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Research article

# Product environmental footprint of strawberries: Case studies in Estonia and Germany

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ABSTRACT

The environmental impacts of strawberries have been assessed in several studies. However, these studies either present dissimilar results or only focus on single impact categories without offering a comprehensive overview of environmental impacts. We applied the product environmental footprint (PEF) methodology to broadly indicate the environmental impacts of various strawberry production systems in Germany and Estonia by 15 impact categories. Data for the 7 case studies were gathered from two farms with organic and two farms with conventional open field production systems in Estonia and from one farm with conventional open field and one farm with a polytunnel and greenhouse production system in Germany. The greenhouse production system had the highest environmental impact with a PEF of 0.0040. In the field organic production systems, the PEF was 0.0029 and 0.0028. The field conventional production systems resulted in a PEF of 0.0008, 0.0009 and 0.0002. Polytunnel PEF was 0.0006. Human toxicity cancer effects, particulate matter and human toxicity non-cancer effects resulted in the highest impact across all analysed production systems. The main contributors were electricity for cooling, heating the greenhouse and the use of agricultural machinery including fuel burning. While production stage contributed 85% of the total impact in the greenhouse, also other life cycle stages were important contributors: pre-chain resulted in 71% and 90% of impact in conventional and polytunnels, respectively, and cooling was 47% in one organic system. Environmental impact from strawberry cooling can be reduced by more efficient use of the cooling room, increasing the strawberry yield or switching from oil shale electricity to other energy sources. Greenhouse heating is the overall impact hotspot even if it based on renewable resources. A ranking of production systems based on the environmental impact is possible only if all relevant impacts are included. Future studies should aim for detailed results across a variety of impact categories and follow product category rules in defining the life cycle stages.



## 1. Introduction

The environmental impact of goods and services (hereafter called products) has long been measured by the life-cycle assessment (LCA) methodology. LCA is often used in several industries for comparing different processes and products based on their environmental performance. Also consumers and other stakeholders require environmental impact information and show an interest in choosing products with lower environmental burden (Galatola and Pant, 2014). The flexibility in the standards, which guide the LCA calculation (i.e. ISO 14040, 2006a and ISO 14044, 2006b), leads to LCA results that are often neither reproducible nor comparable (Galatola and Pant, 2014). To increase the comparability of the environmental assessment studies, the European Union (EU) member states have developed an EU-wide environmental assessment method called the product environmental footprint (PEF) (European Commission, 2013). It is based on the LCA procedure trying to avoid shifting of problems between life cycle stages trade-offs of environmental impacts and considering all relevant impacts of the resource use and emissions across the whole life cycle of a product (Climatop, 2009; Page et al., 2012). It defines 15 impact categories which must be included in the analysis (European Commission, 2013). The PEF also provides more prescriptive guidelines and sacrifices flexibility by minimising the number of choices and decisions that the user would have to take (Manfredi et al., 2015).

During the last 20 years the amount of strawberries cultivated

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globally has grown 2.4 times (FAOSTAT, 2015). China is currently the biggest producer utilizing both, open field and weather protected cropping (Herrick, 2012) while the USA as the second biggest producer cultivates mainly in the open field systems (The Protected Agriculture Project, 2009). The strawberry production in Estonia and Germany only represents a very small fraction of the world produce but both cultivation systems, open field and protected cropping are used in these countries. Strawberries are popular summer fruits and are suitable for both conventional and organic cultivation (Kahu et al., 2010). In 2013, Estonia dedicated 640 ha to strawberry growth (Ots, 2014), and its population consumed 2652 tonnes of strawberries (approximately 2 kg per person), of which 40% were imported mainly from Spain (calculated from Ots 2014 data). The production area of strawberries in Germany is ca. 19,000 ha (Statistisches Bundesamt, 2014). Germany's strawberry crop was 168,791 t in 2014 (Statistisches Bundesamt, 2015), and an additional 99,812 t (59%) were imported, also mainly from Spain (Bundesanstalt für Landschaft und Ernährung). The per capita consumption was approximately 3.3 kg.

Many studies have evaluated the product carbon footprint (PCF) of strawberries and have reached contradictory conclusions on the global warming potential (GWP). For example, in a REWE study (2009) on 500 g PET-punnet Spanish strawberries, transport to Germany was identified as the main emissions source, accounting for 32% of the total PCF. Gunady et al. (2012) concluded that agricultural machinery generates 58% of the total greenhouse gas (GHG) emissions. Stoessel et al. (2012) suggested that the GWP can be most effectively reduced by consuming seasonal fruits and vegetables that are not cropped in greenhouses. The energy use of strawberry production also differs amongst regions; fresh strawberries from Sweden, southern Europe and the Middle East (which are transported by plane) require 6.2, 8.6 and 29 MJ/kg, respectively, whereas frozen strawberries from central Europe require 16 MJ/kg (DEFRA, 2005). The environmental impacts of strawberries in other impact categories have been rarely reported. Amongst the few published studies, Juraske et al. (2009) researched the human toxicity of pesticide residues in fruits and vegetables, Stevens et al. (2006) reported on soil loss from rain-induced surface runoff in a strawberry field and García Morillo et al. (2015) mentioned the need for irrigation in Spain. So far, the overall environmental impact of strawberries, including a variety of impact categories, has been analysed only by Brooks et al. (2011), Khoshnevisan et al. (2013) and Williams et al. (2008). Up to now, the PEF of different strawberry production systems is unknown.

The system boundaries also differ amongst the published studies. Some studies cover the whole strawberry life cycle, that means from cradle (= cultivation of the plants) to grave (= waste management of residues) including also upstream processes for the production and transport of inputs and field processes like harrowing and pre-cropping, which are conducted before the strawberry production and including the user stage (Schäfer, 2014; Yoshikawa et al., 2008; Soode et al., 2014), others cover only the pre-production stages, the production and transport to the point of sale (POS), omitting the consumer stage (Gunady et al., 2012; Lindenthal et al., 2010). Yet other studies have considered only the environmental impacts of the production stage (Banaeian et al., 2011; DEFRA, 2005). None of the studies had information on the field clean-up impact, which occurs after the last harvest in the strawberry field.

The environmental impacts of strawberry production have rarely been thoroughly researched and information on the PEF of strawberries is missing. Impacts in separate life cycle stages lead to conflicting conclusions. The current research contributes to the knowledge by conducting PEF case studies on strawberries in open field and protected systems. We posed the following research questions:

1. How do the PEF results differ in alternative strawberry production systems?
2. What are the results by single impact categories?
3. Which life cycle stages are relevant contributors to the PEF results?
4. Which processes are the impact hotspots?

## 2. Material and methods

### 2.1. Production systems

The analysed fields were two organic and two conventional open-field strawberry production farms in Estonia, one conventional open field, and one farm with greenhouse and polytunnel production systems in Germany. The open field strawberry producers were installed with minimal or no weather protection systems. Amongst the Estonian producers, one organic producer was located on an island in Western Estonia, the remainder were in southern Estonia. Both German producers were located in North Rhine–Westphalia, West Germany. The growing and climatic conditions of the farms are summarised in Table 1.

### 2.2. Functional unit

The functional unit in this study was 1 kg strawberries. When the strawberries were packaged in e.g. 500 g punnets at the producers' location, the plastic packaging contributed to the environmental impact of processing. We also accounted for the delivery of the strawberries from the field to the point of sale in reusable plastic boxes.

**Table 1**
Analysed strawberry farms, climatic conditions, landscapes and soil types.

| Farm | Field size ha | Region | Annual average temperature °C | Annual average precipitation mm | Annual sunshine h | Landscape type | Soil type |
|---|---|---|---|---|---|---|---|
| Organic 1 (O1) | 0.3 | Western Estonia | 7.1 (Estonian Weather Service, 2015) | 585 (Estonian Weather Service, 2015) | 1982 (Estonian Weather Service, 2015) | Flat (Penu, 2006) | Gley (Penu, 2006) |
| Organic 2 (O2)<br>Conventional 1 (C1)<br>Conventional 2 (C2) | 0.3<br>6<br>5 | Southern Estonia | 6.1 (Estonian Weather Service, 2015) | 665 (Estonian Weather Service, 2015) | 1659 (Estonian Weather Service, 2015) | Hilly (Penu, 2006) | Eroded or albeluvisol (Penu, 2006) |
| Conventional 3 (C3)<br>Protected system greenhouse (GH)<br>Protected system polytunnels (PT) | 28<br>3<br>2 | Western Germany | 9.0 (Deutscher Wetterdienst, 2014) | 857 (Deutscher Wetterdienst, 2014) | 1487 (Deutscher Wetterdienst, 2014) | Flat (Landwirtschaftskammer Nordrhein-Westfalen, 2011) | luvisol (producer)<br>Substrate: peat with coconut fibre (producer) |