5,723975	5,923529	7,22
Marine ecotoxicity	kg 1,4-DB eq	4,997188	5,185584	5,373981	7,54
Ionising radiation	kBq U235 eq	38,065	38,94255	39,82009	4,61
Agricultural land occupation	m2a	941,2261	941,3764	941,5266	0,03
Urban land occupation	m2a	6,646268	7,101489	7,55671	13,70
Natural land transformation	m2	0,087115	0,091666	0,096217	10,45
Water depletion	m3	61,82319	61,8627	61,90221	0,13
Metal depletion	kg Fe eq	19,40977	19,89256	20,37535	4,97
Fossil depletion	kg oil eq	99,67451	103,9226	108,1707	8,52

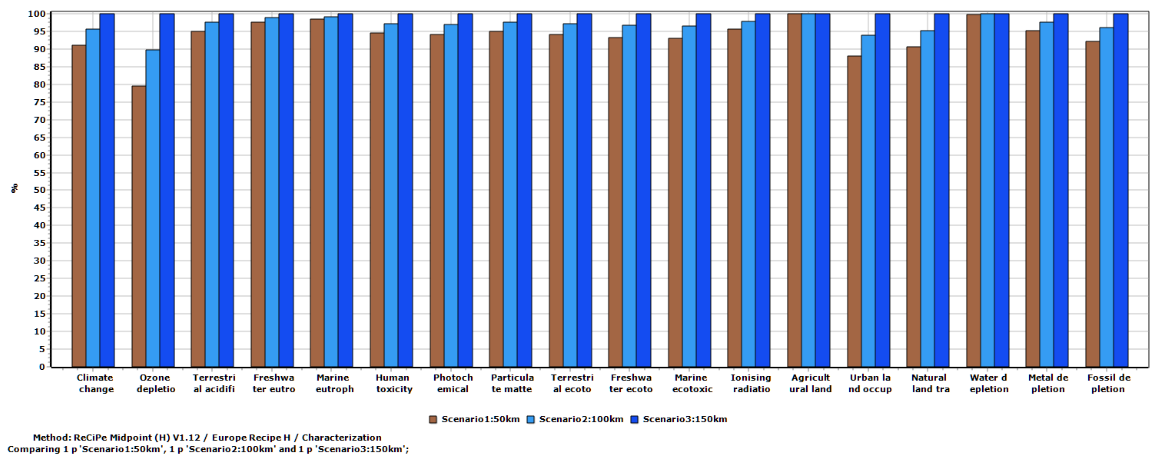

Figure 22: Sensitivity analysis results in Fresh Apple case using 50 km, 100 km and 150 km of distribution distances from processing facility to retailer

Table 13: Sensitivity analysis results for Dried Apple model (per FU)

Impact category	Unit	Scenario1: 50 km	Scenario2: 100 km	Scenario3: 150 km	Increase from Scenario1 to 3 [%]
Climate change	kg CO2 eq	141,377	145,3303	149,2835	5,59
Ozone depletion	kg CFC-11 eq	4,34E-05	4,56E-05	4,79E-05	10,37
Terrestrial acidification	kg SO2 eq	0,549114	0,557461	0,565808	3,04
Freshwater eutrophication	kg P eq	0,041133	0,041466	0,041798	1,62
Marine eutrophication	kg N eq	0,050392	0,050719	0,051046	1,30
Human toxicity	kg 1,4-DB eq	43,69279	44,4221	45,1514	3,34
Photochemical oxidant formation	kg NMVOC	0,437504	0,445403	0,453302	3,61
Particulate matter formation	kg PM10 eq	0,300682	0,304907	0,309133	2,81
Terrestrial ecotoxicity	kg 1,4-DB eq	0,032187	0,032879	0,033571	4,30
Freshwater ecotoxicity	kg 1,4-DB eq	3,131371	3,192288	3,253204	3,89
Marine ecotoxicity	kg 1,4-DB eq	2,856575	2,914086	2,971596	4,03
Ionising radiation	kBq U235 eq	49,08595	49,35384	49,62172	1,09
Agricultural land occupation	m2a	856,2453	856,2911	856,337	0,01
Urban land occupation	m2a	3,720889	3,859852	3,998814	7,47
Natural land transformation	m2	0,055214	0,056603	0,057993	5,03
Water depletion	m3	61,13732	61,14938	61,16144	0,04
Metal depletion	kg Fe eq	10,83041	10,97779	11,12517	2,72
Fossil depletion	kg oil eq	59,62508	60,92186	62,21865	4,35

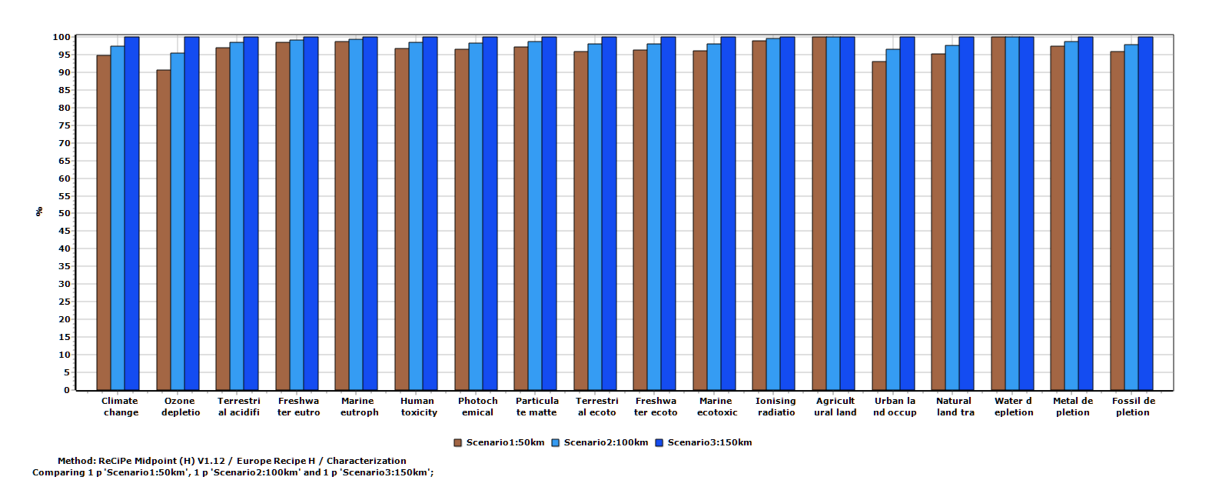

Figure 23: Sensitivity analysis results in Dried Apple case using 50 km, 100 km and 150 km of distribution distances from processing facility to retailer

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The goal of this study was to assess the environmental burdens of organic apple fruits produced in Sweden considering two product supply systems i.e. Fresh Apple product and Dried Apple product. These two systems were modeled in SimaPro v8.2 and analyzed using Cumulative Energy Demand (CED) and Europe ReCiPe Midpoint (H) methods. The CED method energy analysis results indicated that post-harvest processing stage consumes more energy in both Fresh Apple and Dried Apple cases. The contribution of agricultural production, post-harvest, and transport stages to the total energy demand for Fresh Apple case is 21.67%, 54.49%, and 23.84% respectively. Similarly, for Dried Apple case these values became 33.94%, 41.10%, and 24.96% respectively.

Fresh Apple product case has more energy demand (6.11 GJ) than Dried Apple product (3.9 GJ) i.e. the energy demand in Dried Apple model is reduced by 36% when compared to energy demand in Fresh Apple product case. Reduced packaging material and related packaging processes as well as the reduced transport activity and related fossil fuel uses contributed to this reduction of energy demand in Dried Apple case. This points out that the energy required for apple slicing and drying processes was relatively lower than the energy saved due to reduced packaging material and packaging process in Dried Apple model.

Except the ionization radiation impact which increased by about 29%, other impact categories were reduced due to apple drying process. The quantified climate change impact values were 265.08 kg CO_2 eq and 141.34 kg CO_2 eq in Fresh Apple and Dried Apple cases respectively. The fossil depletion was found to be 99.68 kg-oil-eq and 59.63 kg-oil-eq in Fresh Apple and Dried Apple products respectively. Post-harvest and transport stages are found to be major contributors to climate change in both Fresh Apple and Dried Apple cases. However, in the fossil depletion case, the major contributors are post-harvest and transport stages in Fresh Apple model while it was agricultural production (farming stage) that contributes more to fossil depletion. Regarding water depletion and land use impacts, agricultural production stage is the major contributor in both Fresh Apple and Dried Apple product systems.

Transport distance influences the impact categories in Fresh Apple and Dried Apple cases. For instance, the energy demand increased by 6.38 % (in Fresh Apple case) and 3.08% (in

Dried Apple case) when distribution distance increased from 50 km to 150 km. Similarly the climate change increased by 9.77% and 5.59% for Fresh Apple and Dried Apple cases respectively.

In general, the drying process could be important process not only to improve preserving methods of organic apple fruits but also to reduce environmental impacts. The CED and ReCiPe method analyses pointed out that post-harvest and transport stages are major contributors to energy demand and climate change impacts. This indicates that in the fruit supply chains, improving post-harvest processes and product distribution systems can leads to reduction of environmental impacts and improvement of sustainability of apple fruit supply chains.

6.2. Recommendations

Based on the findings of this study, the following recommendations proposed:

- Apple drying process is recommendable for environmental point of view as it reduces energy consumption and many other impact categories like climate change. However further LCA studies that consider the impact apple drying on food nutrition and quality of apple is recommended.
- It was noticed that the packaging stage has significant contribution to environmental impacts. However the waste management of this packaging material and food waste was not included in this LCA study. Further study, incorporating the Waste treatment stage in the LCA system boundary is also recommended for better understanding of the systems.
- More detailed LCA studies considering both organic and conventional apple fruit product are recommended to understand the influence of drying process on environmental impacts.
- This study indicated that apple drying process could reduce significantly the environmental burdens of fruit supply while increasing shelf life of fruits. Therefore, LCA study should be replicated with more comprehensive primary data on apple drying process.

REFERENCES

Antal T. (2015). Comparative study of three drying methods: freeze, hot airassisted freeze and infrared-assisted freeze modes. *Agronomy Research* **13**(4), 863–878, 2015. http://agronomy.emu.ee/wp-content/uploads/2015/05/13_4_1_B5.pdf . [accessed on 2016-11-20].

Ascard, J., Håkansson, B. Hansson, A., Stridh H. and Söderlind M. (2010). Cost price calculations for organically and conventionally grown apples in Sweden. Eco.fruit conference proceeding: http://www.ecofruit.net/2010/46_RP_J_Ascard_B_Hakansson_A_Hansson_et_al_S304bis312.pdf . [Accessed on 02-12-2016].

Assomela (2012). Environmental Product Declaration **of Italian Apples.** EPD-environmental product declaration, S-P-00369, version 3.

Berggren A., Marklund E. Magnusson N. (2012). LCA of three different school lunches with the same nutritional content. Course project. Kungl. Tekniska Högskolan, Division of Environmental Strategies Research, Stockholm.

Csaki D., Rudolfsson A. (2005). Internal logistics solutions for Äppelriket [Interna logistiklösningar för Äppelriket]. Högskolan Kirstianstad.

DİKBASAN, T. (2007). Determination of effective parameters for drying of apples: A Master Thesis; İzmir Institute of Technology, İZMİR. http://library.iyte.edu.tr/tezler/master/enerjimuh/T000743.pdf . [accessed on 2016-12-12].

Fadiji T., Coetzee C., Pathare P., Opara U.L. (2016). Susceptibility to impact damage of apples inside ventilated corrugated paperboard packages: Effects of package design. Postharvest Biology and Technology 111 (2016): 286–296.

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M., 2005, The ecoinvent database: Overview and methodological framework, International Journal of Life Cycle Assessment 10, 3–9.

Frischknecht, R., Wyss F., Knöpfel S.B., Lützkendorf T., Balouktsi M. (2015). Cumulative energy demand in LCA: the energy harvested approach. Int J Life Cycle Assess (2015) 20: 957. doi:10.1007/s11367-015-0897-4.

Google maps 2016. webpage maps.google.se 2016-12-14

Johansson D. (2017). Life cycle assessment (LCA) of apples - A comparison between apples produced in Sweden, Italy and Argentina. Master’s thesis, Swedish university of agricultural sciences, Uppsala.

Jönsson Å.H. (2007). Organic Apple Production in Sweden: Cultivation and Cultivars. Doctor’s dissertation. ISSN 1652-6880, ISBN 978-91-576-7313-8. Swedish university of agricultural sciences. Faculty of Landscape Planning, Horticulture and Agricultural Science, Department of Crop Science, Alnarp.

Notarnicola B., Salomone R., Petti L., Renzulli P.A., Roma R., Cerutti A.K. (2015). Life cycle assessment in the agri-food sector. Case studies, methodological issues, and best practices. ISBN 978-3-319-11939-7, Springer.

PRé Consultants (2015). SimaPro 8 [computer software]. PRé Consultants, The Netherlands.

Sonia Longo, Marina Mistretta, Francesco Guarino, Maurizio Cellura (2017). Life Cycle Assessment of organic and conventional apple supply chains in the North of Italy. Journal of Cleaner Production 140, 654-663.

Stadig M (1997). Life cycle analysis of apple production. Case study fror Sweden, New Zeeland, and Italy. Swedish university of agricultural sciences, department of food and biotechnology.

UN (1998). UNECE STANDARD DDP-16 : concerning the marketing and commercial quality control of DRIED APPLES, 1998 EDITION, UNITED NATIONS. https://www.unece.org/fileadmin/DAM/trade/agr/standard/dry/dry_e/16DriedApples_e.pdf . [Accessed on 2016-12-12].

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: http://link.springer.com/10.1007/s11367-016-1087-8 [Accessed 25, 11, 2016].

www.alibaba.com: https://www.alibaba.com/product-detail/automatic-apple-chips-cutting-machine-banana_60520517697.html

Appendix A: Figures

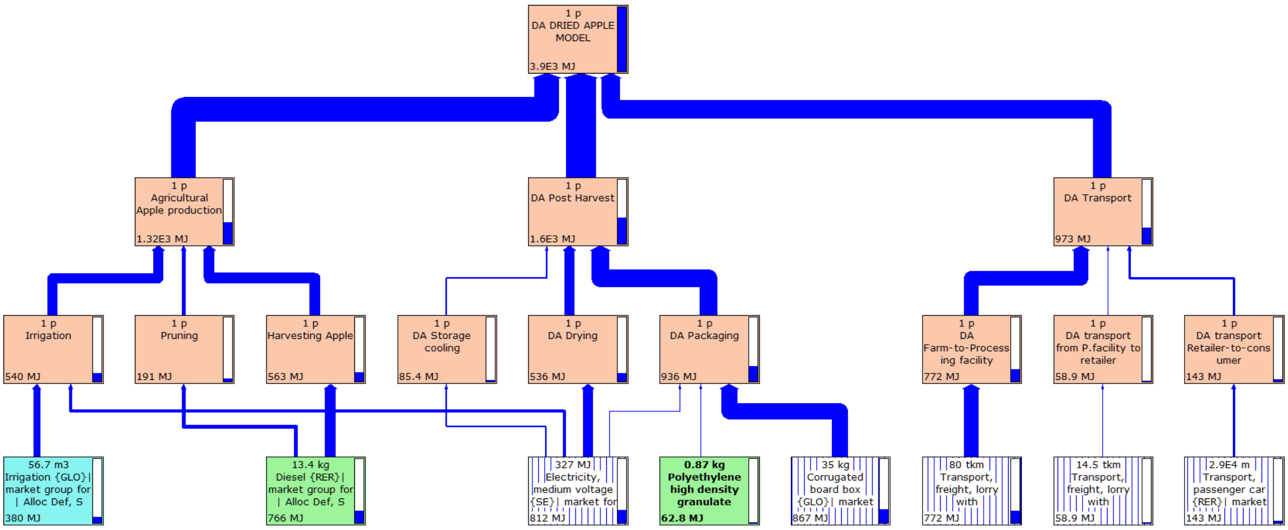

Figure A-1: SimaPro modeling (Network) for Dried Apple product (energy demand analysis with CED method)

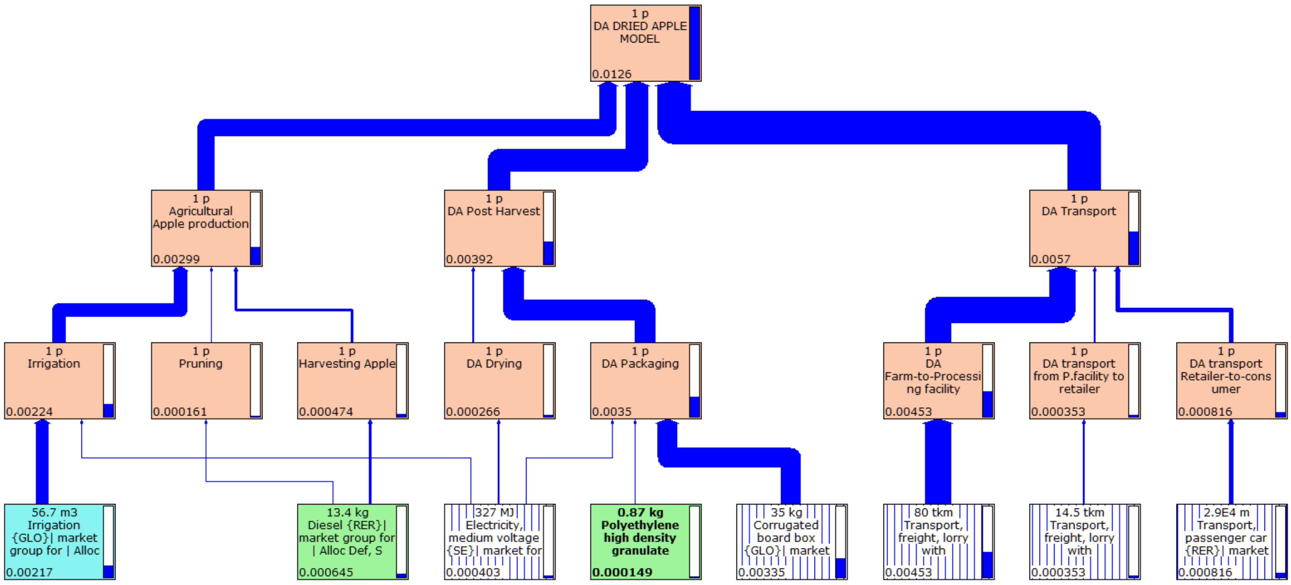

Figure A-2: SimaPro modeling (Network) for Dried Apple product (analysis with ReCiPe method)

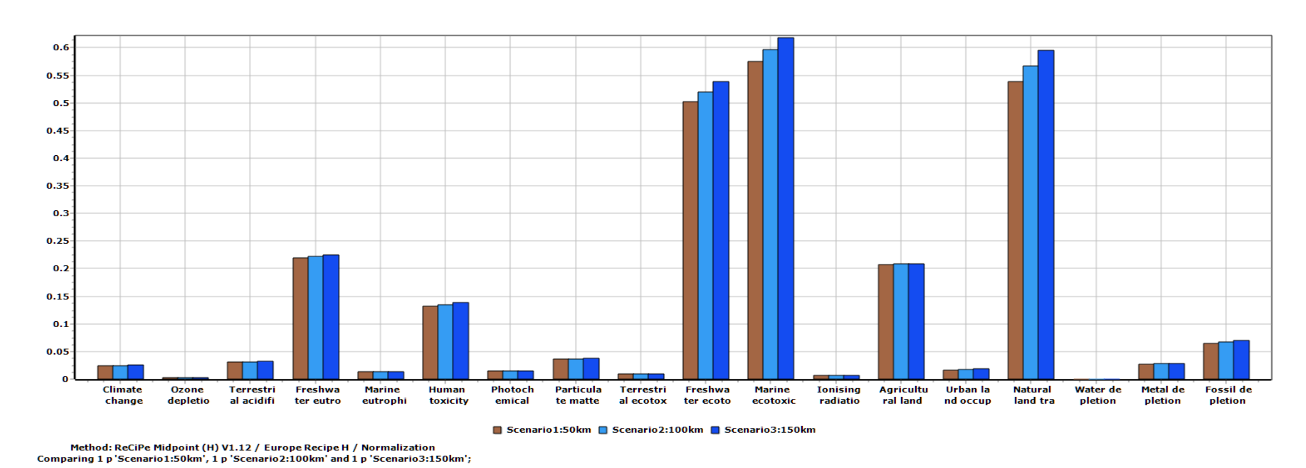

Figure A-3: Normalization result of sensitivity analysis for Fresh Apple model

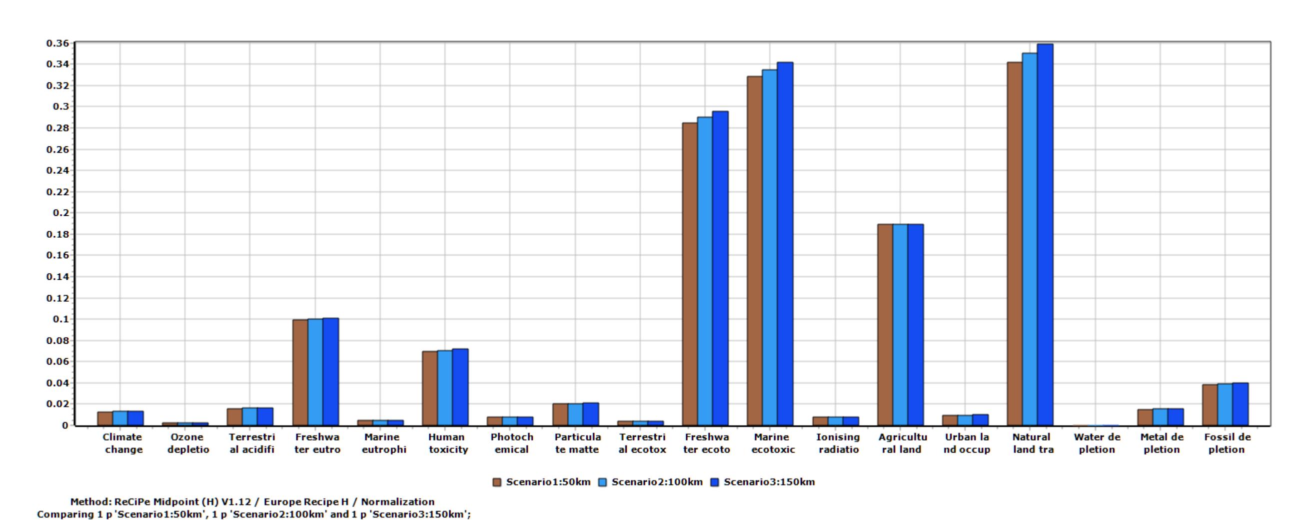

Figure A-4: Normalization result of sensitivity analysis for Dried Apple model

Appendix B- Tables

Table B-1: Input materials and processes as implemented in modeling with SimaPro 8.2 (per FU)

Input Materials/assemblies and process in SimaPro 8.2	**Quantity**	**Unit**	**Component**	**Data base**
Diesel {RER}| market group for | Alloc Def, S	0,21	kg	Farm Operation-Tillage	Ecoinvent 3
Diesel {RER}| market group for | Alloc Def, S	3,34	kg	Pruning	Ecoinvent 3
Horn meal {GLO}| market for | Alloc Def, S	12	kg	Fertilization	Ecoinvent 3
Diesel {RER}| market group for | Alloc Def, S	9,83	kg	Harvesting Apple	Ecoinvent 3
Polyethylene high density granulate (PE-HD), production mix, at plant RER	3	kg	FA Packaging	ELCD database 3.1
Corrugated board box {GLO}| market for corrugated board box | Alloc Def, S	120	kg	FA Packaging	Ecoinvent 3
Tap water {Europe without Switzerland}| market for | Alloc Def, S	2900	kg	Washing	Ecoinvent 3
Polyethylene high density granulate (PE-HD), production mix, at plant RER	0,87	kg	DA Packaging	ELCD database 3.1
Corrugated board box {GLO}| market for corrugated board box | Alloc Def, S	35	kg	DA Packaging	Ecoinvent 3
Processes	**Quantity**	**Unit**	**Remark**	
Occupation, arable, organic	0,08	ha a	Apple cultivation area	SimaPro8.2
Irrigation {GLO}| market group for | Alloc Def, S	56,7	m3	Irrigation	
Electricity, medium voltage {SE}| market for | Alloc Def, S	64,42	MJ	Irrigation	Ecoinvent 3
Transport, tractor and trailer, agricultural {GLO}| market for | Alloc Def, S	0,6	tkm	Fertilization	Ecoinvent 3
Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, R134a refrigerant, cooling {GLO}| market for | Alloc Def, S	80	tkm	Farm to processing facility	Ecoinvent 3
Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO6, R134a refrigerant, cooling {GLO}| market for | Alloc Def, S	47,5	tkm	FA transport from P.facility to retailer	Ecoinvent 3
Electricity, medium voltage {SE}| market for | Alloc Def, S	34,4	MJ	Storage cooling	Ecoinvent 3
Electricity, medium voltage {SE}| market for | Alloc Def, S	5,33	MJ	Sorting	Ecoinvent 3
Small lorry transport, Euro 0, 1, 2, 3, 4 mix, 7,5 t total weight, 3,3 t max payload RER S	1,23	tkm	FA Packaging	ELCD database 3.1
Electricity, medium voltage {SE}| market for | Alloc Def, S	7,17	MJ	FA Packaging	Ecoinvent 3
Electricity, medium voltage {SE}| market for | Alloc Def, S	17,2	MJ	Retailer cooling for Fresh Apple	Ecoinvent 3
Transport, passenger car {RER}| market for | Alloc Def, S	100	km	FA Transport (Retailer to consumer)	Ecoinvent 3
Electricity, medium voltage {SE}| market for | Alloc Def, S	1,3	kWh	DA apple Slicing	Ecoinvent 3
Electricity, medium voltage {SE}| market for | Alloc Def, S	60	kWh	DA Drying	Ecoinvent 3
Small lorry transport, Euro 0, 1, 2, 3, 4 mix, 7,5 t total weight, 3,3 t max payload RER S	358,7	kgkm	DA Packaging	ELCD database 3.1
Electricity, medium voltage {SE}| market for |	2,08	MJ	DA Packaging	Ecoinvent 3

Alloc Def, S				
Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO6, R134a refrigerant, cooling {GLO}| market for | Alloc Def, S	14,5	tkm	DA transport from P.facility to retailer	Ecoinvent 3
Electricity, medium voltage {SE}| market for | Alloc Def, S	5	MJ	DA Retail cooling	Ecoinvent 3
Transport, passenger car {RER}| market for | Alloc Def, S	29	km	DA transport Retailer-to-consumer	Ecoinvent 3

Table B-2: Quantified impacts (per FU) for Fresh Apple model

Impact category	Unit	Total	Agricultural Apple production	FA Post Harvest	FA Transport
Climate change	kg CO2 eq	265,0801	33,54465	136,2276	95,30786
Ozone depletion	kg CFC-11 eq	5,68E-05	1,13E-05	1,18E-05	3,37E-05
Terrestrial acidification	kg SO2 eq	1,050669	0,197406	0,610967	0,242297
Freshwater eutrophication	kg P eq	0,091192	0,012795	0,06569	0,012707
Marine eutrophication	kg N eq	0,136089	0,007278	0,118716	0,010095
Human toxicity	kg 1,4-DB eq	82,64093	11,2868	46,28234	25,07178
Photochemical oxidant formation	kg NMVOC	0,827441	0,150061	0,442175	0,235206
Particulate matter formation	kg PM10 eq	0,533328	0,131253	0,278226	0,123849
Terrestrial ecotoxicity	kg 1,4-DB eq	0,07273	0,002495	0,051801	0,018434
Freshwater ecotoxicity	kg 1,4-DB eq	5,524422	0,648885	1,917299	2,958238
Marine ecotoxicity	kg 1,4-DB eq	4,997188	0,584599	1,746877	2,665712
Ionising radiation	kBq U235 eq	38,065	12,39216	18,90826	6,76458
Agricultural land occupation	m2a	941,2261	805,3385	134,4459	1,441698
Urban land occupation	m2a	6,646268	0,898108	3,031034	2,717127
Natural land transformation	m2	0,087115	0,022011	0,032223	0,032881
Water depletion	m3	61,82319	57,11954	4,328439	0,375213
Metal depletion	kg Fe eq	19,40977	3,799439	9,12469	6,48564
Fossil depletion	kg oil eq	99,67451	24,77243	43,22273	31,67934

Table B-3: Characterization result (per FU) of Impact analysis for Dried Apple model

Impact category	Unit	Total	Agricultural Apple production	DA Post Harvest	DA Transport
Climate change	kg CO2 eq	141,377	33,54465	43,91749	63,91487
Ozone depletion	kg CFC-11 eq	4,34E-05	1,13E-05	7,18E-06	2,49E-05
Terrestrial acidification	kg SO2 eq	0,549114	0,197406	0,200549	0,15116
Freshwater eutrophication	kg P eq	0,041133	0,012795	0,020882	0,007456
Marine eutrophication	kg N eq	0,050392	0,007278	0,036885	0,00623
Human toxicity	kg 1,4-DB eq	43,69279	11,2868	16,47082	15,93517
Photochemical oxidant formation	kg NMVOC	0,437504	0,150061	0,14713	0,140313
Particulate matter formation	kg PM10 eq	0,300682	0,131253	0,091522	0,077907
Terrestrial ecotoxicity	kg 1,4-DB eq	0,032187	0,002495	0,016018	0,013674
Freshwater ecotoxicity	kg 1,4-DB eq	3,131371	0,648885	0,907577	1,574909
Marine ecotoxicity	kg 1,4-DB eq	2,856575	0,584599	0,818691	1,453286
Ionising radiation	kBq U235 eq	49,08595	12,39216	32,23361	4,460191
Agricultural land occupation	m2a	856,2453	805,3385	50,02361	0,883164
Urban land occupation	m2a	3,720889	0,898108	1,014511	1,808271
Natural land transformation	m2	0,055214	0,022011	0,010947	0,022256
Water depletion	m3	61,13732	57,11954	3,786585	0,2312
Metal depletion	kg Fe eq	10,83041	3,799439	3,389784	3,641188
Fossil depletion	kg oil eq	59,62508	24,77243	13,58276	21,26988