# Environmental footprint of Phalaenopsis
# Representative product study

Roel Helmes, Tommie Ponsioen, Rick van der Linden, Irina Verweij-Novikova

WAGENINGEN
UNIVERSITY & RESEARCH

# Environmental footprint of Phalaenopsis Representative product study

Roel Helmes,[1] Tommie Ponsioen,[2] Rick van der Linden,[3] Irina Verweij-Novikova[1]

1 Wageningen Economic Research
2 FootPrinting
3 Foundation Benefits of Nature and Greenhouse Marketeers

This study was carried out in the framework of the Public-Private Partnership project HortiFootPrint: 'Methodology for environmental footprint TU17005' for the Top sector Agri & Food, as part of the Programme 'Consumer, Market and Society' (project number BO-61-001-007, BO-49-002-012).

Wageningen Economic Research
Wageningen, May 2021

This report was made possible by the Consortium Partners: Wageningen Economic Research, Blonk Consultants, PRé Sustainability, Foundation Benefits of Nature, MPS, Royal FloraHolland, Fresh Produce Centre, Glastuinbouw Nederland, ABN AMRO Bank N.V., Rabobank, Dutch Ministry of Agriculture, Nature and Food Quality.

REPORT
2021-059
ISBN 978-94-6395-809-7

Roel Helmes, Tommie Ponsioen, Rick van der Linden, Irina Verweij-Novikova, 2021. *Environmental footprint of Phalaenopsis Representative product study.* Wageningen, Wageningen Economic Research, Report 2021-059. 44 pp.; 14 fig.; 15 tab.; 27 ref.

This it is not a stand-alone document but should be read in parallel to the report *Hortifootprint category rules - towards a PEFCR for horticultural products* (Helmes, R., T. Ponsioen, H. Blonk, M. Vieira, P. Goglio, R. van der Linden, P. Gual Rojas, D. Kan and I. Verweij-Novikova (2020). Wageningen, report 2020-041, Wageningen Economic Research. The summary of this report has been published in *Environmental footprint of Phanaelopsis: Summary of the representative product study* Helmes, R., P. Goglio and R. van der Linden (2020), Wageningen. Report 2020-041c.

This document represents a product study carried out in the context of the development of a methodology for calculating the environmental footprints of horticultural products, according to the newly released methodological standard - HortiFootprint category rules. This study is performed outside of the official Product Environmental Footprint Category Rules (PEFCR) framework as endorsed by the European Commission. The purpose of this product study was to identify the most relevant impact categories, life cycle stages, processes and direct elementary flows and also to identify the data needs, all feeding into the methodology development. This publication is meant as an illustration of a product environmental footprint (PEF) for Phalaenopsis plants, packed, produced in an technically advanced Dutch greenhouse, sold in a Dutch supermarket and consumed in the Netherlands. The plant of focus is in a 12 cm pot of a two-stem Phalaenopsis as sold in retail.

Key words: life cycle assessment, Phalaenopsis, horticulture, environmental impact, glasshouse

This report can be downloaded for free at https://doi.org/10.18174/546615 or at www.wur.eu/economic-research (under Wageningen Economic Research publications).


P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30,
E communications.ssg@wur.nl, http://www.wur.eu/economic-research. Wageningen Economic Research is part of Wageningen University & Research.



Wageningen Economic Research Report 2021-059 | Project code 2282100273

Cover photo: Shutterstock

# Contents

# Summary


This representative product study (RP study) was done in the context of the development of a methodology for calculating the environmental footprints of horticultural products, the HortiFootprint Category Rules (HFCR, see Helmes et al. 2020 (a)).

In the HFCR, an RP study is a preliminary study carried out on the representative product(s) and intended to identify the most relevant life cycle stages, processes, elementary flows, impact categories and data quality needs to derive the preliminary indication about the definition of the benchmark for the product category/sub-categories in scope, and any other major requirement to be part of the final PEFCR.

While the latest PEFCR Guidelines 2019 (Zampori and Pant, 2019) stimulate developing the Category Rules for a virtual product category (calculated based on average European market sales-weighted characteristics of all existing technologies/materials covered by the product category or sub-category), the HFCR followed the previous version of the earlier Guidelines (2018) and engaged into six RP studies. The RP studies have been performed as prescribed in the previous version of the Guidelines, namely EC (2018) where these studies are referred to as 'screening studies'.

This RP study is one of the six studies on horticultural representative products that have been selected based on a wide and economically relevant variety of applied technologies and origins of productions. The other five studies are:

- Roses (perennial plant yielding flower stems, grown in a greenhouse)
- Tulip bulbs (annual crop in soil, grown without greenhouse protection, with ornamental function)
- Tomatoes (annual vegetable cultivated in greenhouse, on substrate)
- Bananas (tropical perennial fruit with variability in energy-consuming global transport)
- Apples (temperate perennial fruit with variability in energy-consuming storage and global transport).

This is the full version of this RP study report. A short summary of this study can be found in Helmes et al. (2020b). The study was finalised in 2018.

The objectives of this study were:

- To identify the most relevant impact categories, life cycle stages and processes
- To determine the data (quality) requirements
- To test the draft HFCR: in particular, to provide input to check it for completeness and clarity, and to check the feasibility of completing a study in accordance with this.

This report describes the screening study for Phalaenopsis plants, packed, with two flowering stems, in a 12 cm pot. These plants are produced in a Dutch greenhouse with combined heat and power (CHP) system in the young plant stage, and geothermal heat in the large plant stage. The two stages occur in different organisations and represent a high-technological case from reality, including the energy supply. The plants are sold in a Dutch supermarket and consumed in the Netherlands.

The most relevant impact categories, which contribute cumulatively to at least 80% of the normalised and weighted life cycle results of this study, were:

- Climate change
- Resource use, energy carriers
- Resource use, mineral and metals
- Terrestrial and freshwater acidification.

Ecotoxicity freshwater was not included in the weighted results, but considered as relevant due to the perceived importance of the environmental impact of pesticides.

The most relevant life cycle stages of the studied Phalaenopsis plant are capital goods, energy production, cultivation, packaging, use and end of life.

The RP study is *not* intended to make statements about the product group impacts as such, nor is it intended to be used in the context of comparison or for comparative assertions to be disclosed to the public. The results can be used to see where potential hotspots are by looking at the most relevant impact categories, life cycle stages, processes and elementary flows.

In practice, there is a clear variety in Dutch greenhouse Phalaenopsis production with respect to how energy is produced, and what sources of energy and purified carbon dioxide are, and in what quantities they are used. In many cases like the current case, a mix of different sources is used and the quantities will vary year by year due to weather conditions and economic developments. The absolute results of the current case cannot be regarded as representative of the large variety in practice, but the general conclusions on the hotspots and the resulting data quality requirements will apply to Dutch heated and protected Phalaenopsis production in general.

# Abbreviations

| Abbreviation | Explanation |
|---|---|
| CHP | Combined Heat and Power |
| CPA | Classification of Products by Activity |
| EF | Environmental Footprint |
| EU | European Union |
| FU | Functional Unit |
| GHG | Greenhouse Gas |
| ha | hectare |
| HFCR | Hortifootprint Category Rules |
| kg | kilogram |
| km | kilometre |
| kWh | kilowatt-hour |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| m | metre |
| $m^2$ | square metre |
| $m^3$ | cubic metre |
| MJ | megajoule |
| PEF | Product Environmental Footprint |
| PEFCR | Product Environmental Footprint Category Rules |

# 1 Introduction

This representative product study (RP study) was done in the context of the development of a methodology for calculating the environmental footprints of horticultural products, the HortiFootprint Category Rules (HFCR, see Helmes et al. 2020 (a)). The development of the methodology followed as much as possible the most recent Guidance for developing Product Environmental Category Rules (PEFCR) published by the European Commission. The HortiFootprint Category Rules (HFCRs) is a set of life-cycle-based rules for the 16 environmental impact categories. Among these categories are climate change, land use and resource depletion. Within horticulture, this methodology applies to fruits and vegetables as well as flowers and plants.

This report is not a stand-alone document but should be read in parallel to the HFCR report. In the HFCR context, a representative product study (RP study) is a preliminary study carried out on the representative product(s) and intended to identify the most relevant life cycle stages, processes, elementary flows, impact categories and data quality needs to derive the preliminary indication about the definition of the benchmark for the product category/sub-categories in scope, and any other major requirement to be part of the final PEFCR.

While the latest PEFCR Guidelines 2019 (Zampori and Pant, 2019) stimulate developing the Category Rules for a virtual product category (calculated based on average European market sales-weighted characteristics of all existing technologies/materials covered by the product category or sub-category), the HFCR followed the previous version of the earlier Guidelines (2018) and engaged in six RP studies. The RP studies (representative product studies) have been performed as prescribed in the previous version of the Guidelines, namely EC (2018) where these studies are referred to as 'screening studies'.

This RP study is one of the six studies on horticultural representative products that have been selected based on a wide and economically relevant variety of applied technologies and origins of productions. The other five studies were:

- Roses (perennial plant yielding flower stems, grown in a greenhouse). For a published summary, see Helmes et al. (2020b) and full report, see Helmes et al. (2021)
- Tulip bulbs (annual crop in soil, grown without greenhouse protection, with ornamental function). For a published summary, see Goglio (2020)
- Tomatoes (annual vegetable cultivated in greenhouse, on substrate). For a published summary, see Ponsioen and Helmes (2020a)
- Bananas (tropical perennial fruit with variability in energy-consuming global transport). For a published summary, see Kan et al. (2020)
- Apples (temperate perennial fruit with variability in energy-consuming storage and global transport). For a published summary, see Ponsioen and Helmes (2020b).

The study was finalised in 2018. Short summary of this study can be found in Helmes et al. (2020c). This report is a complete version of this RP study.

The development of the HFCR was initiated by Royal FloraHolland, Dutch Fresh Produce Center and Wageningen Economic Research, with co-financing from the Dutch Fund for Horticulture & Propagation Materials, ABN AMRO Bank N.V., the Dutch sector organisation for greenhouse horticulture (Glastuinbouw Nederland), MPS, Rabobank, Foundation Benefits of Nature and in co-production with experts from Blonk Consultants and PRé Sustainability.

# 2 Goal of the study

The objectives of this study are:

- To identify the most relevant impact categories, life cycle stages and processes
- To determine the data (quality) requirements
- To test the draft HFCR: in particular, to provide input to check it for completeness and clarity, and to check the feasibility of completing a study in accordance with this.

This report describes the representative product (RP) study for Phalaenopsis plants, packed, produced in a Dutch greenhouse with combined heat and power (CHP) system in the young plant stage, and geothermal heat in the large plant stage, sold in a Dutch supermarket and consumed in the Netherlands. The plant of focus is in a 12 cm pot of a two-stem Phalaenopsis as sold in retail. This is also the reference flow.

The system includes a greenhouse structure (built from glass, steel, aluminium, concrete, etc.) with a combined heat and power unit with a flue gas cleaner to provide heat, electricity and purified carbon dioxide, and a greenhouse with a geothermal heat system at another organisation. The Phalaenopsis are grown by planting propagation material on substrate and the plant is then treated with fertilisers, water and pesticides in two stages. Surplus electricity is supplied to the grid. After harvest the Phalaenopsis are packed and transported to retail. In the use phase, consumers use the plant for decoration during which the substrate decomposes a little. Once the decoration value has diminished, the plant, the packaging, pot and substrate in the pot are treated at disposal in the end-of-life phase.

Main limitations:

- The RP study is *not* intended to make statements about the product group impacts as such, nor is it intended to be used in the context of comparison or for comparative assertions to be disclosed to the public.
- In practice, there is a clear variety in Dutch greenhouse Phalaenopsis production with respect to how energy is produced, and what sources of energy and purified carbon dioxide are, and in what quantities they are used. In many cases like the current case, a mix of different sources is used and the quantities will vary year by year due to weather conditions and economic developments. The absolute results of the current case cannot be regarded as representative of the large variety in practice, but the general conclusions on the hotspots and the resulting data quality requirements will apply to Dutch heated and protected Phalaenopsis production in general.

# 3 Scope of the study

## 3.1 Function, functional unit and reference flow

When developing Category Rules (CR) for horticultural products falling under one product category – horticulture – it is recognised that rules should be fine-tuned to the specifics of the horticultural products, in particularly to Functional Unit (FU), reference flows and issues around data collection in this guideline.

The functional unit of product is described in Table 3.1. The functional unit defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated. The functional unit definition answers the questions 'what?', 'how much?', 'how well?', and 'for how long?'

***Table 3.1*** *Key aspects of the functional unit*

| Aspect | Defined in this RP study |
|---|---|
| What (function provided)? | Phalaenopsis (2 branches) in 12 cm pot, packed, produced in a Dutch greenhouse with geothermal heat, sold in Dutch retail and consumed in the Netherlands. |
| How much (reference flow)? | 1 pot with the phalaenopsis, with packaging, as sold in retail |
| How well (quality)? | Normal quality to the standard of the Large plant producing company |
| How long (duration)? | For one year |

## 3.2 System boundaries and system boundary diagram

The life cycle assessment has been carried out with a cradle-to-grave approach. The phalaenopsis are grown by planting propagation material from tissue culture on substrate and the crop is treated with fertilisers, water and pesticides in two cultivation steps. The first step includes a greenhouse structure from glass, steel and aluminium and a combined heat and power unit with flue gas cleaner to provide heat, electricity and purified carbon dioxide. Surplus electricity is supplied to the grid. In another greenhouse heated with geothermal heat and powered by Dutch grid electricity, the plant is grown to a full grown, blooming state. The plants and their pots are packed and transported to retail. Next, consumers enjoy the plant's decoration value and the packaging and biowaste is treated as disposal (Figure 3.1). The capital goods, carbon dioxide and energy production and cultivation sub-stages belong to the cultivation stage. The storage stage was assumed to last one day.

The following processes are excluded:

- Capital goods at distribution centre and at retail: due to the small contribution and the low level of control capital goods are often excluded from the background processes if they are not included in secondary data.
- Only usages larger than 0.010 g per phalaenopsis plant were included, since the impact per mass of these small use amounts needs to be at least 100 times bigger than the common use items such as fertilisers, carbon dioxide fertilisation and the greenhouse structure, which is highly unlikely. This approach can be seen as a 'worst case impact cut-off'. This approach was not used for capital goods (unit in pieces) and for energy consumption (unit in MJ) in order to check their importance.

  The Circular Footprint Formula was not yet applied. Instead the EcoInvent processes for waste treatment with cut-off approach were included for all waste flows. This approach implies that the impacts during waste treatment are allocated to the waste and impacts during the processes of turning the waste into a valuable product are allocated to the following life cycle.

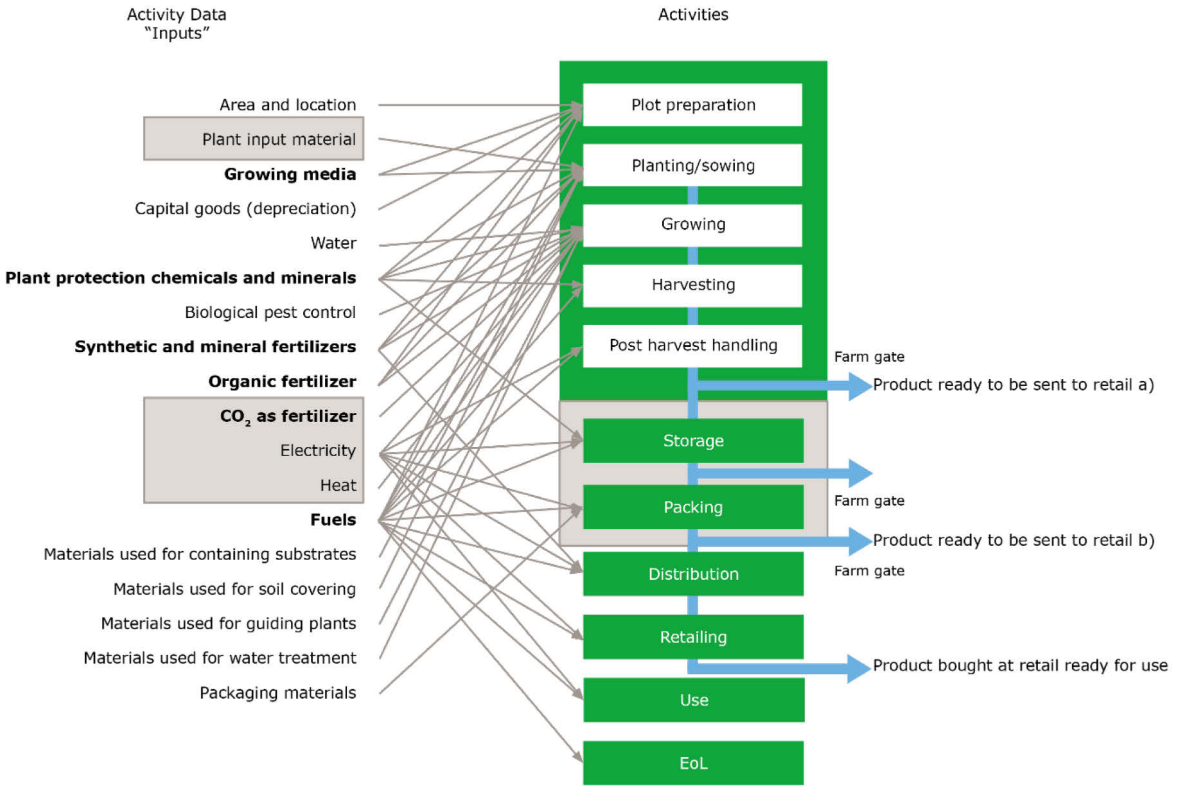



***Figure 3.1*** *Product system processes and elementary flows*

In Figure 3.1, the life cycle stages (dark green) shall be presented in the results if they occur and when in scope. Cultivation at a farm always includes 5 subgroups of activities: plot preparation; planting or sowing; growing; harvesting and post-harvest handling. Storage and packing can take place at the farm, it may also be a separate operation outside the farm. Greenhouse farmers can also produce their own heat, electricity or $CO_2$ fertiliser in a central heat and power (CHP) unit. A part of a horticulture farm can also be designated to the production of young plant material. Farm activities require inputs (activity data). Those are listed on the left-hand side. In the LCA activity data are connected to production processes which cause interventions (emissions and resource use) or they are used as input for emissions modelling.

## 3.3 Assumptions and value judgments

The following assumptions and value judgments were made, along with justifications for the assumptions.

The heat production efficiency of the CHP was assumed at 48% and the electricity production efficiency 40%. These efficiencies are not commonly measured by the growers. It is therefore suggested to use these number by default, but use actual numbers when measured and verified. The technical lifetime of the capital goods for cultivation (greenhouse structure) is assumed to be 15 years. In practice, phalaenopsis growers may use the greenhouse structure for longer, which would mean that the impact of the material production and construction will be lower. A shorter life span is also possible due to fast innovation in the sector. This may lead to premature depreciation of capital goods. Nevertheless, 15 years is used here as the default. Deviation from this life span must be substantiated by the study practitioner with verified evidence that the structure is different from common structures and, if applicable, from alternative structure(s) in the same study. The technical lifetime of the capital goods for geothermal heat production is assumed to be 30 years. Because this technology is relatively new in the Dutch horticultural sector, it is difficult to accurately estimate this number and it may need more substantiation.

## 3.4 Treatment of multifunctionality

These sections provide documentation and justification of the treatment of multifunctionality issues encountered in the PEF modelling activity. Hence, there is only one foreground process where co-production takes place, which is the energy production (CHP).

In the first step of phalaenopsis cultivation, energy is provided with combined heat and power (CHP), and surplus electricity is sold by the grower to the grid. This multi-functionality was handled by first subdividing the system: the CHP unit, the flue gas cleaner that produces purified carbon dioxide for stimulating crop growth and the cultivation processes are divided into separate unit processes.
So, the only multifunctional process is then the production of heat and electricity, where the flue gas is not considered as a co-product, but as emissions, which are attributed to the CHP process. The flue gas cleaner subsequently captures the flue gas, which is attributed to the flue gas cleaner process as reversed emissions, but the resulting purified carbon dioxide and other gasses will eventually be released to the air and are attributed to the flue gas cleaner process.

Energy allocation between electricity and heat is chosen because there is a clear relationship between the energy content of the natural gas input (upper heating value) and the energy of the electricity and the heat produced. The consequences of applying exergy allocation is explored in a sensitivity analysis. The rationale behind the chosen method is explained in detail in Ponsioen et al. (2020).

## 3.5 Information about the data used and data gaps

Information about the data used and data gaps refers to:

- Data representativeness, appropriateness of data, and types/sources of required data and information; includes information on data quality requirements and generic data sources including the data quality scores according to the EF requirements.
- Assessment of the precision, completeness and representativeness of data used.

This is described in Chapter 4.

## 3.6 Impact categories, models and indicators

The EF LCIA method was applied. No additional impact categories are used; although the impact category ecotoxicity freshwater is not considered as a possible relevant impact category in the selection procedure, it is selected as relevant because of the perceived relevance due to expected impact of pesticide use.

## 3.7 Normalisation and weighting factors

Normalisation and weighting from the EF LCIA method were applied to select the most relevant impact categories.

# 4 Compiling and recording the life cycle inventory analysis

## 4.1 Description and documentation of all unit process data

This chapter gives a description and documentation of all unit processes, including for each life cycle stage. A unit process is the smallest element considered in the life cycle inventory for which input and output data are quantified (based on ISO 14040:2006). Tables with all processes involved are given, listing inputs, outputs, elementary flows and land use. The processes are grouped into case specific processes, reflecting on the life cycle stages:

- Starting material from tissue culture (Table 4.1)
- Young Plant cultivation (Table 4.2)
- Large Plant cultivation (Table 4.3)
- Packaging, transport, retail, consumption and disposal processes not considering biomass (Table 4.4)
- Biomass waste treatment & Peat waste treatment (Table 4.5).

And into generic processes:

- Combined heat and power (Table 4.6)
- Flue gas cleaning for $CO_2$ from combined heat and power and the same process from industrial processes (Table 4.7)
- Geothermal heat production (Table 4.8)
- Geothermal heat production system capital goods production (Table 4.9)
- Geothermal heat production system deep well production (Table 4.10)
- Capital goods production for cultivation (Table 4.11).

For each dataset used the source is specified together with an assessment of its data quality, based on the PEF data quality assessment approach. Next, the values needed for assessing the data quality rating (DQR) of the datasets are presented. The calculation of the DQR shall be based on four data quality criteria:

$$\boldsymbol{DQR} = (\boldsymbol{TeR}+\boldsymbol{GeR}+\boldsymbol{TiR}+\boldsymbol{P})/\mathbf{4}$$

where TeR is the Technological-Representativeness, GeR is the Geographical-Representativeness, TiR is the Time-Representativeness, and P is Precision. The representativeness (technological, geographical and time-related) characterises to what degree the processes and products selected are depicting the system analysed, while the precision indicates the way the data is derived and related level of uncertainty.

### 4.1.1 General approach

Foreground data was collected as averaged primary data from Phalaenopsis-growing operations in the Netherlands as compiled by Benefits of Nature, and augmented with data from literature. For storage, retail and the use stages, datasets were created using default data for these, processed using the PEFCR guidance documentation (EC, 2018). The end of life was modelled using details from Annex C from the same document.

For the background data, EcoInvent version 3.4 cut-off was used (Wernet et al., 2016) as well as Agri-footprint 4.0 (economic, see Agri-footprint 2018 a,b). The EF Life Cycle Inventory (LCI) database could not be used, because the original study was not part of an official PEF pilot by the European Commission, as it was conducted before the current transition phase. The modelling was done in SimaPro version 8.5.2, following the PEF rules at that time (EC, 2018).

All calculations for LCI and LCIA were done in SimaPro 8.5.2.0. The default EF impact assessment method (version of October 2018) was used with European normalisation and equal weighting. The PEF impact assessment results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

### 4.1.2 Case Specific Processes

Data in Tables 4.1-4.3 are required for the LCA modelling of the primary processes. The achieved data quality for the data are reported per each cultivation stage: tissue culture, growing young plants and large plants. Since in this study the three cultivation steps happen at individual companies (various locations), the data in Tables 4.1-4.3 originate from specialised individual companies and cannot be reported due to confidentiality agreements. Thus only the assessed data quality is reported. Benefits of Nature has facilitated the data collection and interpretation.

***Table 4.2*** *Data sources and achieved data quality for inputs, outputs, elementary flows and land use of the cultivation process: Tissue culture*

| Inputs, products, interventions | Amount (not disclosed) | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| Phalaenopsis | 1 | p | | | | | | |
| **From technosphere** | | | | | | | | |
| Charcoal {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Ethanol, without water, in 95% solution state, from fermentation {RoW}\| ethanol production from rye \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Sugar, from sugar beet {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Paper, woodcontaining, lightweight coated {RER}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Packaging film, low density polyethylene {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Polypropylene, granulate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Extrusion, plastic film {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Weaving, bast fibre {GLO}\| market for \| Cut-off, S | | g | (1) | 3 | 3 | 2 | 2 | 2.5 |
| Injection moulding {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Lime {FR}\| production, algae \| Cut-off, S | | g | (1) | 3 | 2 | 2 | 2 | 2.25 |
| Synthetic rubber {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Electricity, low voltage {NL}\| market for \| Cut-off, S | | Wh | (1) | 1 | 1 | 2 | 1 | 1.25 |
| Heat, central or small-scale, natural gas {RER}\| market group for \| Cut-off, S | | kJ | (1) | 1 | 2 | 2 | 1 | 1.5 |
| Tap water {RER}\| market group for \| Cut-off, S | | g | (1) | 1 | 2 | 2 | 1 | 1.5 |
| **To technosphere (waste treatment)** | | | | | | | | |
| Paper (waste treatment) {GLO}\| recycling of paper \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 3 | 3.5 |
| Waste plastic, mixture {Europe without Switzerland}\| market for waste plastic, mixture \| Cut-off, S | | g | (1) | 1 | 2 | 2 | 3 | 3.5 |
| Wastewater, unpolluted {RoW}\| market for wastewater, unpolluted \| Cut-off, S | | $cm^3$ | (1) | 1 | 3 | 2 | 3 | 3.5 |

Table footnotes:

1. Benefits of Nature dataset from Phalaenopsis Cultivation. Due to confidentiality issues, the values are not reported. Links between use and process defined by Benefits of Nature; Since this is a laboratory based process, there is no fertiliser application to soil or substrate and no resulting emissions to soil, water or air. Waste water contains the emissions from this process and is treated as a default EcoInvent process.

***Table 4.3*** *Data sources and achieved data quality for inputs, outputs, elementary flows and land use of first step in the cultivation process: Young Plant cultivation*

| Inputs, products, interventions | Amount (not disclosed) | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| P1. Phalaenopsis, Young plant for Large Plant cultivation, WKK | 1 | p | | | | | | |
| **From nature** | | | | | | | | |
| Occupation, industrial area | | m$^2$a | (1),(2) | 1 | 1 | 1 | 2 | 1.25 |
| Carbon dioxide, in air | | g | (1),(3) | 2 | 1 | 2 | 2 | 1.75 |
| Water, rain | | l | (1) | 1 | 1 | 1 | 2 | 1.25 |
| Water, well, in ground, NL | | l | (1) | 1 | 1 | 1 | 2 | 1.25 |
| **From technosphere** | | | | | | | | |
| P0. Phalaenopsis, Starting Material for Small Plant cultivation | | p | (4) | 1 | 1 | 1 | 2 | 1.25 |
| Greenhouse, glass walls and roof Horti-footprint | | m$^2$a | (1),(4) | 1 | 1 | 1 | 2 | 1.25 |
| $CO_2$ from flasks | | g | (1),(4) | 1 | 1 | 1 | 2 | 1.25 |
| $CO^2$ from OCAP | | g | (1),(4) | 1 | 1 | 1 | 2 | 1.25 |
| Packaging, for fertilisers or pesticides {GLO}\| packaging production for solid fertiliser or pesticide, per kilogram of packed product \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Packaging, for fertilisers or pesticides {GLO}\| packaging production for liquid fertiliser or pesticide, per kilogram of packed product \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Ethanol, without water, in 95% solution state, from fermentation {RoW}\| ethanol production from rye \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Lime {FR}\| production, algae \| Cut-off, S | | g | (1) | 3 | 2 | 2 | 2 | 2.25 |
| Hydrogen peroxide, without water, in 50% solution state {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Water, ultrapure {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 1 | 1.75 |
| Elec WKK NL | | Wh | (1),(4) | 1 | 1 | 1 | 1 | 1 |
| Heat WKK NL | | kJ | (1),(4) | 1 | 1 | 1 | 1 | 1 |
| Polystyrene, general purpose {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Magnesium sulfate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Dolomite {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Potassium nitrate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Calcium nitrate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Phosphate fertiliser, as P2O5 {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Thermoforming, with calendering {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Water, ultrapure {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 1 | 1.75 |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Cut-off, S | | kgkm | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Coconut, dehusked {GLO}\| market for coconut, dehusked \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Peat moss {GLO}\| market for \| Cut-off, S | | dm$^3$ | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Cut-off, S | | kgkm | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Transport, freight, sea, transoceanic ship {GLO}\| market for \| Cut-off, S | | kgkm | (1) | 1 | 3 | 2 | 2 | 2 |
| **To Nature** | | | | | | | | |
| Ammonia to air | | mg | (1),(5) | 1 | 2 | 1 | 3 | 1.75 |
| Dinitrogen monoxide to air | | mg | (1),(5) | 1 | 2 | 1 | 3 | 1.75 |
| Nitrogen oxides to air | | mg | (1),(5) | 1 | 2 | 1 | 3 | 1.75 |
| Water, NL to river | | l | (1) | 1 | 2 | 1 | 2 | 1.5 |
| Nitrate to river | | mg | (1),(5) | 1 | 2 | 1 | 3 | 1.75 |
| 1-Methyl-2-pyrrolidinone | | g | (1),(6) | 1 | 2 | 1 | 4 | 2 |
| Benzoic acid | | g | (1),(6) | 1 | 2 | 1 | 4 | 2 |
| Cyclohexanol | | g | (1),(6) | 1 | 2 | 1 | 4 | 2 |
| Ethanol | | g | (1),(6) | 1 | 2 | 1 | 4 | 2 |
| Propamocarb | | g | (1),(6) | 2 | 2 | 1 | 4 | 2.25 |

| Inputs, products, interventions | Amount (not disclosed) | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| Thiophanate-methyl | | g | (1),(6) | 1 | 2 | 1 | 4 | 2 |
| Carbon dioxide, fossil | | mg | (1),(5) | 1 | 2 | 1 | 3 | 1.75 |
| **To technosphere (waste treatment)** | | | | | | | | |
| Municipal solid waste {NL}\| treatment of, incineration \| Cut-off, S | | g | (1),(7) | 2 | 1 | 2 | 2 | 1.75 |
| Waste plastic, mixture {Europe without Switzerland}\| market for waste plastic, mixture \| Cut-off, S | | g | (1),(7) | 2 | 2 | 2 | 2 | 2 |

Table footnotes:

1. Benefits of Nature dataset from Phalaenopsis Cultivation; Due to confidentiality issues, the values are not reported. Unless other footnote is given, links between use and process defined by Benefits of Nature.
2. Greenhouse area; Related to the duration from harvest date of previous crop to harvest date of main crop.
3. $CO_2$ uptake by biomass; 1.89 kg $CO_2$ is released on processing 1 kg of dry biomass; 25% of total dry mass is assumed to be fixed in this process; the remaining 75% in the large plant process; Mass from Paradiso et al. 2012: 6.03 g/stem, 2-stem plant.
4. Process is modelled for HortiFootprint project; explained in table in this report under 4.1.2 Generic Processes.
5. Based on total N, P and C inputs through fertilisers; N and C emission calculation was PEFCR Guidance compliant. The PEFCR Guide (EC, 2018) indicates that if no transfer model for P emissions to water is available, emissions are to be modelled as emissions to the soil. The soil is the substrate in the pot, in the case of phalaenopsis, so that P fertiliser application to not result in an emission to the environment.
6. Based on largest use of active ingredients and coformulants in pesticide mixtures with a 0.5% mass cut-off (relative to largest use); distributed according to PEFCR Guide (EC, 2018): 9% to air, 1% to water, 90% to soil; no consideration of greenhouse.
7. Assessment of which input from technosphere is treated as which type of waste was based on links to EcoInvent processes.

***Table 4.4*** *Data sources and achieved data quality for inputs, outputs, elementary flows and land use of second step in the cultivation process: Large Plant cultivation*

| Inputs, products, interventions | Amount (not disclosed) | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| P2. Phalaenopsis, Large Plant for Packaging, WKO | 1 | p | | | | | | |
| **From nature** | | | | | | | | |
| Occupation, industrial area | | $m^2a$ | *(1),(2)* | 1 | 1 | 1 | 2 | 1.25 |
| Water, rain | | $dm^3$ | *(1)* | 1 | 1 | 1 | 2 | 1.25 |
| Water, well, in ground, NL | | $cm^3$ | *(1)* | 1 | 1 | 1 | 2 | 1.25 |
| Carbon dioxide, in air | | g | *(1),(3)* | 2 | 1 | 2 | 2 | 1.75 |
| Carbon dioxide, in air | | g | *(1),(4)* | 2 | 1 | 2 | 2 | 1.75 |
| **From technosphere** | | | | | | | | |
| Boric acid, anhydrous, powder {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Polypropylene, granulate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Transport, freight, sea, transoceanic ship {GLO}\| market for \| Cut-off, S | | kgkm | (1) | 1 | 3 | 2 | 2 | 2 |
| Wire drawing, steel {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Wood preservative, water-based, indoor use, occasionally wet {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Lime {FR}\| production, algae \| Cut-off, S | | g | (1) | 3 | 2 | 2 | 2 | 2.25 |
| Packaging, for fertilisers or pesticides {GLO}\| packaging production for liquid fertiliser or pesticide, per kilogram of packed product \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Bark chips, wet, measured as dry mass {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| EUR-flat pallet {GLO}\| market for \| Cut-off, S | | p | (1) | 1 | 3 | 2 | 2 | 2 |
| Packaging film, low density polyethylene {RER}\| production \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Peat moss {RoW}\| peat moss production, horticultural use \| Cut-off, S | | $dm^3$ | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Cut-off, S | | kgkm | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Transport, freight, sea, transoceanic ship {GLO}\| market for \| Cut-off, S | | kgkm | (1) | 1 | 3 | 2 | 2 | 2 |
| Transport, freight train {Europe without Switzerland}\| market for \| Cut-off, S | | kgkm | (1) | 1 | 2 | 2 | 2 | 1.75 |
| Injection moulding {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Polypropylene, granulate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Thermoforming, with calendering {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Ammonium nitrate, as N {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Calcium nitrate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| EDTA, ethylenediaminetetraacetic acid {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Iron sulfate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Magnesium sulfate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Maize grain, organic {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Nitrogen fertiliser, as N {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Pea seed, for sowing {GLO}\| market for \| Cut-off, S | | g | (1) | 3 | 3 | 2 | 2 | 2.5 |
| Phosphate fertiliser, as P2O5 {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Potassium fertiliser, as K2O {GLO}\| market for \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Potassium nitrate {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Water, ultrapure {GLO}\| market for \| Cut-off, S | | g | (1) | 1 | 3 | 2 | 1 | 1.75 |
| Packaging, for fertilisers or pesticides {GLO}\| packaging production for solid fertiliser or pesticide, per kilogram of packed product \| Cut-off, S | | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| CO2 from OCAP | | g | (1),(5) | 1 | 1 | 1 | 2 | 1.25 |
| Transport, freight, lorry 16-32 metric ton, EURO5 {RER}\| transport, freight, lorry 16-32 metric ton, EURO5 \| Cut-off, S | | kgkm | (1) | 2 | 3 | 2 | 2 | 2.25 |

| Inputs, products, interventions | Amount (not disclosed) | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| Greenhouse, glass walls and roof Horti-footprint | | m2a | (1),(5) | 1 | 1 | 1 | 2 | 1.25 |
| Heat pump, for heat and power co-generation unit, 160kW electrical {GLO}\| market for heat pump, heat and power co-generation unit, 160kW electrical \| Cut-off, S | | p | (1) | 1 | 3 | 2 | 2 | 2 |
| Deep well, drilled, for geothermal power {GLO}\| market for \| Cut-off, S | | m | (1) | 1 | 3 | 2 | 2 | 2 |
| Gas boiler {GLO}\| market for \| Cut-off, S | | p | (1) | 1 | 3 | 2 | 2 | 2 |
| Heat and power co-generation unit, 200kW electrical, diesel SCR, common components for heat+electricity {RER}\| construction \| Cut-off, S | | p | (1) | 1 | 2 | 2 | 2 | 1.75 |
| Borehole heat exchanger, 150m {GLO}\| market for \| Cut-off, S | | p | (1) | 1 | 3 | 2 | 2 | 2 |
| P1. Phalaenopsis, Young plant for Large Plant cultivation, WKK | | p | (1),(5) | 1 | 1 | 1 | 2 | 1.25 |
| **To Nature** | | | | | | | | |
| Ammonia to air | | mg | (1),(6) | 1 | 2 | 1 | 3 | 1.75 |
| Dinitrogen monoxide to air | | mg | (1),(6) | 1 | 2 | 1 | 3 | 1.75 |
| Carbon dioxide, fossil to air | | mg | (1),(6) | 1 | 2 | 1 | 3 | 1.75 |
| Water, NL to river | | dm3 | (1) | 1 | 2 | 1 | 2 | 1.5 |
| Nitrate to river | | mg | (1),(6) | 1 | 2 | 1 | 3 | 1.75 |
| **To technosphere (waste treatment)** | | | | | | | | |
| Biowaste {NL}\| treatment of biowaste, industrial composting \| horti-footprint | | g | (1),(7) | 2 | 1 | 2 | 2 | 1.75 |
| Municipal solid waste {NL}\| treatment of, incineration \| Cut-off, S | | g | (1),(7) | 2 | 1 | 2 | 2 | 1.75 |
| Waste plastic, mixture {Europe without Switzerland}\| market for waste plastic, mixture \| Cut-off, S | | g | (1),(7) | 2 | 2 | 2 | 3 | 2.25 |
| Waste wood, untreated {RoW}\| treatment of waste wood, untreated, municipal incineration \| Cut-off, S | | kg | (1),(8) | 3 | 3 | 2 | 2 | 2.5 |

Table footnotes:

1. Benefits of Nature dataset from Phalaenopsis Cultivation; Due to confidentiality issues, the values are not reported. Unless another footnote is given, links between use and process were defined by Benefits of Nature.
2. Greenhouse area; Related to the duration from harvest date of previous crop to harvest date of main crop.
3. $CO_2$ uptake by biomass; 1.89 kg $CO_2$ is released in processing 1 kg of dry biomass; 75% of total dry mass is assumed to be fixed in this process; the remaining 25% in the small plant process; Mass from Paradiso et al. 2012: 6.03 g/stem, 2-stem plant.
4. Biogenic $CO_2$ emissions from treating Biowaste are $CO_2$ uptakes during cultivation.
5. Process is modelled for HortiFootprint project; explained in table in this report under 4.1.2 Generic Processes.
6. Based on total N, P and C inputs through fertilisers; N and C emission calculation was PEFCR Guidance compliant. The PEFCR Guidance indicates that if no transfer model for P emissions to water is available, emissions are to be modelled as emissions to the soil. The soil is the substrate in the pot, in the case of phalaenopsis, so that P fertiliser application to not result in an emission to the environment.
7. Assessment of which input from technosphere is treated as which type of waste was based on links to EcoInvent processes.
8. Assuming 25 kg weight of pallet; use of 0.000188 pallets per plant; 0.5 kg C/kg total mass; divided by 1.46 to correct for all biogenic carbon emissions and not for the share in the selected process.

**Table 4.5** *Inputs, outputs, elementary flows and land use of packaging, distribution, retail and use*

| Inputs, products, interventions | Amount | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| ***Process: Packaging*** | | | | | | | | |
| P3. Phalaenopsis, Packaged for Distribution, WKO | 1 | p | | | | | | |
| **From technosphere** | | | | | | | | |
| P2. Phalaenopsis, Large Plant for Packaging, WKO | 1 | p | (1) | 1 | 1 | 1 | 2 | 1.25 |
| Extrusion, plastic film {GLO}\| market for \| Cut-off, S | 1 | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Corrugated board box {GLO}\| market for corrugated board box \| Cut-off, S | 18.0 | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Thermoforming, with calendering {GLO}\| market for \| Cut-off, S | 1.7 | g | (1) | 2 | 3 | 2 | 2 | 2.25 |
| Polystyrene, general purpose {GLO}\| market for \| Cut-off, S | 14.7 | g | (1) | 1 | 3 | 2 | 2 | 2 |
| Polypropylene, granulate {GLO}\| market for \| Cut-off, S | 14.7 | g | (1) | 1 | 3 | 2 | 2 | 2 |
| ***Process: Distribution*** | | | | | | | | |
| P4. Phalaenopsis, Distributed to NL retail, WKO | 1 | p | | | | | | |
| **From technosphere** | | | | | | | | |
| P3. Phalaenopsis, Packaged for Distribution, WKO | 1 | p | | | | | | |
| Transport, freight, lorry 16-32 metric ton, EURO5 {GLO}\| market for \| Cut-off, S | 120 | kgkm | (2) | 2 | 3 | 2 | 2 | 2.25 |
| ***Process: Retail*** | | | | | | | | |
| P5. Phalaenopsis, Sold at NL retail for NL Use, WKO | 1 | p | | | | | | |
| **From technosphere** | | | | | | | | |
| Electricity, low voltage {NL}\| market for \| Cut-off, S (horti-footprint retail | 0.017 | kWh | (2) | 1 | 1 | 2 | 3 | 1.75 |
| To technosphere (waste treatment) | | | | | | | | |
| Waste paperboard {Europe without Switzerland}\| market for waste paperboard \| Cut-off, S | 1.66 | g | (1),(3) | 2 | 2 | 2 | 2 | 2 |
| Municipal solid waste {NL}\| treatment of, incineration \| Cut-off, S | 1.47 | g | (1),(3) | 2 | 1 | 2 | 2 | 1.75 |
| ***Process: Use*** | | | | | | | | |
| P6. Phalaenopsis, Used in NL and Disposal, WKO | 1 | p | | | | | | |
| **To nature** | | | | | | | | |
| Carbon dioxide, fossil to air | 23.2 | g | (4) | 1 | 1 | 1 | 3 | 1.75 |
| Dinitrogen monoxide to air | 14.8 | mg | (4) | 1 | 1 | 1 | 4 | 1.75 |
| Carbon dioxide, biogenic to air | 4.68 | g | (4) | 1 | 1 | 1 | 4 | 1.75 |

Table footnotes:

1. Benefits of Nature dataset from Phalaenopsis; Unless other footnote is given, links between use and process defined by Benefits of Nature.
2. Assumptions taken over from Tomato Study (Ponsioen et al., 2020).
3. Assessment of which input from technosphere is treated as which type of waste was based on links to EcoInvent processes.
4. Based on Blonk et al. (2009), Paradiso et al. (2012) and own assumptions, further explained in paragraph 4.3.

***Table 4.6*** *Inputs, outputs, elementary flows and land use of the Phalaenopsis cart production and use of the processing either any biowaste or specifically peat*

| Inputs, products, interventions | Amount | Unit | Ref. | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **The process processing 'any biowaste'** | | | | | | | | |
| Biowaste {NL}\| treatment of biowaste, industrial composting \| horti-footprint | 1 | kg | | | | | | |
| **The process processing 'peat biowaste'** | | | | | | | | |
| Biowaste {NL}\| treatment of peat biowaste, industrial composting \| horti-footprint | 1 | kg | | | | | | |
| **From technosphere (both processes)** | | | | | | | | |
| Composting facility, open {GLO}\| market for \| Cut-off, S | 7.41E-09 | p | (1) | 2 | 3 | 2 | 1 | 2 |
| Electricity, low voltage {NL}\| market for \| Cut-off, S (horti-footprint waste) | 1.18E-02 | kWh | (1) | 1 | 1 | 2 | 1 | 1.25 |
| Machine operation, diesel, >= 74.57 kW, low load factor {GLO}\| market for \| Cut-off, S | 3.52E-04 | hr | (1) | 3 | 3 | 3 | 1 | 2.5 |
| **To Nature (both processes)** | | | | | | | | |
| Ammonia to air | 7.00E-04 | kg | (1) | 2 | 3 | 2 | 1 | 2 |
| Hydrogen sulfide to air | 5.26E-04 | kg | (1) | 2 | 3 | 2 | 1 | 2 |
| Methane, biogenic to air | 1.00E-03 | kg | (1) | 2 | 3 | 2 | 1 | 2 |
| Water/$m^3$ to air | 1.25E-04 | $m^3$ | (1) | 2 | 3 | 2 | 1 | 2 |
| Dinitrogen monoxide to air | 3.73E-01 | g | (2) | 2 | 1 | 2 | 4 | 2.25 |
| **To Nature ('any biowaste' processes)** | | | | | | | | |
| Carbon dioxide, biogenic to air | 3.93E-01 | kg | (1), (2) | 2 | 1 | 2 | 4 | 2.25 |
| **To Nature ('peat biowaste' processes)** | | | | | | | | |
| Carbon dioxide, fossil | 8.35E-01 | kg | (1), (2) | 2 | 1 | 2 | 3 | 2 |

Table footnotes:

1. Based on EcoInvent process 'Biowaste {GLO}| treatment of biowaste, municipal incineration | Cut-off, U'.
2. Based on Blonk et al. (2009), Paradiso et al. (2012) and own assumptions, further explained in paragraph 4.3.

### 4.1.3 Generic Processes for PEFCR Horticulture

The processes related to operating the Cogeneration of Heat and Power (CHP) and $CO_2$ from OCAP or flue gas treatment were developed for the purpose of the RP-study (Table 4.6 and 4.7).

***Table 4.7*** *Inputs, outputs, elementary flows and land use of the CHP production*

| Inputs, products, interventions | Amount (allocation) | Unit/m³ Gas | Ref | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| Heat product | 15.2 (54.5%) | MJ | (1) | | | | | |
| Electricity product | 3.5 (45.5%) | kWh | (1) | | | | | |
| **Inputs from technosphere** | | | | | | | | |
| Heat and power co-generation unit, 1MW electrical (common) | 2.7E-8 | P | (2) | 1 | 5 | 3 | 3 | 3 |
| Heat and power co-generation unit, 1MW electrical (electricity) | 2.7E-8 | P | (2) | 1 | 5 | 3 | 3 | 3 |
| Heat and power co-generation unit, 1MW electrical (heat) | 2.7E-8 | p | (2) | 1 | 5 | 3 | 3 | 3 |
| Lubricating oil {GLO}\| market for | 1.2 | g | (3) | 1 | 5 | 3 | 3 | 3 |
| Natural gas (LHV 31.65 MJ/$m^3$) | 1 | $m^3$ | own | 1 | 1 | 3 | 3 | 2 |
| **To nature:** | | | | | | | | |
| Carbon dioxide, fossil emissions to air | 1.78 | kg | (4) | | | | | |
| Nitrous oxide emissions to air | 3.17 | mg | (4) | | | | | |
| Methane, fossil, emissions to air | 1,600 | mg | (6) | | | | | |
| Nitrogen oxides emissions to air | 2,310 | mg | (5) | | | | | |
| Carbon monoxide, fossil, emissions to air | 760 | mg | (5) | | | | | |
| NMVOC emissions to air | 11 | mg | (5) | | | | | |
| Sulfur dioxide emissions to air | 44 | mg | (5) | | | | | |
| Particulates, <2.5um emissions to air | 14 | mg | (5) | | | | | |
| **To technosphere (waste treatment)** | | | | | | | | |
| Waste mineral oil | 1.2 | g | (3) | 3 | 5 | 3 | 3 | 3.5 |

Table footnotes:

1. Assuming a heat production efficiency of 48% and an electricity production efficiency of 40% (Van der Velden and Smit (2017); allocation factor for heat = 15.2 MJ energy/(15.2 MJ + 12.7 MJ).
2. Assuming 2,500,000 $m^3$ natural gas consumption over 15 years.
3. EcoInvent 3.4.
4. Derived from IPCC (Gomez et al. 2006) for $CO_2$ and $N_2O$.
5. European Environmental Agency (2016); Tier 2 emission factors for non-residential sources, medium-sized (> 50 kWth to ≤ 1 MWth) boilers burning natural gas.
6. Maximum allowed in the Netherlands (Plomp and Kroon, 2013).

***Table 4.8*** *Inputs, outputs, elementary flows and land use of the flue gas cleaner purified carbon dioxide production (or from external source)*

| Inputs, products, interventions | Amount (allocation) | Unit/m³ gas | Ref | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| Purified carbon dioxide | 1 | kg | | | | | | |
| **Inputs from nature** | | | | | | | | |
| Water, cooling, unsp. natural origin, NL | 0.0164 | $m^3$ | (1) | | | | | |
| Water, river, NL | 0.00086 | $m^3$ | (1) | | | | | |
| Water, well, in ground, NL | 0.00083 | $m^3$ | (1) | | | | | |
| **Inputs from technosphere** | | | | | | | | |
| Heat and power co-generation unit, 1MW electrical, common components for heat+electricity {GLO}\| market for | 4.0E-10 | p | (2) | 5 | 5 | 3 | 3 | 4 |
| Electricity from CHP, NL **OR** Electricity, medium voltage {NL}\| market (external) | 0.3 | kWh | (3) | 1 | 1 | 1 | 1 | 1 |
| Heat from CHP, NL or Heat, district **OR** industrial, natural gas {Europe without Switzerland}\| heat production, natural gas, at boiler modulating >100kW \| (external) | 2 | kg | (4) | 1 | 1 | 1 | 1 | 1 |
| Monoethanolamine {GLO}\| market | 0.013 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Tap water {NL}\| tap water production | 0.026 | kg | (1) | 1 | 1 | 3 | 3 | 2 |
| Transport, pipeline, long distance, natural gas {DE}\| processing \| (external) | 5229 | kg-km | (5) | 2 | 2 | 3 | 3 | 2.5 |
| **To nature:** | | | | | | | | |
| Monoethanolamine | 0.013 | kg | (1) | | | | | |
| Water/$m^3$ | 0.0014 | $m^3$ | (1) | | | | | |
| Water, NL | 0.0167 | $m^3$ | (1) | | | | | |

Table footnotes:

1. Based on the EcoInvent 3.4 process Carbon dioxide, liquid {RER}| production | Cut-off, U.
2. Based on the EcoInvent 3.4 process Carbon dioxide, liquid {RER}| production | Cut-off, U but reference process changed from chemical factory organics.
3. Based on Xuezhong He and May-Britt Hägg, 2014.
4. Estimate based on Veneman et al. (2013) and Frischknecht (1999).
5. Based on OCAP (2018), 83 km distance of specifically the OCAP pipeline for supplying purified $CO_2$ to greenhouses.

***Table 4.9*** *Inputs, outputs, elementary flows and land use of the geothermal heat production process*

| Inputs, products, interventions | Amount (allocation) | Unit/m³ gas | Ref | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| Heat product | 1 | MJ | (1) | | | | | |
| **Inputs from technosphere** | | | | | | | | |
| Geothermal power plant, 5.5MWel {NL}\| horti-footprint | 2E-10 | P | (2) | 1 | 5 | 3 | 3 | 3 |
| Electricity, low voltage {NL}\| market for \| Cut-off, S | 0.0253 | kWh | (2) | 1 | 5 | 3 | 3 | 3 |

Table footnotes:

1. Based on Vlaar (2013): 1/(166,633,000 MJ annual production*30 years).
2. Based on Vlaar (2013): 15,148 GJ electricity use/166,633 GJ annual production/3.6 MJ/kWh.

***Table 4.10*** *Inputs, outputs, elementary flows and land use of the geothermal heat production system capital goods production*

| Inputs, products, interventions | Amount (allocation) | Unit/m³ gas | Ref | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| Geothermal power plant, 5.5MWel {NL}\| horti-footprint | 1 | p | | | | | | |
| **From nature** | | | | | | | | |
| Occupation, industrial area | 8,000 | $m^2a$ | (1) | | | | | |
| Transformation, from unspecified, natural (non-use) | 8,000 | $m^2$ | (1) | | | | | |
| Transformation, to industrial area | 8,000 | $m^2$ | (1) | | | | | |
| **Inputs from technosphere** | | | | | | | | |
| Deep well, drilled, for geothermal power CE data {NL}\| deep well drilling, for deep geothermal power \| horti-footprint | 2,000 | m | (1) | 1 | 5 | 3 | 3 | 3 |
| Heat and power cogeneration unit, 1MWel, 6.4MWth {GLO}\| market for heat and power cogeneration unit, 1MWel, 6.4MWth \| Cut-off, U | 5.05 | P | (1) | 3 | 5 | 3 | 3 | 3.5 |
| Steel, low-alloyed {GLO}\| market for \| Cut-off, U | 20,000 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Stimulation, deep well {GLO}\| market for \| Cut-off, U | 3,000 | $m^3$ | (1) | 1 | 5 | 3 | 3 | 3 |
| **To technosphere (waste treatment)** | | | | | | | | |
| Inert waste, for final disposal {CH}\| market for inert waste, for final disposal \| Cut-off, U | 20,000 | kg | (1) | 1 | 5 | 3 | 3 | 3 |

Table footnotes:

1. Based on the EcoInvent process Geothermal power plant, 5.5MWel {CH}| geothermal power plant construction | Cut-off, U; amounts adapted based on Vlaar (2013).

***Table 4.11*** *Inputs, outputs, elementary flows and land use of the geothermal heat production system deep well production*

| Inputs, products, interventions | Amount (allocation) | Unit/m³ gas | Ref | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| **Products** | | | | | | | | |
| Deep well, drilled, for geothermal power {NL}\| deep well drilling \| horti-footprint | 1 | m | | | | | | |
| **From nature** | | | | | | | | |
| Water, well, in ground, RoW | 0.5 | $m^3$ | (1) | | | | | |
| Occupation, industrial area | 6E-5 | $m^2a$ | (1) | | | | | |
| Transformation, from unspecified, natural (non-use) | 0.6 | $m^2$ | (1) | | | | | |
| Transformation, to industrial area | 0.6 | $m^2$ | | | | | | |
| **Inputs from technosphere** | | | | | | | | |
| Barite {GLO}\| market for \| Cut-off, U | 20 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Bentonite {GLO}\| market for \| Cut-off, U | 20 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Cellulose fibre, inclusive blowing in {GLO}\| market for \| Cut-off, U | 17.5 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Cement, Portland {RoW}\| market for \| Cut-off, U | 78.5 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| Chemical, organic {GLO}\| market for \| Cut-off, U | 20 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Diesel, burned in diesel-electric generating set {GLO}\| market for \| Cut-off, U | 111 | MJ | (1) | 1 | 5 | 3 | 3 | 3 |
| Electricity, medium voltage {NL}\| market for \| Cut-off, U | 1,130 | kWh | (2) | 1 | 5 | 3 | 3 | 3 |
| Potassium carbonate {GLO}\| market for \| Cut-off, U | 15 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Reinforcing steel {GLO}\| market for \| Cut-off, U | 131 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| Sodium chloride, powder {GLO}\| market for \| Cut-off, U | 6 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Sodium hydroxide, without water, in 50% solution state {GLO}\| market for \| Cut-off, U | 1 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Steel, low-alloyed {GLO}\| market for \| Cut-off, U | 0.5 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| **To technosphere (waste treatment)** | | | | | | | | |
| Drilling waste {GLO}\| market for \| Cut-off, U | 466 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Wastewater, average {RoW}\| market for wastewater, average \| Cut-off, U | 0.6 | $m^3$ | | | | | | |

Table footnotes:

1. Based on the EcoInvent process Deep well, drilled, for geothermal power {DE}| deep well drilling, for deep geothermal power | Cut-off, U.
2. amounts adapted based on Vlaar (2013).

***Table 4.12*** *Inputs, outputs, elementary flows and land use of the capital goods production for cultivation*

| Inputs, products, interventions | Amount | Unit/m² | Ref | TeR | GeR | TiR | P | DQR |
|---|---|---|---|---|---|---|---|---|
| Products: | | | | | | | | |
| Greenhouse | 1 | $m^2a$ | | | | | | |
| Inputs from technosphere | | | | | | | | |
| Aluminium alloy, AlMg3 {GLO}\| market for | 0.19 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Steel, low-alloyed {GLO}\| market for | 0.73 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Flat glass, uncoated {GLO}\| market for | 0.79 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Section bar extrusion, aluminium {GLO}\| market for | 0.19 | kg | (1) | 1 | 5 | 3 | 3 | 3 |
| Steel, chromium steel 18/8 {GLO}\| market for | 0.0328 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| Tractor, 4-wheel, agricultural {GLO}\| market for | 0.0152 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| Concrete, sole plate and foundation {RoW}\| market | 0.0003 | $m^3$ | (1) | 1 | 5 | 3 | 3 | 3 |
| Electronics, for control units {GLO}\| market for | 0.003 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| HDPE, granulate {GLO}\| market for | 0.0475 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| LDPE, linear, granulate {GLO}\| market for | 0.0476 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| Zinc coat, coils {GLO}\| market for | 0.0185 | kg | (2) | 1 | 5 | 3 | 3 | 3 |
| Concrete block {GLO}\| market for | 0.72 | kg | (1, 3) | 1 | 5 | 3 | 3 | 3 |

Table footnotes:

1. Montero et al., 2011. Assuming duration of 15 years.
2. EcoInvent Greenhouse, glass walls and roof {FR}| greenhouse construction, glass walls and roof, metal tubes (inputs contributing less than 1% to the most relevant impact categories are excluded from the table).
3. Assuming a density of 2,400 kg/$m^3$.

## 4.2 Data collection procedures

The organisation Benefits of Nature had collected typical data from three companies representing tissue cultivation, young plants cultivation and large plants cultivation for prior advisory work for these companies, using a standardised Excel sheet. In this sheet, the amount of used materials (e.g., substrate, pots, fertilisers, crop protection), energy and water usage, production figures, CHP-data and product compositions are filled in. Additional information not used for original advice (e.g. capital goods) were gathered separately from existing literature, LCI databases and own assumptions. The sources and the treatment of data gaps are described in the following sections.

## 4.3 Methodological assumptions used in the representative product study

### 4.3.1 Linking usage data to background (EcoInvent processes) datasets

For materials, a relevant global average, 'market for'-reference is preferably used. As the supply chains are mostly comprised of multiple links, the origin of the material is mostly unknown. If a direct match between database and material is not found, a proxy is used. This is for instance the case for many chemicals, where the specific substance is not available in the database and a reference for the compound type is used instead. For energy, the most relevant local, regional or country-specific reference is used.

A longlist of usage data and links to background data was available from Benefits of Nature, consisting of 68 and 96 items for the Young Plant and Large Plant stages respectively. The worst case impact cut-off approach was applied to limit the data entry burden and to exclude data that does not inform the data quality needs.

### 4.3.2 Direct emissions from decomposing biomass

Both substrate and the plant itself decompose during its life cycle and cause emissions. Peat, bark and coconut fibre usages were tracked with the Benefits of Nature company dataset for both the Young Plant and the Large plant stage. Plant mass itself was derived from Paradiso et al (2012). Losses of the plants of 6.6% occur in the Large Plant cultivation stage according to the Benefits of Nature dataset. The following approach was taken to calculate emissions resulting from decomposition:

- It is assumed that 100% of the carbon (PAS2050-1) and the nitrogen (extrapolation) present in the substrate and the plant is mineralised during the life cycle. 2% of the mineralised nitrogen becomes $N_2O$ (Blonk et al., 2009).
- Emissions during cultivation result from 1% peat oxidation per week (PAS2050-1). It was assumed non-fossil substrate oxidises with the same rate, and that the plant does not decompose.
- The remaining mineralisation was allocated to the use stage.
- Because all carbon and $N_2O$ emissions have been accounted for in the life cycle stages before waste processing, the linked biowaste treatment process was adjusted by setting all emissions containing carbon and the $N_2O$ emission to zero.
- The required data were taken from the following sources:
  - The density (378 g/L), carbon content (0.423 g C/g WM), nitrogen content (0.022 g N/g WM) of peat were taken from Blonk et al. (2009).
  - The carbon content (0.5 g C/g DM) for other substrate types and for phalaenopsis was assumed based on expert judgment from the tomato screening study. The dry matter content (0.4 g DM/g WM) for these biomass types was based on the default EcoInvent process for biowaste composting. This results in a wet mass carbon content of 0.2 g C/g WM. The nitrogen content was extrapolated from Blonk et al. (2009)
  - The Young Plant stage and the Large Plant stage take 30 and 40 weeks respectively, according to the Benefits of Nature dataset.

Some mineralisation occurs during the biowaste treatment and probably during the following life cycle, but no assumptions on the distribution could be derived from literature and a total of 100% mineralisation is a reasonable worst case assumption. It furthermore writes off the fossil carbon storage within the first life cycle of peat, so that the secondary peat content of compost used in following life cycles does not need to be tracked.

### 4.3.3 Direct emissions of C, N and P from fertilisers

A PEFCR Guidance (Zampori and Pant, 2019) compliant approach was followed:

- Usage of all fertilisers was collected in g per reference flow for the cultivation stage
- The usages are converted to use of elementary N and P and summed and amounts included in harvested product were subtracted from these total loads.
- $NH_3$ emission to air, $NO_3$ emission to water, $N_2O$ emission to air and Phosphate to water are calculated from the total loads compliant with the PEF guide: the $NO_3$ emission is the balance of N application and losses to $NH_3$, $N_2O$, $N_2$.
- In addition, $CO_2$ emissions from urea application are calculated and included as fossil emissions.

This approach is quite inaccurate and conservative because water emissions are usually collected as excess irrigation water and fed back into the fertigation system. A certain share of the water is purified and emitted to the surface water once the salinity of the recirculated water becomes too high.

### 4.3.4 Including Plant Protection Products in LCA

None of the plant protection products (PPPs) were included in raw materials usage because of the worst case impact cut-off approach described in 3.2 System Boundaries. A preliminary approach was followed to test if active ingredients and other products in the crop protection product contribute to toxicity impacts:

- Total usages for Young Plant and for Large Plant stage were taken from separate data file from Benefits of Nature’s company datasets. Each use is reported in the list for all components of the product, not only active substance, so that all components are known for each formulation.

- From all chemical-based PPPs, the use of the active ingredient was included as emissions.
- The most used substances present in the formulations (in addition to the active ingredient) were selected for inclusion:
  - Water, mineral salts, simple organic substances were excluded based on their low toxicity.
  - Components with a of more than 0.5% of the use of the largest component were included.
  - Common additives like ethanol and cyclohexanol were included in order to test sensitivity of toxicity to such co-formulants

The emissions of active ingredients and most used substances were entered as a distribution over air, water, soil according to the PEFCR guidance recommendation of 1% to air, 9% to water, 90% to soil. Either the substance itself or a proxy based on molecular structure was included, provided that it could be characterised with the USETOX characterisation factor set of the EF characterisation method.

### 4.3.5 Other assumptions

Other assumptions used in this study are the following:

- Carbon storage: corrections were applied for carbon storage in the product or materials used in the life cycle, such as (secondary) packaging containing wood. The methods to do so are not very accurate, because EcoInvent does not have waste treatment processes for all ingoing raw materials. Furthermore, some estimations about the mass and carbon content of the product itself and of the wooden pallet generate uncertainty. Consequentially, the calculation of the biogenic carbon balance is not complete, while it is certain that all carbon sequestered during this life cycle is released again during this life cycle.
- Land use change: no land use change is associated with horticultural production in the Netherlands. The starting material from tissue culture occurs in Germany in a laboratory (without land use change).
- Transports: all transport of the product and inputs were included with estimates, and assumptions from the retail OEFSR
- Treatment of multi-functionality (allocation): energy allocation to heat and electricity was applied. Details are explained in the PEFCR on horticultural products.
- Re-use (if appropriate): the pallet for transportation of cultivation inputs was assumed to be reused 20 times.

# 5 PEF impact assessment results

## 5.1 Most relevant life cycle impact categories

The most relevant life cycle impact categories for Phalaenopsis are: Climate change; Resource use, energy carriers; Resource use, mineral and metals, Acidification terrestrial and freshwater (Figure 5.1). These contribute cumulatively to more than 80% of the total environmental impact. These impact categories will be reported in detail. Although ecotoxicity freshwater is not included in the weighted results, this category is selected as relevant due to the perceived importance of the environmental impact of pesticides.

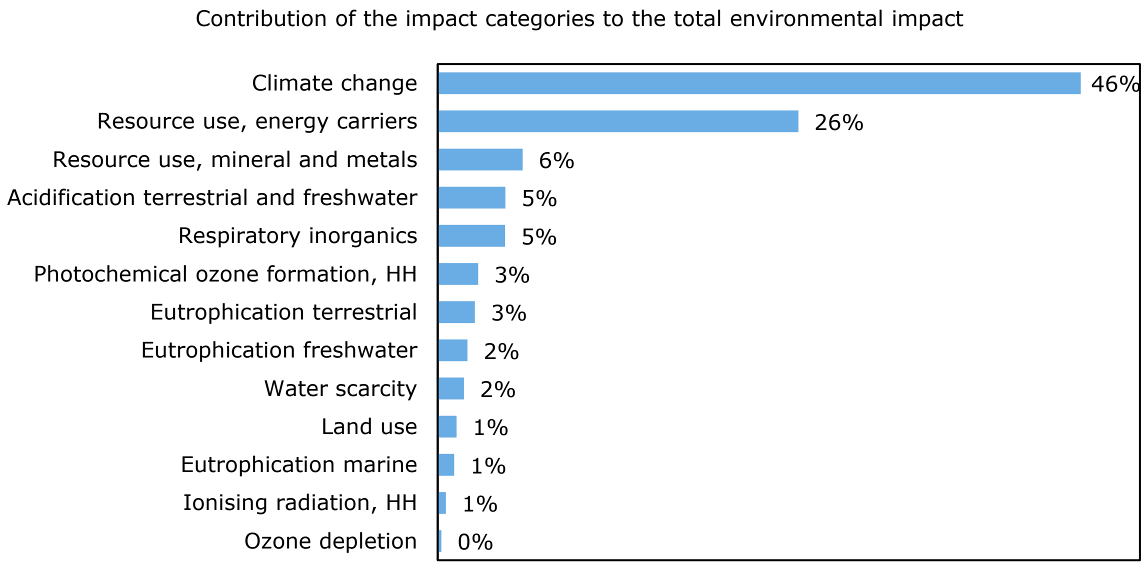
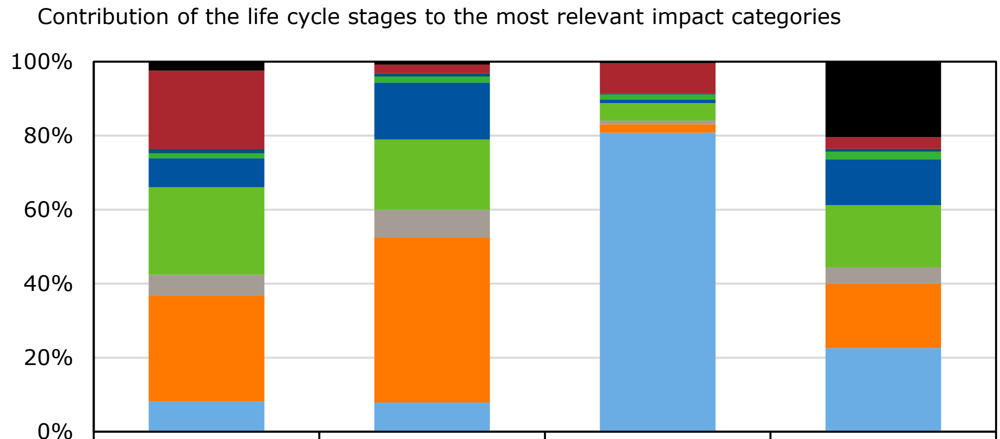



***Figure 5.1*** *Contribution of the life cycle impact categories to the normalised and weighted impact of Phalaenopsis*

## 5.2 Most relevant life cycle stages




| | Climate change | Resource use, energy carriers | Resource use, mineral and metals | Acidification terrestrial and freshwater |
|---|---|---|---|---|
| End of Life | 2% | 1% | 0% | 20% |
| Use | 21% | 2% | 8% | 3% |
| Retail | 1,2% | 1% | 0% | 1% |
| Distribution | 1% | 2% | 1% | 2% |
| Packaging | 7,9% | 15% | 1% | 12% |
| Cultivation | 24% | 19% | 5% | 17% |
| Carbon Dioxide | 6% | 7% | 1% | 4% |
| Energy | 29% | 45% | 2% | 17% |
| Capital Goods | 8% | 8% | 81% | 23% |

***Figure 5.2*** *Contribution of the life cycle stages of Phalaenopsis plant to the relevant impact categories*

Figure 5.2 shows the contribution of the Phalaenopsis life cycle stages to the relevant impact categories. Contributions from individual processes are shown in Table 5.1. We observe that the most relevant (contributing cumulatively to 80% of one of the most relevant environmental impact categories) life cycle stage of Phalaenopsis are capital goods, energy, cultivation, packaging and end of life. For resource use, minerals, only capital goods are relevant.

***Table 5.1*** *Contribution of the most relevant processes and life cycle stages to the most relevant impact categories of Phalaenopsis, as well as ecotoxicity*

| | Climate change | Resource - energy | Resource - minerals | Acidification | Ecotoxicity | LC Stage |
|---|---|---|---|---|---|---|
| Emissions during use | 19% | - | - | - | - | Use |
| Heat from CHP | 18% | - | - | 7% | - | Energy |
| Emissions during cultivation | 9% | - | - | - | - | Cultivation |
| Electricity from grid, low voltage | 6% | 7% | - | 5% | 2% | Retail, Distribution |
| Polypropylene | 5% | 14% | - | 7% | 5% | Cultivation |
| Peat substrate | 5% | 5% | - | - | - | Cultivation |
| Polystyrene | 4% | 8% | - | 6% | 4% | Cultivation |
| Natural gas production | 3% | 37% | - | 5% | - | Energy |
| Electricity from grid, medium voltage | 3% | 4% | - | 3% | - | Cultivation |
| Deep well | 2% | 2% | - | 5% | 6% | Energy |
| Transport with car by user | 2% | 2% | 8% | 3% | 10% | Use |
| Heat from boiler | 2% | 2% | - | - | - | Energy |
| Plastic waste processing | 2% | - | - | - | 5% | Cultivation |
| Zinc coat in greenhouse | - | - | 33% | 3% | - | Capital Goods |

| | Climate change | Resource - energy | Resource - minerals | Acidification | Ecotoxicity | LC Stage |
|---|---|---|---|---|---|---|
| Aluminium in greenhouse | - | - | 22% | 3% | 3% | Capital Goods |
| Electronics in greenhouse | - | - | 12% | - | - | Capital Goods |
| Steel in greenhouse | - | - | 6% | 3% | 12% | Capital Goods |
| Biowaste treatment | - | - | - | 19% | - | Cultivation, End of Life |
| Glass in greenhouse | - | - | - | 4% | - | Capital Goods |
| Thermoforming plastic | - | - | - | 3% | - | Cultivation |
| Transport in lorry, EURO5, Global | - | - | - | 2% | 9% | Distribution |
| Moulding plastic | - | - | - | 2% | - | Cultivation |
| Municipal waste treatment | - | - | - | - | 14% | End of Life |
| Coconut fiber | - | - | - | - | 5% | Cultivation |
| Chromium steel in greenhouse | - | - | - | - | 2% | Capital Goods |
| Ethanol | - | - | - | - | 2% | Cultivation |
| Carbon Dioxide fertilisation | - | - | - | - | 2% | Cultivation |
| Remaining processes | 19% | 19% | 18% | 20% | 19% | |

***Table 5.2*** *Contribution of the most relevant elementary flows to the most relevant impact categories*

| | Climate change | Resource - energy | Resource - minerals | Acidification | Ecotoxicity |
|---|---|---|---|---|---|
| Carbon dioxide, fossil | 87% | - | - | - | - |
| Gas, natural/m$^3$ | - | 55% | - | - | - |
| Oil, crude | - | 22% | - | - | - |
| Coal, hard | - | 11% | - | - | - |
| Cadmium | - | - | 34% | - | - |
| Lead | - | - | 23% | - | - |
| Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In | - | - | 6% | - | - |
| Chromium | - | - | 5% | - | - |
| Zinc | - | - | 4% | - | - |
| Gold, Au 6.7E-4%, in ore | - | - | 4% | - | - |
| Gold | - | - | 4% | - | - |
| Gold, Au 4.9E-5%, in ore | - | - | 3% | - | - |
| Sulfur dioxide | - | - | - | 42% | - |
| Ammonia | - | - | - | 29% | - |
| Nitrogen oxides | - | - | - | 29% | - |
| Antimony, to Water | - | - | - | - | 31% |
| Chromium VI, to Water | - | - | - | - | 17% |
| Antimony, to Air | - | - | - | - | 10% |
| Chromium, to Air | - | - | - | - | 5% |
| Zinc, to Water | - | - | - | - | 5% |
| Zinc, to Air | - | - | - | - | 4% |
| Zinc, to Soil | - | - | - | - | 3% |
| Pyrene, to Water | - | - | - | - | 3% |
| Copper, to Air | - | - | - | - | 2% |
| Arsenic, to Water | - | - | - | - | 2% |
| Remaining substances | 13% | 12% | 18% | 0% | 17% |

## 5.3 Impact indicator results of Phalaenopsis

Table 5.3 shows the impact indicator results of Phalaenopsis.

***Table 5.3*** *Impact indicator results*

| Midpoint indicator | Unit | Total |
|---|---|---|
| Climate change | kg $CO_2$ eq | 1.59E+00 |
| Ozone depletion | kg CFC11 eq | 9.02E-08 |
| Ionising radiation, HH | kBq U-235 eq | 4.52E-02 |
| Photochemical ozone formation, HH | kg NMVOC eq | 2.27E-03 |
| Respiratory inorganics | disease inc. | 3.17E-08 |
| Non-cancer human health effects | CTUh | 7.88E-08 |
| Cancer human health effects | CTUh | 1.70E-08 |
| Acidification terrestrial and freshwater | mol H+ eq | 3.99E-03 |
| Eutrophication freshwater | kg P eq | 1.82E-04 |
| Eutrophication marine | kg N eq | 1.06E-03 |
| Eutrophication terrestrial | mol N eq | 1.19E-02 |
| Ecotoxicity freshwater | CTUe | 6.75E-01 |
| Land use | Pt | 2.11E+01 |
| Water scarcity | $m^3$ depriv. | 2.34E-01 |
| Resource use, energy carriers | MJ | 1.86E+01 |
| Resource use, mineral and metals | kg Sb eq | 4.29E-06 |
| Climate change - fossil | kg $CO_2$ eq | 1.58E+00 |
| Climate change - biogenic | kg $CO_2$ eq | 0.00E+00 |
| Climate change - land use and transform. | kg $CO_2$ eq | 1.35E-03 |

## 5.4 Most relevant processes and elementary flows of Phalaenopsis

In the following sections, the detailed results are shown for the contributions of individual life cycle stages and substage to the most relevant impact categories, as shown in 5.1.

### 5.4.1 Climate change

Figure 5.3 shows the relevant processes that contribute to at least 80% of the climate change impact of 1 phalaenopsis plant. The total impact is 1.38 kg $CO_2$eq/phalaenopsis plant.

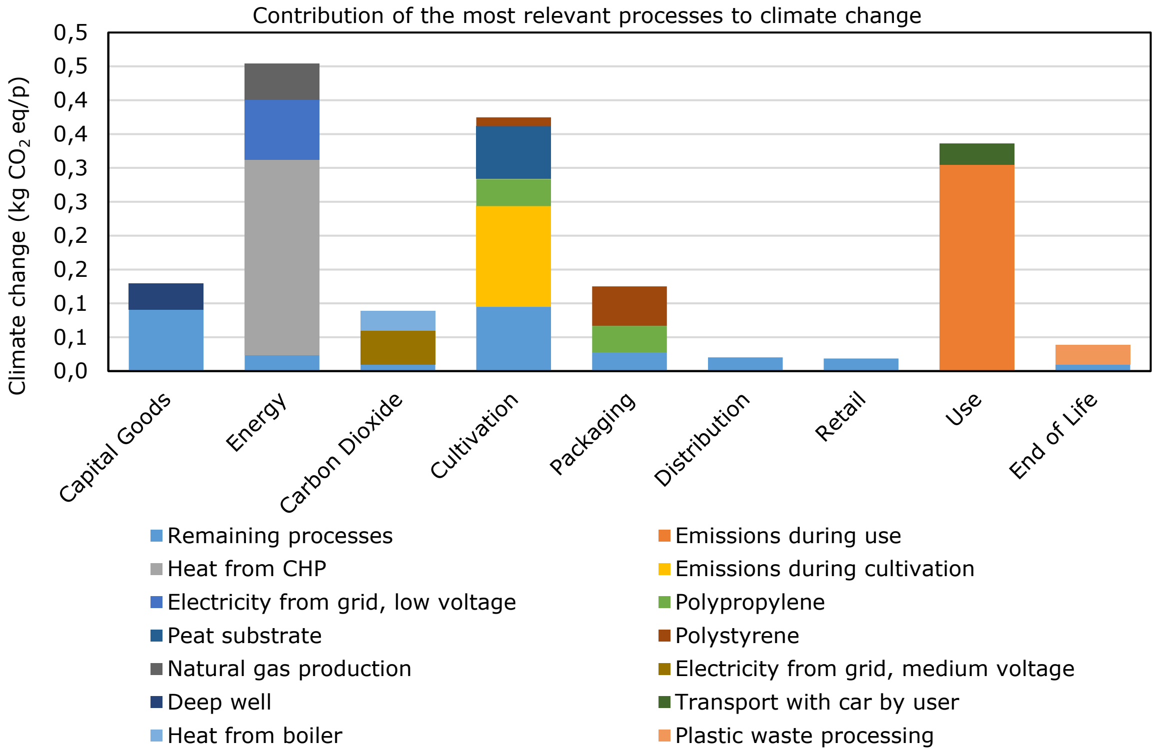



***Figure 5.3*** *Climate change impact in kg $CO_2$eq per phalaenopsis plant per life cycle stage and relevant process*

Figure 5.4 shows the relevant elementary flows that contribute to at least 80% of the climate change impact of 1 phalaenopsis plant.

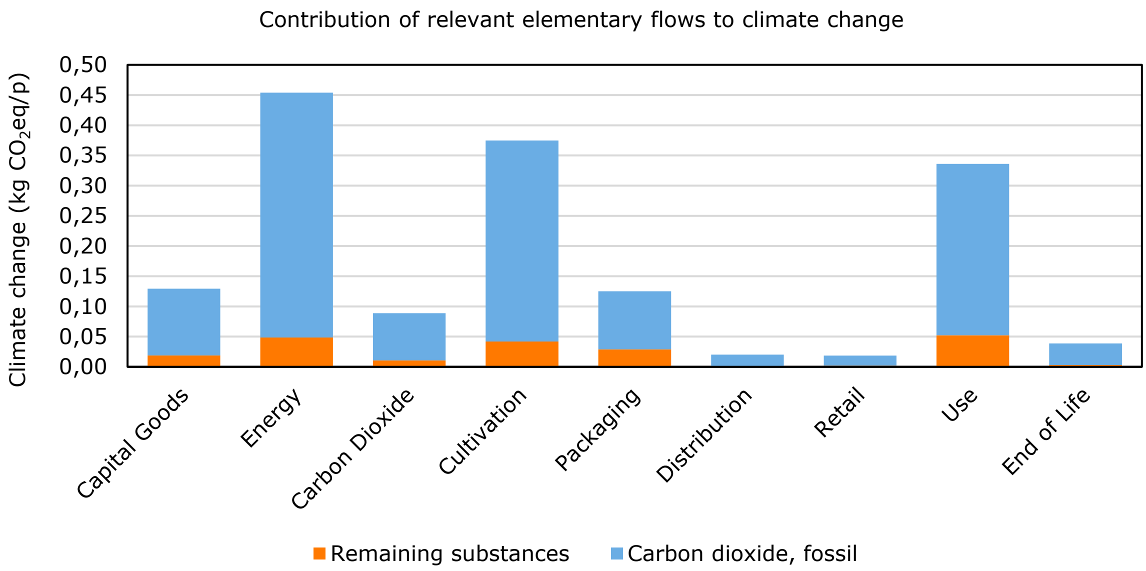



***Figure 5.4*** *Climate change impact in kg $CO_2$eq per phalaenopsis plant per life cycle stage and relevant elementary flows*

### 5.4.2 Resource use, energy carriers

Figure 5.5 shows the relevant processes that contribute to at least 80% of the resource use, energy carriers impact of 1 phalaenopsis plant. The total impact is 18.2 MJ/phalaenopsis plant. In particular energy (heating and electricity in cultivation stage) has a large contribution.

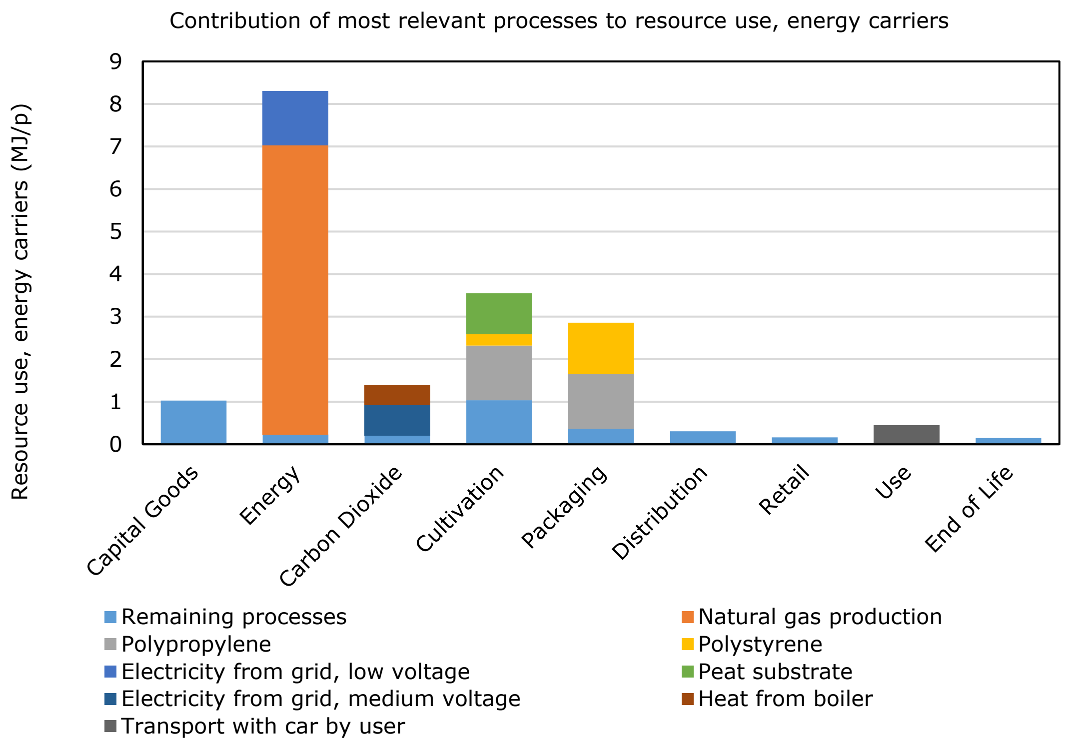



***Figure 5.5*** *Resource use, energy carriers impact in MJ per Phalaenopsis plant per life cycle stage and relevant process*

Figure 5.6 shows the relevant elementary flows that contribute to at least 80% of the resource use, energy carriers impact of 1 Phalaenopsis plant.

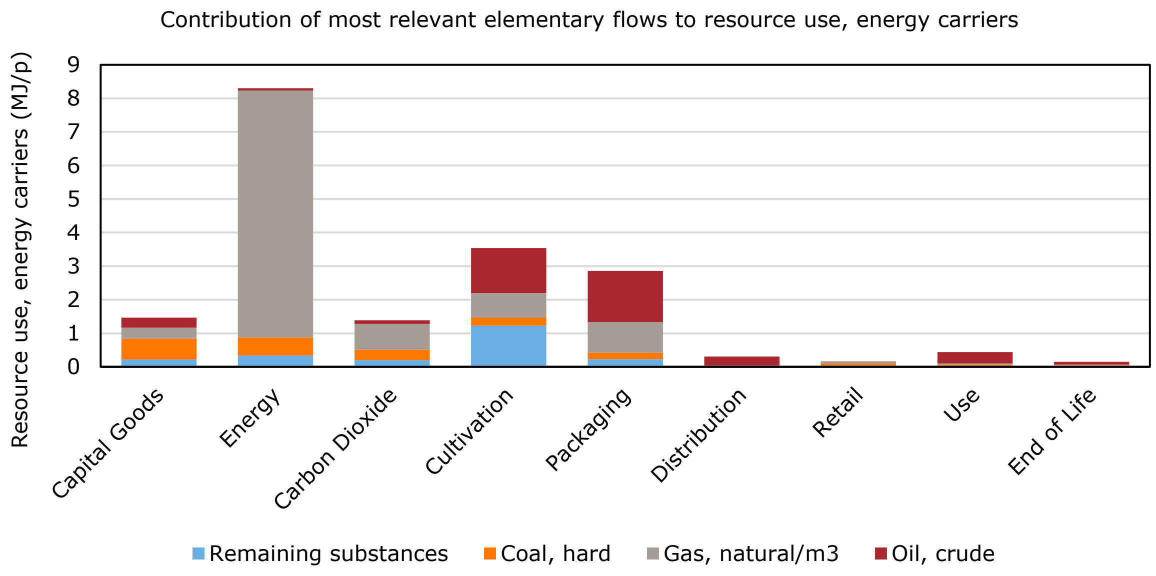



***Figure 5.6*** *Resource use, energy carriers impact in kg MJ per phalaenopsis plant per life cycle stage and relevant elementary flows*

### 5.4.3 Resource use, minerals and metals

Figure 5.7 shows the relevant processes that contribute to at least 80% of the resource use, minerals and metals impact of 1 phalaenopsis plant. The total impact is 3.9E-6 kg Sb eq/phalaenopsis plant. Capital goods has a large contribution to resource use, minerals and metals.

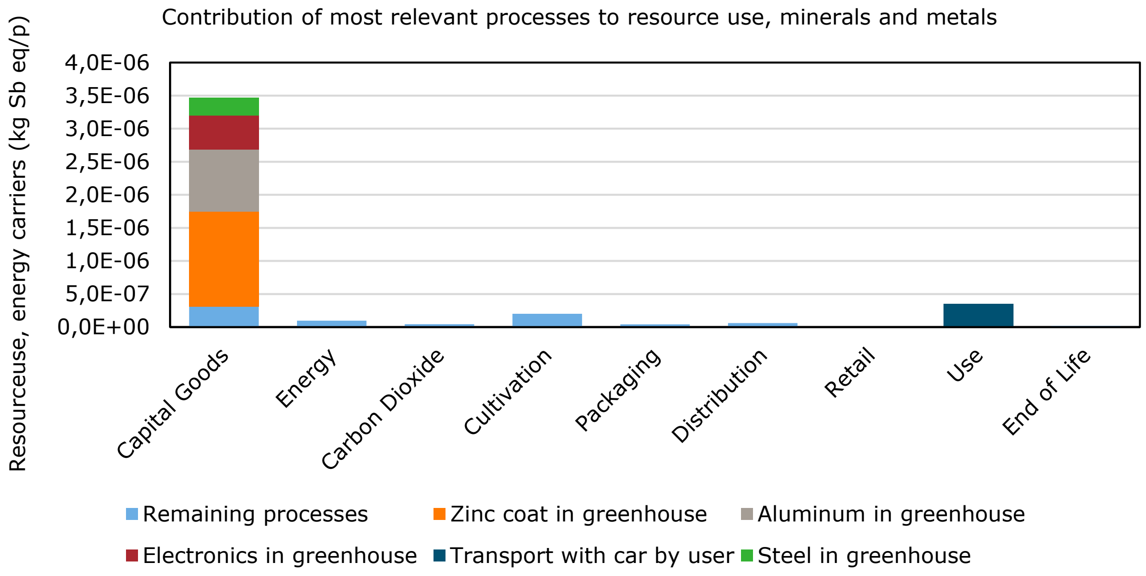



***Figure 5.7*** *Resource use, minerals and metals impact in kg Sb eq per phalaenopsis plant per life cycle stage and relevant process*

Figure 5.8 shows the relevant elementary flows that contribute to at least 80% of the resource use, minerals and metals impact of 1 phalaenopsis plant.

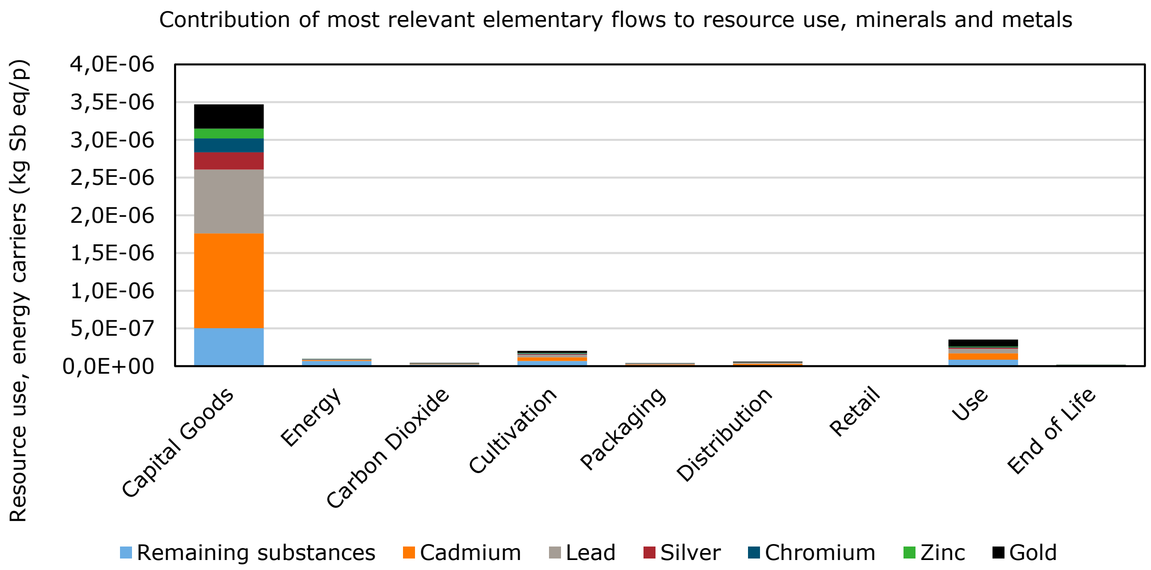



***Figure 5.8*** *Resource use, minerals and metals impact in kg Sb eq per phalaenopsis plant per life cycle stage and relevant elementary flows*

### 5.4.4 Acidification terrestrial and freshwater

Figure 5.9 shows the relevant processes that contribute to at least 80% of the acidification terrestrial and freshwater impact of 1 phalaenopsis plant. The total impact is 0.0039 mol H+ eq/phalaenopsis plant.

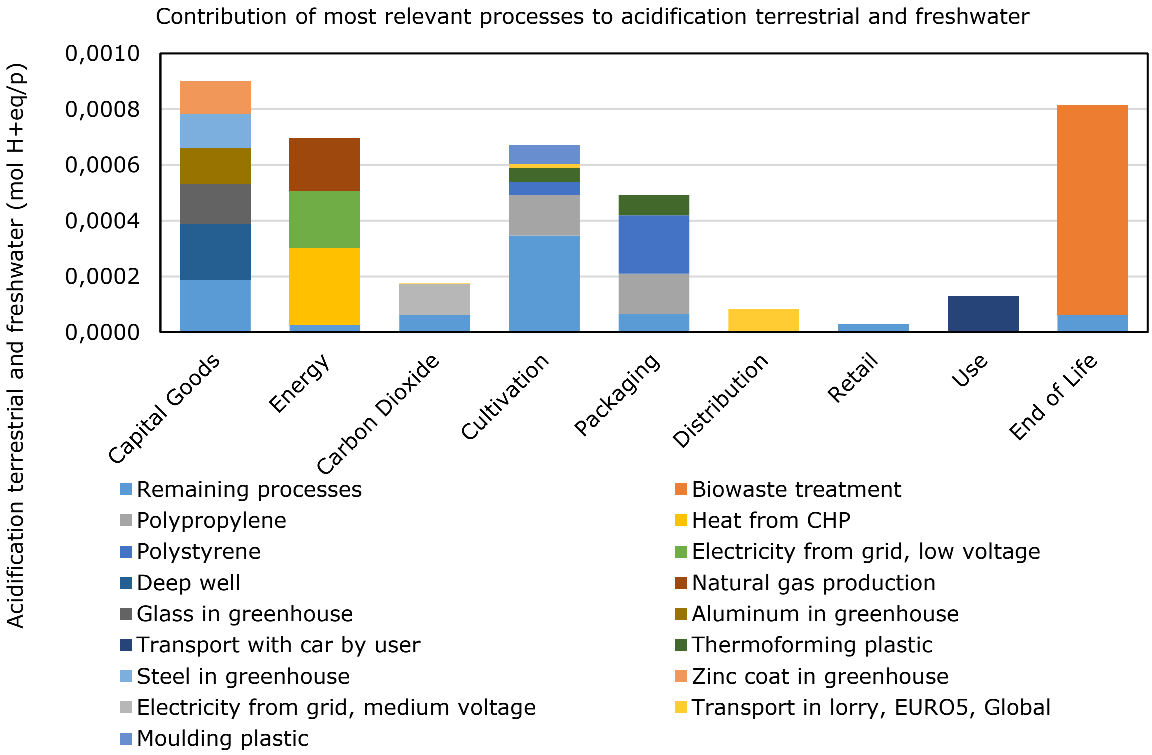



***Figure 5.9*** *Acidification terrestrial and freshwater impact in mol H+ eq per phalaenopsis plant per life cycle stage and relevant process*

Figure 5.10 shows the relevant elementary flows that contribute to at least 80% of the acidification terrestrial and freshwater impact of 1 phalaenopsis plant.

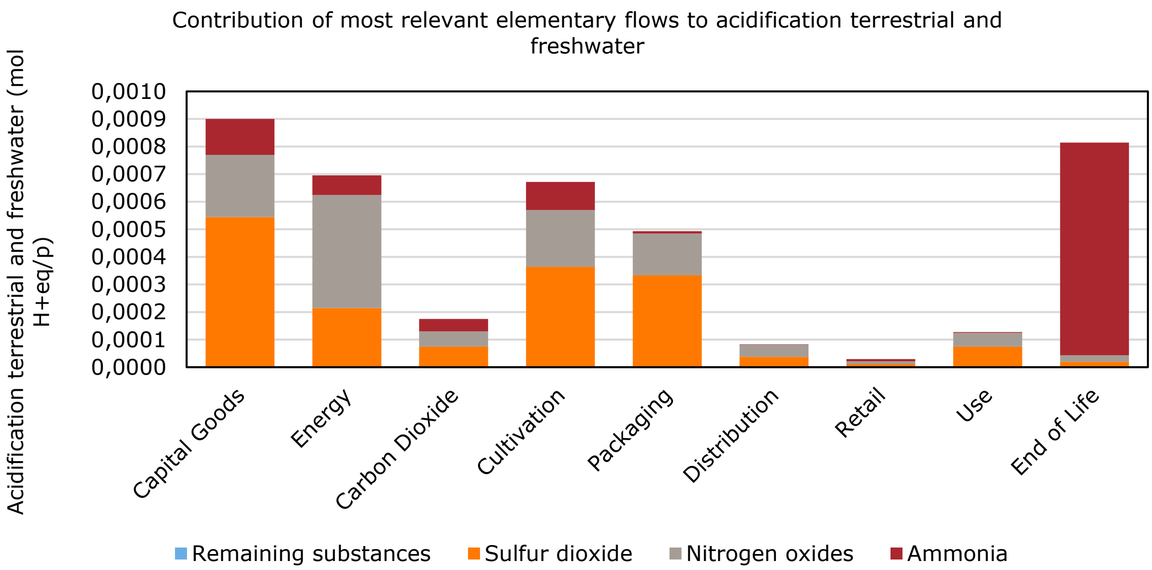



***Figure 5.10*** *Acidification terrestrial and freshwater impact in mol H+ eq per phalaenopsis plant per life cycle stage and relevant elementary flows*

### 5.4.5 Ecotoxicity freshwater

Figure 5.11 shows the relevant processes that contribute to at least 80% of the ecotoxicity freshwater impact of 1 phalaenopsis plant. The total impact is 0.60 CTUe/phalaenopsis plant.

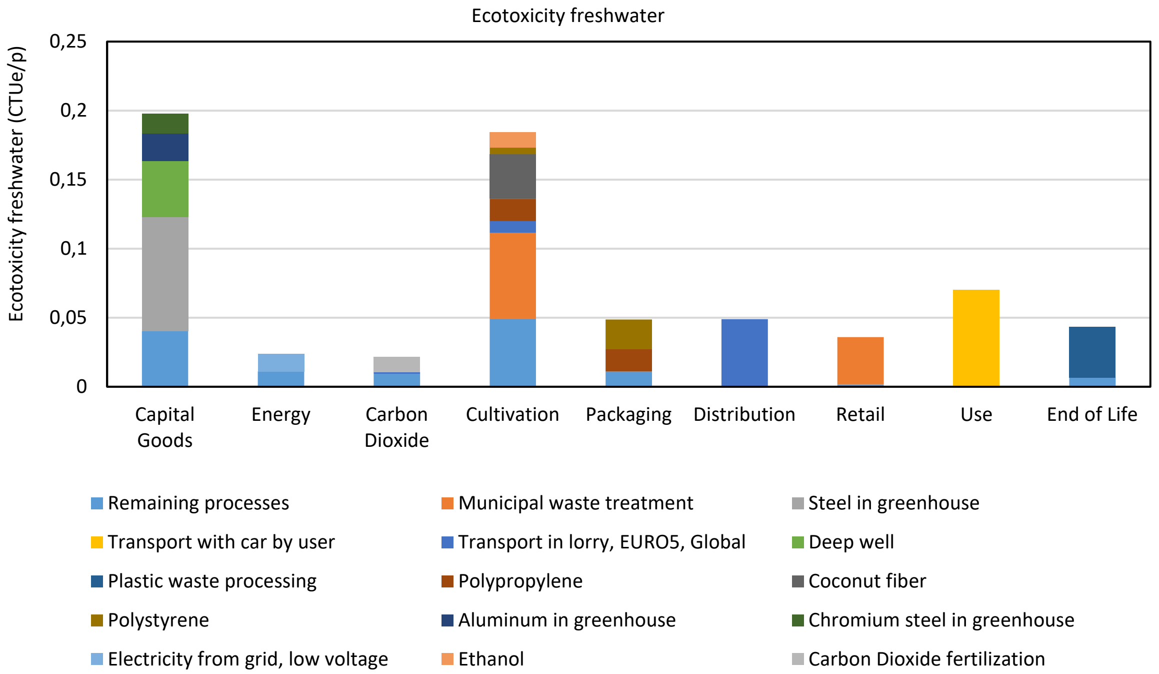



***Figure 5.11*** *Freshwater ecotoxicity impact in CTUe per Phalaenopsis plant per life cycle stage and relevant process*

Figure 5.12 shows the relevant elementary flows that contribute to at least 80% of the ecotoxicity freshwater impact of 1 Phalaenopsis plant.

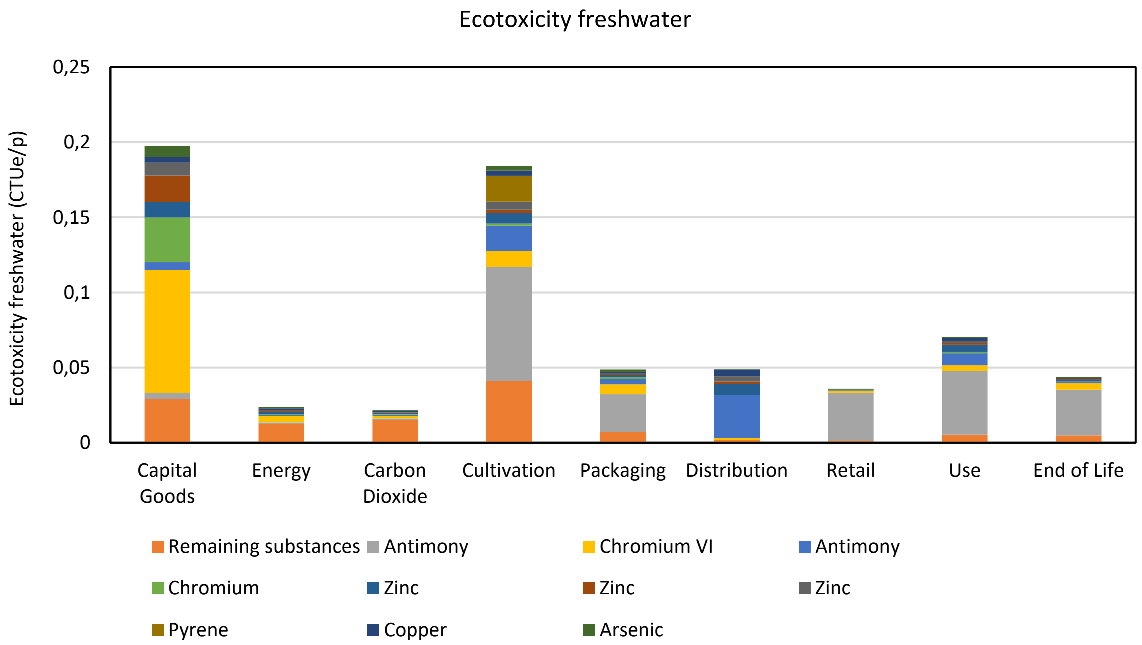



***Figure 5.12*** *Ecotoxicity freshwater impact in CTUe per Phalaenopsis plant per life cycle stage and relevant elementary flows*

# 6 Interpretation

## 6.1 Uncertainties in the most relevant impacts

### 6.1.1 Climate change

Most contributions to the climate change indicator have a high certainty and these add up to 72% of the indicator value, with heat, gas, electricity and plastics used for cultivation as the largest contributors. The grower has control over these processes and the underlying models in the databases are relatively good. The efficiencies of electricity and heat production in the CHP system, the lifetime of the geothermal heat production capital goods, and the input data for producing purified carbon dioxide contribute to some degree of uncertainty for this part.

A significant share of the climate change indicator (28%) has a significant uncertainty because it is due to mineralisation of peat substrate. The PAS2050-1 guidance used for calculating the emissions leaves room for different interpretation, especially on when in the life cycle stage mineralisation occurs. The choice to allocate 100% of the mineralisation to the first life cycle in which the peat is used is sensitive to stakeholder discussion. The data from Blonk et al. (2009) may be a source of uncertainty as well.

### 6.1.2 Resource use, energy carriers

The indicator on 'resource use, energy carriers' has a high certainty because it is determined by primary data on heat and electricity consumption and fossil resources for plastics. The energy resource use of peat production is not considered a relevant resource flow, because of its contribution of 5%. It could be assessed and may be improved in order to improve certainty.

### 6.1.3 Resource use, minerals and metals

The indicator on 'resource use, minerals and metals' results are highly sensitive to the material use for the capital goods for cultivation, and the assumption on the technical lifetime of the greenhouse structure. The variation in greenhouse construction and the extent of control the grower has over its capital goods should be revisited in order to improve certainty.

### 6.1.4 Acidification terrestrial and freshwater

The indicator on 'acidification terrestrial and freshwater' is sensitive to the assumptions on acidifying emissions from capital goods and energy production, emissions during biowaste treatment and the production of plastics for cultivation and packaging. The related elementary flow data of background database are regarded as reasonably certain except for biowaste treatment. The database values used for this process should be assessed and may be improved in order to improve certainty.

## 6.2 Plant protection products and ecotoxicity in freshwater

The ecotoxicity freshwater indicator results are most strongly influenced by the metal emissions in the background database, and to the assumptions on the greenhouse structure lifetime. Antimony emissions from municipal waste treatment from cultivation and retail are contributing as well. The active ingredients from PPPs together have a small contribution (0.7%). The PPPs involved in the background process on ethanol production through sugar cultivation contribute another 0.8% to the freshwater toxicity impact. Plant protection products do not seem to contribute significantly to freshwater ecotoxicity in the case of phalaenopsis production.

In the case of greenhouse cultivation, and because of the exclusion of substance properties or PPP application properties in the PEFCR Guidance or in the background database, the distribution of PPP applications over environmental compartment is highly uncertain. The characterisation model USETOX and the selection of proxies for some PPPs is an additional source of uncertainty. These large uncertainties in pesticide modelling (both in primary and secondary data) do not likely contribute to overall uncertainty in the freshwater ecotoxicity indicator.

## 6.3 Other uncertainties

Several uncertainties or inconsistencies have no major consequences on the most important impact categories. Direct emissions from fertiliser application are uncertain but do not contribute to overall uncertainty in indicators for which P and N emissions are relevant. If all P emissions are emitted to the environmental compartment soil, instead of to the substrate, their contribution to freshwater eutrophication would be 1,000 times smaller than the total impact. Furthermore, the cut-off approach of EcoInvent was followed regarding waste treatment, and not the Circular Footprint Formula. It is assumed that the avoided impact of using the compost and the part of the impact of processing the biowaste that is allocated to the next life cycle more or less compensate each other. The additional uncertainties in biomass decomposition modelling for the plant itself and for substrate components other than peat do not influence the most important impact categories.

# 7 Conclusion

This RP study is part of the development of a PEFCR for horticultural products. It is not intended to make statements about the impact of Phalaenopsis plants grown in Dutch heated greenhouses. The aim is to identify the hotspots (most relevant impact categories, life cycle stages, processes and elementary flows) and the data quality requirements for future PEFCR compliant studies.

## 7.1 Most relevant impact categories and life cycle stages

The most relevant life cycle impact categories based on weighted results are (as shown in Figure 5.1):
- Climate change
- Resource use, energy carriers
- Resource use, mineral and metals
- Acidification terrestrial and freshwater.

Ecotoxicity freshwater was not included in the weighted results, but is considered relevant due to the perceived importance of the environmental impact of pesticides.

The most relevant life cycle stages of the studied Phalaenopsis are (as shown in Figure 5.2):
- capital goods
- energy production
- cultivation
- packaging
- use, and
- end of life.

## 7.2 Most relevant processes

The most relevant processes and most relevant elementary flows is shown in Table 5.1 and Table 5.2. Each process or elementary flow listed contributes to the total of 80% to the impact of one or more impact categories.

## 7.3 Overall appreciation of the uncertainties of the results

The uncertainty of the results is due to different factors depending on the impact category. A large part of the uncertainty is caused by the quality of the background databases. There are also several important parameters in the foreground data which have been estimated based on various sources, which may not be representative or accurate, specifically considering peat production and peat mineralisation. It needs to be critically reviewed if these will be used as defaults in case no accurate activity data are available. Furthermore, a lot of primary data was collected for this study which can be replaced with secondary data within the cultivation stage as long as the most impactful processes within that stage are modelled with a sufficient data quality. For the purpose of the current study, all assumptions and data estimations are considered adequate.

## 7.4 Sensitivity analysis

When the allocation to heat and electricity of the grower's CHP system would be based on exergy rather than energy, the climate change and resource use, energy carriers impact indicators would be about 40-50% lower. The acidification terrestrial and freshwater indicator would be about significantly lower as well. So, this choice has a very significant effect on the results. Exergy allocation is not recommended as discussed in this report and in the draft PEFCR for horticultural products. Nevertheless, the EcoInvent database applies exergy allocation. If CHP processes from EcoInvent would be adjusted according to the current recommendation, the impact of heat from CHP from EcoInvent will increase significantly and the impact of electricity from CHP will decrease significantly, depending on how much of the heat can be utilised. It is recommended to pursue consistency between the recommendations between background databases and calculations using primary data in the long run.

## 7.5 Data quality requirements

This study aimed at identifying the data collection and data quality requirements to ensure robust and high-quality results for similar horticultural products. The requirements determined on the basis of this study are displayed in Table 7.1.

The results are compliant to the Data Needs Matrix from the PEFCR Guidance. The basic requirements are that DQR is lower or equal to 1.6, implying good data is collected, for processes that are in the grower's control and for processes that contribute to the most relevant life cycle impact categories.

For the cultivation stage, the DQR of the overall life cycle stage cannot be determined, since the stage is modelled as multiple processes. The cultivation activities (Table 4.1), including energy and heat use, has a DQR of 1.6. It should be decided which data quality the CHP processes modelling providing heat and electricity needs to have, since it indirectly determines most environmental impacts, especially the most relevant. It should also be critically assessed which data items should be reliable within the cultivation life cycle stage and which can have a lower reliability, in order to limit data collection burden. For tracking the individual fertilisers applied and linking pesticide active ingredients to their production impacts does not show up in the results. The crop protection process (Table 4.2) has a DQR of 2 – 2.25; if freshwater toxicity (or other toxicity categories) would be selected as a relevant environmental impact, their data quality should be improved to 1.6.

***Table 7.1*** *Data quality requirements (DQR) for the different life cycle stages for Phalaenopsis*

| Life cycle stage | Data collection needs | Required data quality rating score) |
|---|---|---|
| Cultivation | Amounts of inputs and elementary flows | ≤1.6: Very good to excellent quality |
| Post-harvest handling | No post-harvest handling | Not applicable |
| Packaging | Generic data allowed | ≤1.6: Very good to excellent quality |
| Distribution | Amounts of main materials | ≤3.0: Good quality[1] |
| Storage | Distance and mode | ≤3.0: Good quality |
| Retail | Generic data allowed | ≤3.0: Good quality |
| Use | Generic data allowed | ≤3.0: Good quality[2] |
| End of life | Percentages and types of waste treatment, generic data allowed | ≤3.0: Good quality[3] |
| Inputs of the processes above and waste treatment processes | Generic data allowed | ≤3.0: Good quality |

Notes:

1 The variation in distance and transport mode need to be reviewed.

2 Because peat is a fossil material causing fossil CO2 emissions, the share of mineralisation of peat should be set as a default generic value of high data quality.

3 For the same reason as footnote 2, the carbon emissions from biowaste treatment should be set as a default generic value of high data quality.

# 8 Disclaimer

The RP study is NOT intended to make statements about the product group impacts as such, nor is it intended to be used in the context of comparison or for comparative assertions to be disclosed to the public. The results can be used to see where potential hotspots are by looking at the most relevant impact categories, life cycle stages, processes and elementary flows.

In practice, there is a clear variety in Dutch greenhouse Phalaenopsis production with respect to how energy is produced, and what sources of energy and purified carbon dioxide are, and in what quantities they are used. In many cases like the current case, a mix of different sources is used and the quantities will vary year by year due to weather conditions and economic developments. The absolute results of the current case cannot be regarded as representative of the large variety in practice, but the general conclusions on the hotspots and the resulting data quality requirements will apply to Dutch heated and protected Phalaenopsis production in general.

# 9 Acknowledgements

This study was carried out in the framework of the public-private partnership project HortiFootprint ‘Methodology for environmental footprint TU17005’ for Topsector Agri & Food, as part of the programme ‘Consumer, Market and Society’. The authors would like to thank the Product Commission Group for Potted Orchids and Piet Briët from Royal FloraHolland for insightful discussion of the results in December 2018, and Marc Ruijs from Wageningen Economic Research for his review.

# References and websites


Agri-footprint 4 (2018a). Agri-footprint 4.0. Part 1: Methodology and basic principles. https://www.agri-footprint.com/wp-content/uploads/2018/03/Agri-Footprint-4.0-Part-1-Methodology-and-basic-principles-2018.pdf

Agri-footprint 4 (2018b). Agri-footprint 4.0. Part 2: Description of data. https://www.agri-footprint.com/wp-content/uploads/2018/03/Agri-Footprint-4.0-Part-2-Description-of-data-2018.pdf

ASABE (2011). ASAE D497.7 MAR 2011 Agricultural machinery management data. American Society of Agricultural and Biological Engineers, St. Joseph, Michigan

Corstanje, R., G.J.D. Kirk, M. Pawlett, R. Read, R.M. Lark (2008). Spatial variation of ammonia volatilization from soil and its scale-dependent correlation with soil properties. Eur J Soil Sci 59:1260–1270. doi: 10.1111/j.1365-2389.2008.01087.x

EC (2018). Product Environmental Footprint Category Rules Guidance – version 6.3, May 2018, European Commission, http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf

European Environment Agency (2016). EMEP/EEA air pollutant emission inventory guidebook 2016. Technical guidance to prepare national emission inventories. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/download

Frischknecht, R. (1999). Umweltrelevanz natürlicher Kältemittel. Ökobilanzen von Wärmepumpen und Kälteanlagen. Bundesamt für Energie (BfE), Bern as pdf-File under: http://www.waermepumpe.ch/fe/Fr_LCA_SB_Anh.pdf

Goglio, P. (2020). Environmental footprint of tulip bulbs: Summary of the representative product study. Wageningen Economic Research, Report 2020-041g.

Gomez, D., J. Watterson, B. Americano, C. Ha, G. Maarland, E. Matsika, L. Nenge Namayanga, B. Osman-Elasha, J. Kalenga Saka, K. Treanton and R. Quadrelli (2006). Chapter 2: Stationary combustion. Volume 2, IPCC guidelines for national greenhouse gas inventories. IPCC International Panel on Climate Change, Geneva, Switzerland, p. 47

Helmes, R., T. Ponsioen, H. Blonk, M. Vieira, P. Goglio, R. van den Linden, P. Gual Rojas, D. Kan and I. Verweij-Novikova (2020a). HortiFootprint category rules: towards a PEFCR for horticultural products: Wageningen, Wageningen Economic Research. Report no 2020-041. https://doi.org/10.18174/526452.

Helmes, R., P. Goglio and R. van der Linden (2020b). Environmental footprint of roses: Summary of the representative product study. Wageningen Economic Research, Report 2020-041f.

Helmes, R., P. Goglio, R. van der Linden, I. Verweij-Novikova (2021). Environmental footprint of roses: Summary of the representative product study. Wageningen Economic Research, Report 2021-018.

Helmes, R., T. Ponsioen and R. van der Linden (2020c). Environmental footprint of phalaenopsis: Summary of the representative product study. Wageningen Economic Research, Report 2020-041c.

Kan, D., L. Golsteijn and M. Vieira (2020). Environmental footprint of bananas: Summary of the representative product study. PRé Sustainability on behalf of Wageningen Economic Research, Report 2020-041e.

OCAP (2018). OCAP network. www.ocap.nl; access date November 1, 2018.

Paradiso, R., Maggio, A., & De Pascale, S. (2012). Moderate variations of day/night temperatures affect flower induction and inflorescence development in Phalaenopsis. Scientia horticulturae, 139, 102-107.

Plomp AJ, Kroon, P (2013) De mogelijke aanscherping van vijf eisen in het Besluit emissie-eisen middelgrote stookinstallaties. CEN Report. https://zoek.officielebekendmakingen.nl/blg-231229.pdf

Ponsioen T., P. Goglio, R. Helmes, P. Goglio, H. Blonk, R. van der Linden and I. Verweij-Novikova (2020). Life cycle analysis of horticultural products: Memo on handling multi-functionality of combined heat and power systems. Wageningen Economic research, report 2020-041h.

Ponsioen, T. and R. Helmes (2020a). Environmental footprint of tomatoes: Summary of the representative product study. Wageningen Economic Research, Report 2020-041b.

Ponsioen, T. and R. Helmes (2020b). Environmental footprint of apples: Summary of the representative product study. Wageningen Economic Research, Report 2020-041d.

Royal FloraHolland (2018). Jaarverslag Royal FloraHolland. http://jaarverslag.royalfloraholland.com/#/feiten-en-cijfers/import-export?_k=zjpdoo. Accessed 6 February 2019.

Velden, N. van der and P. Smit (2017). Effect intensivering, extensivering en energiebesparing op CO2-emissie Nederlandse glastuinbouw. Wageningen, Wageningen Economic Research, Rapport 2017-060.

Veneman, R., H. Kamphuis and D.W.F. Brilman (2013). Post-combustion CO2 capture using supported amine sorbents: a process integration study. Energy Procedia 37:2100-2108.

Vlaar, L.N.C. 2013. Aardwarmte, basis voor duurzame productie van warmte in de glastuinbouw Inzicht in duurzaamheid van aardwarmte in het glastuinbouwcluster Koekoekspolder en perceptie daarvan in de markt. CLM Onderzoek en Advies BV. Culemborg, mei 2013. CLM 828 - 2013

Wernet, G., C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz and B. Weidema (2016). The EcoInvent database version 3 (Part I): overview and methodology. Int J Life Cycle Assess 21:1218–30, https://doi.org/10.1007/s11367-016-1087-8.

Xuezhong H. and H. May-Britt (2014). Energy efficient process for CO2 capture from flue gas with novel fixed-site-carrier membranes. Energy Procedia 63:174–185

Zampori, L. and R. Pant (2019). ‘Suggestions for Updating the Product Environmental Footprint (PEF) Method.’ Luxembourg. https://doi.org/10.2760/424613.

Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

Wageningen Economic Research
REPORT
2021-059

The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,500 employees (5,500 fte) and 12,500 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.

To explore the potential of nature to improve the quality of life

Wageningen Economic Research
P.O. Box 29703
2502 LS Den Haag
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

Report 2021-059
ISBN 978-94-6395-809-7

The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,500 employees (5,500 fte) and 12,500 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.