# Influence of production methods and transport distances on the Greenhouse Gas Balance of organic apple juice

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**Summary**

In the present study the total greenhouse gas emissions (GHG) in the production of organic apple juice from apples from Germany's "Altes Land" region were compared with apples from the Southern Carpathians (Romania). The goal of the analysis was to clarify whether extensive agricultural production methods have a greater influence on the total emissions produced by the apple juice value-added chain in comparison to potentially longer transportation distances to the fruit processing company.

Despite the extensive agricultural cultivation methods used in the Southern Carpathians, which could be assumed not to produce any GHG emissions, the apple juice from these apples had higher total emissions (782 g $CO_2$e/l apple juice) than apples from the "Altes Land" region (630 g $CO_2$e/l apple juice). The reason for this is the distance over which the Romanian apples need to be transported to the fruit processing plant, which exceeded the GHG emissions saved during the apple cultivation.

*Keywords:* apple juice production, greenhouse gas balance, organic farming, transportation

## 1. Introduction

Ecologically produced foods are becoming more and more popular; accordingly, the demand for organic products is growing. In addition to the renunciation of the use of chemical fertilisers and pesticides, the philosophy of this type of food production includes a seasonal and when possible a regional acquisition of the goods to keep the transportation routes as short as possible. The increasing demand for organic products has, however, its consequences. Often the amount of goods traded is larger than that produced within a region. Furthermore, products may be in demand which under the circumstances cannot be produced within a particular region. For these reasons, transportation is playing an increasingly important role in the organic sector. Increasing demand is also inducing an intensification of the production methods. As a consequence of these developments, the question arises as to how the transportation and the intensity of the cultivation methods affect the $CO_2$ audit of organic products.

In the past few years, there has been a vivid discussion about studies in which the energy balance as well as the $CO_2$ audit of domestic apple production and other fruit and vegetable products were compared to that of imported goods from across the seas. Controversy has arisen in reaction to the study published by Schlich and Fleissner (2005), who gave imported goods, including fruit juices, a much better energy balance than regionally produced products. Demmeler and Burdick (2005) alleged that this study, however, had "severe analytical deficiencies" and criticised the fact that the authors had chosen a non-representative sample of juice-producing companies. On the other hand, Blanke and Burdick (2005), in a comparative study on apples from Germany, South Africa and New Zealand, came to the result that despite the higher energy usage for the storage of the German apples, these had a better energy balance than the apples from the two overseas countries. The main reason for this was the high energy requirements for the transportation of the South African and New Zealand apples on a refrigerated container ship. Studies done by Mila i Canals et al. (2006, 2007) and Sim et al. (2006) reached the same result. Furthermore, Reinhardt et al. (2009) set up an energy and $CO_2$ balance for various food groups, including apples from different cultivation areas. The investigation included transportation routes of various lengths and the storage of the apples in some cases. As with Blanke and Burdick (2005), the study came to the conclusion that transportation has an important influence on the balance: an apple from overseas has a poorer balance in comparison to domestic apples, despite the higher greenhouse gas (GHG) emissions arising during storage because of the frequent use of CA[1] storage.

Fritsche and Eberle (2007) investigated vegetables produced in Germany from both conventional and ecological farming with respect to their GHG emissions. Their study showed

[1] CA means controlled atmosphere and describes a type of storage for ripening fruit and vegetables, in which the temperature, humidity, oxygen and carbon dioxide concentrations are strictly controlled and maintained at predetermined levels. This type of storage requires a lot of energy.

that even with domestic transportation, it caused about 15% of the product-specific emissions. These authors also calculated an average emissions factor of about 130 g $CO_2$e per kg product for ecological cultivation. This is a mean value for vegetables, which includes the preparation, processing, cooling and transportation.

The detailed ecological effects of apple production in Switzerland were investigated by Mouron et al. (2006) using a life cycle analysis according to the Swiss agricultural life cycle assessment method Version 1.31 (SALCA). These authors came to the conclusion that the energy requirements for the cultivation of apples depended greatly on the management practices of the producer and can be kept low by a rational utilisation of the available technology.

The objective of this paper is to find out how transportation and the grade of mechanization in agricultural production affect the $CO_2$ balance of organic products, as in the case of apple juice produced in Germany. For this reason, the whole supply chain from the cultivation of the apples up to the delivery of the apple juice to the retailer was investigated based on two apple production regions: the “Altes Land” region in Germany and one in the Southern Carpathians in Romania. The cultivation methods used in these two regions are of very different degrees of mechanization. Additionally the transport distances to the apple-juice factory differ from 230 km from the “Altes Land” Region up to 2050 km from the South Carpathians.

The paper is structured as follows. The methodical framework and the sources of the used data will be explained in the first chapter. Then the results will follow. Finally a comparison between the two cultivation systems and the influence of transportation to the greenhouse gases are discussed in the last section.

## 2. Methods

The analysis follows the ISO 14040 and ISO 14044 guidelines (2006) of a life cycle analysis. The system boundaries are as follows: the GHG emissions from the agricultural production (fertilization, pesticides, and irrigation), the post-harvest processing in the juicing plant (washing, milling, pressing, pasteurization and bottling) as well as the transportation from the site of cultivation to the retailer were investigated for each of the two types of apple juice. The steps of the juice production and therefore the investigated framework are shown in Figure 1 (see appendix). The investigation includes all the direct emissions, which arise, for example, from the use of energy sources such as electricity, diesel, gas, etc., and the indirect emissions, which arise, for example, from the upstream processes of the energy sources and facilities that are used.

For the life cycle inventory a literature research was carried out. The emissions factors used for the individual processes were taken from this literature and the GEMIS data bank (2007) or from the data provided by the German apple juice producers. If there was insufficient information available, then the emissions factors were extrapolated on the basis of sound estimates. In some cases the mean average of different values were calculated. The values used in this example are those of a medium-sized juice-producing plant in Germany. The GHG emissions are given as $CO_2$ equivalents (this shows how high the global warming potential of the individual GHGs are with respect to $CO_2$). According to the IPCC (2001), the global warming potential of the most important GHGs are $CO_2$ 1, methane 23 and nitrous oxide 296.

*2.1 Agricultural production*

The apple juice was produced under two different conditions. On the one hand the organic apple farmers in the “Altes Land” region in Germany cultivate under intensive production conditions, which for this investigation means that organic plant protection products and organic fertilizer as well as irrigation are used. On the other hand, the extensive conditions in the Southern Carpathians are characterized by the non-application of external products and total manual labour during cultivation up to the moment of transport to Germany.

The organic agricultural cultivation of apples is associated with the production of indirect emissions for the manufacture and supply of diesel and organic pesticides. In contrast, organic fertilisers are not associated with indirect emissions according to Reinhardt (1993). Direct emissions are produced only by the burning of diesel for the undertaking of crop protection, fertilisation and irrigation procedures. The calculation of the agricultural emissions per litre of apple juice was done using Formula (1):

Formula (1):

$$EM_L = \frac{x_L * EF * a}{m_E}$$

where

$EM_L$ = quantity of emissions arising from the agricultural production [kg $CO_2$e/l apple juice]

$x_L$ = agricultural operating materials [kg/ha*a] or [l/ha*a]

EF = emissions factor [g $CO_2$e/kg or l active agent]

a = quantity of apples required for producing the juice [kg apples/l apple juice]

$m_E$ = quantity of apples harvested [kg apples/ha*a]

*Assumptions for the apple production in Germany ("Altes Land" region)*

In the "Altes Land" region there is an average annual organic apple harvest of 22.5 t/ha, which corresponds to the data of the producing company and matches with data found in the literature (Stockert, 2010). It was assumed that the production involves the application of 40 kg organic crop protection agents per hectare, with an average 17.5 applications per year. The fuel, needed for the application of the crop protection agents, was assumed to be 1.59 l diesel/ha according to KTBL (2005); it is a mean of different sprayers for transport and application. The application of organic fertiliser is done once a year and the fuel needed was again taken from KTBL (2005), which gives a value of 14.3 l diesel /ha for loading, transportation and application. The organic fertiliser doesn't fall within this investigation because it is connected to the production in animal husbandry, so there are no emissions counted for this product. For the irregular irrigation required, an assumed value of 200 l diesel/ha/year was used. The quantity of apples needed to produce 1 litre of apple juice was taken as being 1.25 kg (GfRS mbH, 2008). The quantities of the different agents used and their emissions factors are given in Table 1

**Table 1: The quantities of agents used in the agricultural production of the German apples and their emissions factors**

| Process | Agent [kg/ha*a] or [l/ha*a] | Emissions factor [g $CO_2$e/kg agent] |
|---|---|---|
| **Preparation of crop protection agents** | 40.0 | 12 083.0[a)] |
| **Diesel for application of crop protection agents** | 27.8 | 3 120.4[b)] |
| **Diesel for application of organic fertiliser** | 14.3 | 3 120.4[b)] |
| **Diesel for irrigation** | 200.0 | 3 120.4[b)] |

a) Gemis 4.42 (2007); Öko-Institut (2004); Kaltschmitt & Reinhardt (1997)
b) Gemis 4.42 (2007); EWI/Prognos (2005); DGMK (1992)

*Assumptions for the apple production in Romania (Southern Carpathians)*

The agricultural production of apples in the Southern Carpathians in Romania occurs under extremely extensive conditions, as mentioned before; that means that no emission-producing steps (direct and indirect) were used in the cultivation. The orchards in Romania are at least 30 years old and are virtually impossible to farm using machinery due to their location and structure. For this reason, the cultivation is done exclusively by hand. As no crop protection measures are used, there are enormous variations in the region's apple harvest. Despite this problem, a long-term average harvest of 12 t/ha could be assumed (GfRS mbH, 2008). After being harvested manually, the apples are collected on horse-drawn carriages and transported to a collection point. Here the apples are transferred to a lorry, again by hand. Due to these extensive cultivation methods, no relevant GHG emissions from the operations examined in this investigation are produced by the agricultural production in Romania; therefore these could be left out of the calculations (GfRS mbH, 2008).

### *2.2 Storage*

As both the apples from Romania and those from Germany are processed very quickly, storage outside of the company is not necessary, hence no GHG emissions are produced.

### *2.3 Transportation steps*

The transportation is divided into two main steps. In the first step, the apples are transported from the orchard in Romania and Germany to the processing company. In the second step, the produced apple juice is transported from the processing company to the retailer. The details of the different steps will be explained as follows.

*Apple transportation*

The transportation of the German apples is divided into two stages. In the first stage, the apples are transported from the producer to the middleman; the average distance was taken to be 30 km according to the German fruit processing company. In the second stage, the apples are transported from the middleman to the processing company; this lies on average at 200 km from the middleman.

The Romanian apples are transported directly to the processing company in Germany after being loaded by hand onto the lorry. The mean transportation distance was taken to be 2 050 km. As the lorries used have an average loading capacity of 20.0 t apples (GfRS mbH, 2008), a lorry with a loading capacity of 19.0 t was used for the calculation according to GEMIS (2007). The whole transportation chain with the associated emissions factor and the properties of the used lorries are shown in Table 2.

**Table 2: Distance, loading capacity, fuel consumption and their emissions factors in the transportation steps of the process chain**

| Transportation steps | Distance [km] | Lorry | | Emission factor [g $CO_2$e/tkm] |
|---|---|---|---|---|
| | | Loading capacitiy [t] | Fuel consumption [l/100 km] | |
| **Orchard (Germany) → middleman** | 30 | 11[a)] | 27.5[a)] | 164.3[b)] |
| **Middleman → processing company** | 200 | 11[a)] | 27.5[a)] | 164.3[b)] |
| **Orchard (Romania) → processing company** | 2 050 | 19[b)] | 30.7[b)] | 104.7[c)] |
| **Processing company → wholesaler** | 385 | 39[b)] | 32.0[b)] | 91.6[b)] |
| **Wholesaler → retailer** | 400 | 15[b)] | 27.5[b)] | 164,3[b)] |

a) KTBL (2005)
b) Gemis 4.42 (2007)
c) Gemis 4.42 (2007); UBA, BUWAL (1999); LastautoOmnibus (1999)

The GHG emissions that arise during the transportation of 1 litre of apple juice were calculated using Formula (2).

Formula (2):

$$EM_T = \frac{x_T * EF * a_1}{1\,000}$$

where

$EM_T$ = quantity of emissions arising from transportation of the apples [kg $CO_2$e/l apple juice]

$x_T$ = transportation distance [km]

EF = emissions factor [g $CO_2$e/tkm]

$a_1$ = quantity of apples needed to produce the juice [kg apples/l apple juice] (for the apple transport)

*Juice transportation*

The transportation of the apple juice from the factory to the retailer also consists of two stages. First of all, the juice is transported to the wholesaler. According to the German processing company, this distance corresponds to 385 km. The juice is transported by lorries with a total weight of 38–40 t (average 39 t), which need 32 litres of diesel for every 100 km when fully loaded. Roughly 11 500 litres of juice in bottles are transported. This represents from 14 000 to 20 000 bottles. The second stage consists of the transportation from the wholesaler to the retailer. This distance is on average 400 km. The different emissions factors come from the different lorries which are used for the various transport steps. The calculation for the emissions from the juice transport is done according to Formula (3) as the finished product was being transported, and it was, therefore, not necessary to multiply the GHG emissions by the quantity of apples used. In spite of this we need to calculate the 11 500 litres which are transported in a lorry with a weight of 39 t.

Formula (3):

$$EM_T = \frac{x_T * EF * a_2}{1\,000}$$

where

$EM_T$ = quantity of emissions arising from transportation of the apples [kg $CO_2$e/l apple juice]

$x_T$ = transportation distance [km]

EF = emissions factor [g $CO_2$e/tkm]

$a_2$ = quantity of apple juice (11,5 t) transported in the lorry with 39 t weight [kg total weight/l apple juice] (3,4 kg/l)

*2.4 Processing in the German juice-making plant*

The post-harvest processing in the German juice-making plant requires energy sources and consumables, as well as equipment and facilities. The energy sources include electricity, natural gas for firing two steam boilers, heating oil for running electricity aggregates as well as diesel and propane gas for the plant's own vehicles. The consumables consist of water, cleaning fluids, foil, plastic, cardboard boxes, crates and glass bottles. The quantities of energy sources and consumables used each year and their respective emissions factors are shown in Table 3. The emissions factor for electricity is a mean value calculated from the German energy mix in 2007, consisting of 22% atomic energy (emissions factor: 38.44 g $CO_2$e/$kWh_{el}$), 63% fossil fuels (emissions factor: 1 219.49 g $CO_2$e/$kWh_{el}$) and 15% renewable energy sources (emissions factor: 121.77 g $CO_2$e/$kWh_{el}$) (BDEW, 2008).

**Table 3: Annual consumption of energy sources and consumables per litre of apple juice and their emissions factors**

| | Annual consumption | Emissions factor [g $CO_2$e/unit energy source or consumable] |
|---|---|---|
| **Energy source** | | |
| Diesel [l/a] | 14 972 | 3 120.40 b) |
| Electricity [kWh/a] | 3 002 840 | 795.00 a) |
| Heating oil[l/a] | 326 055 | 3 077.10 b) |
| Natural gas [kWh/a] | 17 208 500 | 285.12 b) |
| Propane gas [kg/a] | 14 740 | 3 317.70 b) |
| **Consumables** | | |
| Bottles [kg glass/a] | 3 836 894 | 192.00 d) |
| Cardboard boxes [kg cardboard/a] | 303 382 | 641.39 c) |
| Cleaning fluids [kg/a] | 146 982 | 2 551.97 c) |
| Crates [kg plastic/a] | 70 650 | 1 721.60 c) |
| Foil [kg/a] | 40 633 | 3 022.41 c) |
| Plastic [kg/a] | 50 870 | 1 721.60 c) |
| Water [m³/a] | 194 541 | 661.18 c) |

a) Gemis 4.42 (2007); UBA (2007a, 2007b, 2005); Öko-Institut/IZES (2007); ECN (2005); Wollny et al. (2001)
b) Gemis 4.42 (2007); EWI /Prognos (2005); DGMK (1992); Pfeiffer et al. (2000); IFEU (2003)
c) Gemis 4.42 (2007); UBA (1999); Boustead (1999); EM (1995); Hess. Umweltministerium (1993)
d) UBA (2007c)

It was assumed that in the year of investigation, 2007, ca. 25 Mio. l apple juice was produced, as this is the amount equivalent to that produced by a medium-sized juice-producing company. The emissions from the energy sources and consumables were calculated per litre of apple juice according to Formula (4).

Formula (4):

$$EM_{BV} = \frac{x_{BV} * EF}{M_p}$$

where

$EM_{BV}$ = quantity of emissions released by the energy sources or consumables during the juicing process [kg $CO_2$e/l apple juice]

$X_{BV}$ = quantity of energy sources or consumables used [kWh/a, l/a, m³/a, kg/a]

EF = emissions factor [g $CO_2$e/unit energy source or consumable]

$M_P$ = quantity of apple juice produced [l/a]

Included in the "equipment and facilities" rubric are those vehicles used for logistics, the machinery used for juice production, the stainless steel tanks for the storage of the juice and the buildings of the plant producing the apple juice.

The juice-producing company regarded in this investigation has its own vehicles (a tractor, a lorry and 26 forked-lift trucks). As there was no information about the materials present in these vehicles, the balance was simplified using the factors shown in Table 4. An important role is played by the weight of the equipment, the material which the equipment is made of and their emissions factors. The data for the calculation come from the juice producing company and GEMIS 4.42 (2007).

The finished juice was stored in 210 different-sized stainless steel tanks. The amortisation period is also taken into consideration. The different amortisation periods are shown in Table 4. The building for the production (total net floor area: 15 132 m²) is also included in the balance. It was decided that all of the building's total floor area should be considered and it is given an emissions factor of 5.1 g $CO_2$e/m² floor area (GEWOFAG, 2005).

**Table 4: Capacities of equipment and facilities in the post-harvest processing**

| Equipment and facilities | Weight or area of the individual piece of equipment or facility [t or m²] | Material of the equipment or facility | Amortization period [years] | Emission factor [g $CO_2$e/kg or m²] |
|---|---|---|---|---|
| **Tractor** | 10.50 | steel | 12 | 1 574.5[a)] |
| **Lorry** | 12.00 | steel | 10 | 1 574.5[a)] |
| | 1.00 | plastic | | 2 408.8[a)] |
| **26 Forked-lift trucks** | 52.49 | steel | 10 | 1 574.5[a)] |
| **Machines** | 105.00 | steel | 10 | 1 574.5[a)] |
| **Stainless steel tanks** | 465.00 | steel | 12 | 1 574.5[a)] |
| **Building** | 15 132.00 | area | 10 | 5.1[b)] |

a) Gemis 4.42 (2007)
b) GEWOFAG (2005)

The GHG emissions of the operating material per litre of apple juice were calculated according to Formula (5):

Formula (5):

$$EM_{Pm} = \left[ \left( \frac{x_{Pm} * EF}{M_p} \right)_{M1} + \left( \frac{x_{Pm} * EF}{M_p} \right)_{M2} \right] (t_A)^{-1}$$

where

| | | |
|---|---|---|
| $EM_{Pm}$ | = | quantity of emissions from the equipment and facilities used in the juice-making process [kg $CO_2$e/l apple juice] |
| $M_1$, $M_2$ | = | material 1 (steel), material 2 (plastic) |
| $x_{Pm}$ | = | weight or area of the individual piece of equipment or facility [kg or m²] |
| EF | = | emissions factor [g $CO_2$e/unit of the goods] |
| $M_P$ | = | quantity of juice produced [l/a] |
| $t_A$ | = | amortisation period of individual piece of equipment or facility [a] |

The emissions of the individual processes were added to provide a total overview of the apple juice production chain.

## 3. Results

The GHG emissions for the apple juice production chain for the German apples were 869.7 g $CO_2$e/l of apple juice compared to 1021.8 g $CO_2$e/l of apple juice from the Romanian apples. Table 5 compares the emissions from the individual process steps during the apple juice production.

**Table 5: GHG emissions from the production of apple juice made from either German or Romanian apples in g $CO_2$e per litre of apple juice**

| Sector | Emissions apple juice "Altes Land" g $CO_2$e/l | % | Emissions apple juice Southern Carpathians g $CO_2$e/l | % |
|---|---|---|---|---|
| Crop protection | 31.7 | 3.6 | – | – |
| Fertilisation | 2.5 | 0.3 | – | – |
| Irrigation | 34.7 | 4.0 | – | – |
| **Agricultural production ∑** | **68.9** | **7.9** | **–** | **–** |
| Transportation orchard → middleman | 6.2 | 0.7 | – | – |
| Transportation middleman → processing company | 41.1 | 4.7 | – | – |
| Transportation orchard → processing company | – | – | 268.3 | 26.3 |
| Transportation processing company → wholesaler | 119.9 | 13.8 | 119.9 | 11.7 |
| Transportation wholesaler → retailer | 223.4 | 25.7 | 223.4 | 21.9 |
| **Transportation ∑** | **390.6** | **44.9** | **611.6** | **59.9** |
| Diesel | 1.9 | 0.2 | 1.9 | 0.2 |
| Electricity | 95.5 | 11.0 | 95.5 | 9.3 |
| Heating oil | 40.1 | 4.6 | 40.1 | 3.9 |
| Natural gas | 196.3 | 22.6 | 196.3 | 19.2 |
| Propane gas | 2.0 | 0.2 | 2.0 | 0.2 |
| **Energy sources ∑** | **335.8** | **38.6** | **335.8** | **32.8** |
| Cardboard boxes | 7.8 | 0.9 | 7.8 | 0.8 |
| Cleaning fluids | 15.0 | 1.7 | 15.0 | 1.5 |
| Crates | 4.9 | 0.6 | 4.9 | 0.5 |
| Foil | 4.9 | 0.6 | 4.9 | 0.5 |
| Glass bottles | 29.5 | 3.4 | 29.5 | 2.9 |
| Plastic | 3.5 | 0.4 | 3.5 | 0.3 |
| Water | 5.2 | 0.6 | 5.2 | 0.5 |
| **Consumables ∑** | **70.8** | **8.2** | **70.8** | **7.0** |
| Tractor | $55.1*10^{-3}$ | 0.0 | $55.1*10^{-3}$ | 0.0 |
| Lorry | $85.2*10^{-3}$ | 0.0 | $85.2*10^{-3}$ | 0.0 |
| Forked-lift truck | $330.5*10^{-3}$ | 0.0 | $330.5*10^{-3}$ | 0.0 |
| Machines | 0.7 | 0.1 | 0.7 | 0.1 |
| Stainless steel tanks | 2.4 | 0.3 | 2.4 | 0.2 |
| Building | $0.3*10^{-3}$ | 0.0 | $0.3*10^{-3}$ | 0.0 |
| **Equipment and facilities ∑** | **3.6** | **0.4** | **3.6** | **0.3** |
| **Post-harvest processing ∑** | **410.2** | **47.2** | **410.2** | **40.1** |
| **Total ∑** | **869.7** | **100** | **1021.8** | **100** |

Even when using intensive methods, as in the German example, the agricultural production of the apples was only responsible for less than a tenth of the total emissions from the apple juice value-added chain (68.9 g $CO_2$e/l). Transportation can cause, in comparison, up to almost half the GHG emissions as shown by the Romanian apples. From the results of the Romanian apples, it is obvious that the advantages of extensive production can be diminished by the long transportation distances. But the transport of the German apples also causes a big amount of GHG emissions at 343.3 g $CO_2$e/l, due to the long average distance from the company to the retailer.

A great proportion of emissions were indeed associated with the post-harvest processing, especially with respect to the use of energy (38.6–32.8%), while approximately a tenth of the total emissions originate from the consumables (the glass bottles stand out as the biggest individual item). The usage of equipment and facilities, in contrast, had only a marginal effect.

*Sensitivity Analysis*

How the greenhouse gases of the produced apple juice change with different transport distances to the processing plant (Table 6) will be investigated. It is evident that with an increase in the transport distance to 980 km of the German apples, the amount of greenhouse gases would be the same as the greenhouse gases produced by the transport of the Romanian apples with 1021.8 g $CO_2$e/l. With a reduction of the distance from the apples produced under extensive conditions in Romania of 1200 km, the amount of greenhouse gases caused by transport would be the same as the transport of apples to the company within Germany. The results are shown in Table 6.

**Table 6: Analysis of the transport distances in comparison between the Romanian and German apples**

| Apples from Germany | | | | Apples from Romania | | | |
|---|---|---|---|---|---|---|---|
| Distance [km] | Emissions Transport [g $CO_2$e/l] | Total Emissions Production [g $CO_2$e/l] | Emissions Romania [g $CO_2$e/l] | Distance [km] | Emissions Transport [g $CO_2$e/l] | Total Emissions Production [g $CO_2$e/l] | Emissions Germany [g $CO_2$e/l] |
| 30 | 6.2 | 828.6 | 1021.8 | 50 | 6.5 | 760.0 | 869.7 |
| 130 | 26.7 | 849.1 | 1021.8 | 250 | 32.7 | 786.2 | 869.7 |
| 230 | 47.2 | 869.7 | 1021.8 | 450 | 58.9 | 812.4 | 869.7 |
| 330 | 67.8 | 890.2 | 1021.8 | 650 | 6.5 | 760.0 | 869.7 |
| 430 | 88.3 | 910.7 | 1021.8 | 850 | 111.2 | 864.7 | 869.7 |
| 530 | 108.8 | 931.2 | 1021.8 | 1050 | 137.4 | 890.9 | 869.7 |
| 630 | 129.4 | 951.8 | 1021.8 | 1250 | 163.6 | 917.1 | 869.7 |
| 730 | 149.9 | 972.3 | 1021.8 | 1450 | 189.8 | 943.3 | 869.7 |
| 830 | 170.5 | 992.9 | 1021.8 | 1650 | 215.9 | 969.4 | 869.7 |
| 930 | 191.0 | 1013.4 | 1021.8 | 1850 | 242.1 | 995.6 | 869.7 |
| 980 | 201.3 | 1023.7 | 1021.8 | 2050 | 268.3 | 1021.8 | 869.7 |
| 1030 | 211.5 | 1033.9 | 1021.8 | 2250 | 294.5 | 1048.0 | 869.7 |
| 1130 | 232.1 | 1054.5 | 1021.8 | 2450 | 320.6 | 1074.1 | 869.7 |
| 1230 | 252.6 | 1075.0 | 1021.8 | 2650 | 346.8 | 1100.3 | 869.7 |

Another interesting point is the change in the quantity of apples harvested in Germany. With a strong decrease in the apple harvest in Germany, two thirds less than the actual amount of 22.5 t/ha, the total greenhouse gas emissions of apple juice produced by German apples would increase to the same amount as that of the Romanian apples (1039 g $CO_2$e/l) (see Table 7).

**Table 7: Analysis of the average apple harvest in Germany in regard to the greenhouse gases of the total agricultural production and the total juice production**

| Average Apple Harvest [t/ha] | Emissions [g $CO_2$e/l] | | | | | |
|---|---|---|---|---|---|---|
| | Preparation of crop protection agents | Diesel for application of crop protection agents | Diesel for application of organic fertilizer | Diesel for irrigation | Total Agricultural Production | Total Juice Production |
| 1500 | 402.8 | 72.3 | 37.2 | 520.1 | 1032.3 | 1833.1 |
| 2500 | 241.7 | 43.4 | 22.3 | 312.0 | 619.4 | 1420.2 |
| 3500 | 172.6 | 31.0 | 15.9 | 222.9 | 442.4 | 1243.2 |
| 4500 | 134.3 | 24.1 | 12.4 | 173.4 | 344.1 | 1144.9 |
| 5500 | 109.6 | 19.7 | 10.1 | 141.8 | 281.5 | 1082.3 |
| 6500 | 93.0 | 16.7 | 8.6 | 120.0 | 238.2 | 1039.0 |
| 7500 | 80.6 | 14.5 | 7.4 | 104.0 | 206.5 | 1007.3 |
| 8500 | 71.1 | 12.8 | 6.6 | 91.8 | 182.2 | 983.0 |
| 9500 | 63.6 | 11.4 | 5.9 | 82.1 | 163.0 | 963.8 |
| 10500 | 57.5 | 10.3 | 5.3 | 74.3 | 147.5 | 948.3 |
| 11500 | 52.5 | 9.4 | 4.9 | 67.8 | 134.6 | 935.4 |
| 12500 | 48.3 | 8.7 | 4.5 | 62.4 | 123.9 | 924.7 |
| 13500 | 44.8 | 8.0 | 4.1 | 57.8 | 114.7 | 915.5 |
| 14500 | 41.7 | 7.5 | 3.8 | 53.8 | 106.8 | 907.6 |
| 15500 | 39.0 | 7.0 | 3.6 | 50.3 | 99.9 | 900.7 |
| 16500 | 36.6 | 6.6 | 3.4 | 47.3 | 93.8 | 894.6 |
| 17500 | 34.5 | 6.2 | 3.2 | 44.6 | 88.5 | 889.3 |
| 18500 | 32.7 | 5.9 | 3.0 | 42.2 | 83.7 | 884.5 |
| 19500 | 31.0 | 5.6 | 2.9 | 40.0 | 79.4 | 880.2 |
| 20500 | 29.5 | 5.3 | 2.7 | 38.1 | 75.5 | 876.3 |
| 21500 | 28.1 | 5.0 | 2.6 | 36.3 | 72.0 | 872.8 |
| 22500 | 26.9 | 4.8 | 2.5 | 34.7 | 68.8 | 869.6 |
| 23500 | 25.7 | 4.6 | 2.4 | 33.2 | 65.9 | 866.7 |
| 24500 | 24.7 | 4.4 | 2.3 | 31.8 | 63.2 | 864.0 |
| 25500 | 23.7 | 4.3 | 2.2 | 30.6 | 60.7 | 861.5 |
| 26500 | 22.8 | 4.1 | 2.1 | 29.4 | 58.4 | 859.2 |
| 27500 | 22.0 | 3.9 | 2.0 | 28.4 | 56.3 | 857.1 |
| 28500 | 21.2 | 3.8 | 2.0 | 27.4 | 54.3 | 855.1 |
| 29500 | 20.5 | 3.7 | 1.9 | 26.4 | 52.5 | 853.3 |
| 30500 | 19.8 | 3.6 | 1.8 | 25.6 | 50.8 | 851.6 |

## 4. Discussion

The last step of the life cycle analysis according to the ISO 14040 and ISO 14044 guidelines includes the evaluation or interpretation of the results, which will be found in the following discussion section.

The calculated GHG emissions presented here represent only one element in the evaluation of apple juice or the apple production supply chain. Therefore, the present results can only be used as part of the overall life cycle assessment of the apple juice production. Nevertheless, in terms of climatic relevance, these results indicate clearly where prevention measures should be undertaken.

The transport operations within the apple juice supply chain produce a significant proportion of the emissions. With shorter transportation distances, the Romanian apples, in spite of being produced with extensive cultivation methods, would have a better greenhouse gas balance than those from intensive cultivation in Germany. This would only hold true though, if the same type of vehicles as used in this study are utilised for a maximum transportation distance of ca. 850 km to the site of the industrial processing of the apples. If the transportation distance is longer, then the advantages of extensive cultivation are non-effective. A possibility for the German apple juice company would be to produce their apple juice in an extensive way more closely located to the processing facility.

Even though the present data concerns only production and transportation, its results are ratified in comparison with the studies mentioned in the introduction. In order to properly compare the present results with those of the other studies, they must be converted using the extrusion ratio of 1:1.25. The tendencies of the converted data are comparable to the results of Blanke and Burdick (2005), despite the lack of storage. These authors stated that apples from overseas trade have about 25% higher energy requirements than domestic apples. Specifically, Schlich and Fleissner (2005), in their somewhat controversial study, calculated the energy requirements for the subsequent processing. They came, however, to different results, which can be explained by their choice of juice-producing plant.

Reinhardt et al. (2009) calculated both the energy requirements and the GHG emissions and similarly showed that the transportation distance has a significant influence on the GHG balance. The level of GHG emissions [from production, storage, packaging and transportation (to the final customer)] was about 0.1-0.5 kg $CO_2$e/kg apples, depending on the type of cultivation. The cultivation and transportation caused ca. 60% of these emissions; i.e. around 0.2 kg $CO_2$e/kg apples (173.68 g $CO_2$e/kg apples), which is roughly in the same dimensions as the results of this investigation. Fritsche and Eberle (2007), in contrast, attained lower values than Reinhardt et al. (2009) and the present investigation as they found an emission of 130 g $CO_2$e per kg of product from ecological cultivation. In their study, the GHG emissions caused by transportation were also much lower (only 15%). This may have been due to the fact that the transportation value used was that of a general average for fruit and vegetables, so that the specific differences of the individual types of produce were not reflected.

In general it is difficult to compare in detail the results of the various studies due to the differences in the chosen products and system boundaries. For example, the investigations discussed above all included storage in their calculations, which entails a rather significant proportion of the energy requirements or GHG emissions (*c.f.* Fritsche and Eberle, 2007; Reinhardt et al., 2009). In addition, other lorry capacities and fuel requirements were used as the basis for the calculations for the transportation of the goods. Despite this lack of one-to-one comparison, the results presented here clearly show that processing plays an important role in the greenhouse balance of the food supply chain, and that its influence is more important than the transportation or agricultural production of the raw materials.

From the consumers' perspective, the amount of greenhouse gas emissions would have a low priority; it is important for them to know that they are buying organically produced apple juice. If the company would produce two different juices, one from Germany and one from Romania, the local produced juice would probably be preferred.

It is above all clear that the energy sources used have special climatic relevance. This result indicates that in addition to the optimisation of the logistics, efforts must be made to elucidate any possibilities of reducing GHG emissions in the juice-making process. For example, an energetic optimisation of the production process can be achieved by modernisation of the juice-making plant (refrigerating plants, flash pasteurisers, separation equipment, heat exchangers, steam generators and refrigerated containers). Depending on the individual situation, such modernisation could be justified economically by the future savings on energy sources.

## 5. Literature


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## 6. Appendix

**Figure 1: Apple production in Romania, Carpathians, and in Germany, Altes Land, comparatively**