# Life Cycle Assessment of apples at a country level: the case study of Italy

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**ABSTRACT**

Assomela, the Italian Association of apple Producers Organizations (POs), has financed the Life Cycle Assessment (LCA) of the average apple produced in Italy. A study was carried out with the aim of providing an EPD certification and understanding the contribution of the different production phases to the carbon (C) footprint. For the cultivation phase data from several farms were sampled taking into account eight geographical areas and four main apple varieties cultivated in Italy. Data about the apples storage, processing, packaging and distribution phases were then collected from the POs. Four impact categories were considered: Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP) and Eutrophication Potential (AP).Results show that 1 kg of apple, in a cradle to retailer perspective, have a GWP of 0.20 kg $CO_2$ eq., a POCP of 0.18 g $C_2H_4$-eq., a AP of 1.12 g $SO_2$-eq and a EP of 0.62 g $PO_4^{3-}$-eq. The main contributor of the C footprint during the cultivation phase was the consumption of fuel for machinery, which significantly changed according to the distance from the farm center and the field size.

Keywords: Environmental product declaration, carbon footprint, fuel consumption

## 1. Introduction

Assomela, the Italian Association of apple Producers' Organizations (POs) representing 80% of the national production, promoted a project for the certification of the environmental impact of apple production in Italy. Assomela brings together VOG (Marlene), VI.P and VOG-Products in the province of Bolzano, Melinda and La Trentina in the province of Trento, COZ and Nord Est in the region Veneto, Melapiù in the region Emilia Romagna, Rivoira and Lagnasco in the region Piemonte and Melavì in the region Lombardia (Table 1).

Table 1. Main characteristics of the Producers' Organization (POs) involved in the study

| **POs** | **Head office** | **Apple production (t year$^{-1}$)** | **Cultivated land (ha)** |
|---|---|---|---|
| La Trentina | Trento | 100,000 | 1,800 |
| Melinda | Cles | 330,000 | 6,500 |
| VI.P | Laces | 330,000 | 5,100 |
| VOG | Terlano | 660,000 | 10,600 |
| Lagnasco | Lagnasco | 15,000 | 348 |
| Melavì | Ponte in Valtellina | 26,000 | NA |
| OP NordEst | Verona | 15,000 | 400 |
| Rivoira | Verzuolo | 30,000 | 600 |

Several varieties are cultivated in the area under study but for the LCA only the main four (that together represent the 76% of the total production) were considered (table 2).

Table 2. Varieties cultivated by the 8 Producers Organizations (POs)

| **Variety** | **Percentage on the total production** |
|---|---|
| Golden Delicious | 44% |
| Gala | 14% |
| Red Delicious | 11% |
| Fuji | 7% |
| Granny Smith | 5% |
| Other varieties | 19% |

Objectives of the study were 1) to assess the environmental impacts of the apple production chain in Italy following the *Product Category Rules* for *Fruits and nuts* of the International EPD System and 2) to characterize the processes occurring during the cultivation phase that most affect the carbon footprint of the main apple variety.

## 2. Methods

2.1. Functional unit

The functional unit of the study is 1 kg of apples intended for fresh consumption, delivered at the retailer.

2.2. System boundaries

The considered system includes all the activities carried for the agricultural production, the storage, the processing and the distribution. According to the PCR the nursery phase has not been considered since the average orchard duration may exceed 25 years and thus the impacts of this phase can be considered negligible.

The main factors considered for the field phase are the use of oil, water, pesticides and fertilizers (see also table 4).

After the harvest, apples are stored in controlled atmosphere (where they stay in cool chambers at low oxygen concentration), until they are requested by the market. Then they are packed and finally delivered.

The distribution of apples occurs both in Italy and abroad, mainly through land transport by truck even if a small percentage is shipped by sea.

2.3. Treatment of data

The informations presented refer to eight of the ten Producer Organizations associated to Assomela, operating in the regions of Trentino Alto Adige, Piemonte, Lombardia and Veneto. Since the goal of this declaration is to provide information typical of the whole association, the data have been processed in a way that allows to create different averages between the POs participating to the project, using weighting factors based on production volumes. In detail, the average has been organized in three different levels:

- (M1): the average for each variety cultivated by each PO;
- (M2): the overall Assomela average for each variety, calculated by using the single variety production quantity of each PO as weighing element;
- (M3): the overall average for all the apples produced by the POs associated to Assomela.

2.4. Main assumption of the LCA approach in the four production phases

***Cultivation***

Consumption of water and diesel oil was estimated according to the real consumption of the selected farms. Data on other consumption (fertilizers and pesticides) have been obtained by the production specifications of the areas interested and then validated with specific information.

Data about yields were calculated considering the average age of the trees and the production volume. Data about produced waste were collected by APOT, the fruit and vegetable organization of Trentino. The land use change was not included in the calculation, since almost all the orchards are in the studied areas last for more than 20 years.

The global warming potential caused by the cultivation phase was additionally assessed by considering an average "Golden delicious" apple orchard managed according to the integrated fruit production guidelines of South Tyrol, yielding 62 t $ha^{-1}$ $y^{-1}$ (Mazzetto et al., 2012).

To investigate the role of the farm structure on the carbon footprint of apples, simulations about fuel consumption in scenarios with different field sizes and field distances from the farm center were carried out. A farm with a total surface of 3.9 ha, entirely cultivated with apple trees, representative of many farms in Trentino Alto-Adige, was selected as model for the simulations. The total farm surface was split into 15 fields with an average size of 0.26 ha and a distance from the farm center ranging from 200 to 1200 m.

***Processing***

In this phase electric energy consumptions, water consumption and waste production both for processing and for storage have been considered.

Data were collected from a sample of plants.

***Packaging***

The presented data refer to the selling apples considering the use of 1 plastic bag for 1 kg of apples.

***Distribution***

The impacts referred to the transportation phase have been calculated considering an average transport of 850 km by truck and 250 km by ship, which takes into account the Italian and European markets, as well as smaller amounts distributed overseas, in the Asian and North African markets.

## 3. Results and discussion

The main results of the LCA approach are shown in Table 3 and Figure 2.

Table 3. Environmental impacts of the apple production chain in the four considered impact categories. Data are referred to 1 kg of apples commercialized in a plastic bag.

| **Potential impact** | **Cultivation** | **Processing** | **Packaging production** | **Transportation** | **Total** | |
|---|---|---|---|---|---|---|
| Global Warming Potential | 0.04 | 0.06 | 0.01 | 0.09 | 0.20 | kg $CO_2$ eq |
| Photochemical Ozone Creation Potential | 0.06 | 0.02 | 0.03 | 0.07 | 0.18 | g $C_2H_4$ |
| Acidification Potential | 0.31 | 0.22 | 0.04 | 0.55 | 1.12 | g $SO_2$ eq |
| Eutrophication Potential | 0.41 | 0.08 | 0.01 | 0.12 | 0.62 | g $PO_4$-eq |

Transportation had the highest impact on the Global Warming Potential, followed by processing, cultivation and packaging production (Figure 1).

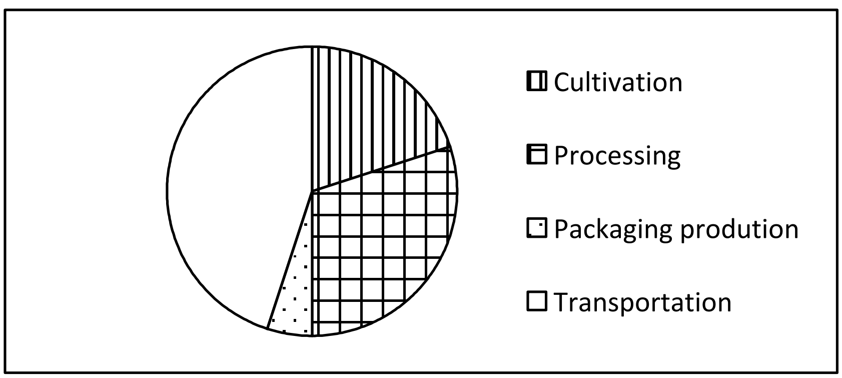


Figure 1. Contribution of the different production phases to the Global Warming Potential impact category.

Transportation has a high GWP because it occurs mainly by trucks. Transport by sea or railway could be a solution to decrease these emissions (Blanke and Burdik, 2005). Processing has also a high relevance because in this phase cool storage is included and it is a process that requires a significant amount of electric energy.

Cultivation is the third contributor in terms of GWP. The main impacts in this phase are due to the amount of diesel for machinery and to production and use of fertilizers (table 4)

Table 4. Carbon footprint of the Golden delicious apple during the cultivation (cradle to gate) phase (data from Mazzetto et al., 2012).

| **Source of emission** | | **$CO_2$ emissions (GWP)** | |
|---|---|---|---|
| | | kg $CO_2$ eq $kg^{-1}$ | % |
| Infrastructure | Buildings | 0.002 | 4 |
| | Machinery | 0.013 | 25 |
| | Planting scaffold | 0.001 | 2 |
| | Irrigating system | 0.007 | 14 |
| | Plant material | 0.001 | 2 |
| Annual management | Fertilizers | 0.006 | 12 |
| | Herbicides | 0.002 | 4 |
| | Pesticides | 0.003 | 6 |
| | Labour | 0.001 | 2 |
| | Fuel | 0.015 | 29 |
| TOTAL | | 0.051 | 100 |

As reported by Zanotelli et al.(2014), the total value of C footprint for the cultivation phase of apple is relatively low when compared with other fruit cultivation (data expressed in MJ $kg^{-1}$ of primary energy use) also due to the high yields reached by modern apple orchard that allow a good use efficiency of external resources. Fuel consumption resulted to be among the most important impact factors also in apple produced in other countries, and in other fruit production chain like olive and grape (Zanotelli et al., 2014).

The sensitivity analysis carried out for the cultivation phase with the analytical approach, quantifies the linear increase of fuel consumption observed by increasing the distance of the fields from the farm center (Table 5). The consumption due to the machines transfer can reach 50% of the total when the fields (with an average size of 0.26 ha) are located at more than 1500 m from the farm (Tab 5). The simulation reported in table 5 has been carried out considering an average apple production of 60 t $ha^{-1}$.

Table 5. Simulation of changes in fuel consumption for machinery (as total yearly amount and as % due to the transfer of machinery) due to the increasing distance of the apple orchard from the farm-center.

| Distance farm center -field | Fuel consumption | % of fuel consumption due to the transfer of machinery |
|---|---|---|
| m | kg $ha^{-1}$ | % |
| 200 | 294 | 10 |
| 500 | 341 | 26 |
| 1000 | 426 | 36 |
| 1500 | 503 | 45 |
| 2000 | 581 | 52 |
| 4000 | 906 | 67 |

A second simulation aimed to assess the variation in fuel consumption when the apple fields, 1000 m far from the farm center and yielding 60 t $ha^{-1}$ of apples, varies their size from 0.26 to 8 ha. Results show that there is a sharp decline in fuel consumption at increasing field size (Tab. 6).

Table 6. Simulation of changes in fuel consumption for machinery (as total yearly amount and as % due to the transfer of machinery) due to the increasing size of the fields. An average yield production of 60 t ha$^{-1}$ and a distance of the fields to the farm center of 1000 m was considered in the sensitivity analysis.

| Field surface | Fuel consumption | % of fuel consumption due to the transfer of machinery |
|---|---|---|
| ha | kg ha$^{-1}$ | % |
| 0.25 | 426 | 36 |
| 0.5 | 358 | 30 |
| 1 | 306 | 23 |
| 2 | 277 | 19 |
| 4 | 261 | 17 |
| 8 | 254 | 17 |

## 4. Conclusions

Considering the difficulties in performing an LCA study at a country level, especially due to the adoption of a good sampling strategy, we believe that the approach used in this study reconciles feasibility of data collection and statistical significance.

The carbon footprint of the whole apple production chain is dominated by the emission occurring in the transport phase from the storehouse to the final market. The use of more efficient transportation means with respect to truck should be explored in the future.

The good level of apple yield per hectare reached by modern orchard (approx. 60 t ha$^{-1}$) indicated a good use efficiency of external resources which is reflected in a relatively low C footprint of the apple cultivation phase (0.04 - 0.05 kg $CO_2$-eq). Anyway a better farm organization in terms of field distance from the farm center and average field size could further diminish the current C footprint value.

This analysis contributed to increase the awareness of environmental impacts of apple production and constitute a scientific basis for improving the sustainability of the whole apple production chain.

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