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The demand of consumers and retailers for sustainably produced horticultural products is increasing. Life Cycle Assessment (LCA), or environmental footprint analysis, is a widely acknowledged methodology to assess, benchmark and monitor the environmental impact. Therefore, all supply chain partners are increasingly asking for footprint calculations of horticultural products. Because no harmonised methodology is available, the footprint calculations based on various methodological choices make those difficult to interpret. The project is carried out in the framework of a Public-Private Partnership project called 'Methodology for environmental footprint'. This report delivers the set of methodological rules for calculating the environmental footprint of horticultural products and is primarily meant for professionals with moderate knowledge of LCA. The development of the methodology follows as much as possible the most recent Guidance for developing Product Environmental Category Rules (PEFCR) published by the European Commission. This Hortifootprint Category Rules guidance suggests a 'flexible' approach, giving practitioners flexibility to 1) define the system boundaries of the study to be performed and 2) select the secondary data to be used as background to model the different life cycle stages in scope. Although this flexibility makes HFCR suitable for a broader set of use cases, it has as a drawback that it only allows for comparisons within the same study, provided that the same background data and scope definition are chosen.

Keywords: Product Environmental Footprint (PEF); Horticulture; Growers; Standard; LCA

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Preface

This document has been prepared by a group of experts from the Netherlands who took the initiative to start developing a methodology for environmental footprinting in horticulture. The development of the methodology is following as much as possible the most recent Guidance for developing Product Environmental Category Rules (PEFCR) published by the European Commission. Within horticulture, this methodology applies to fruits and vegetables as well as flowers and plants. This rather technical document – Hortifootprint Category Rules (HFCR) - is primarily meant for professionals dealing with Life Cycle Assessment (LCA). It delivers a set of calculation rules for the 16 environmental impact categories. Among these categories are climate change, land use and resource depletion.

The document is also of relevance to the chain actors of the horticultural sector. The demand of consumers and retailers for sustainably produced horticultural products is increasing. All supply chain partners are increasingly asking for standardised, objective and scientific-based footprint calculations of horticultural products. Calculating a footprint through a set of 16 environmental impacts for the end product provides insight into how sustainable a product is, where improvements can be made and how it compares to a similar product.

Acknowledgement is given to the significant contribution by Royal FloraHolland, Fresh Produce Centre, MPS, ABN AMRO Bank N.V., Rabobank, Glastuinbouw Nederland (the Dutch sector organisation for greenhouse horticulture) and the Foundation Benefits of Nature for not only their financial support but also for the connection to the horticulture sector, for the help in capacity building and the data. Especially the role of Daan van Empel from Fresh Produce Centre and Piet Briët from Royal FloraHolland is gratefully acknowledged.

A word of thanks goes to several professionals that helped the team in reviewing and discussing the interim versions of this document as well as of four supplementary memos on methodological advances and of six summaries from representative product studies. We would like to thank all the participants to the stakeholder workshops. Also, we especially would like to thank the growers from the Netherlands for providing sector-specific data and for reflecting on the results of the representative product studies that have been contributing to the methodology development, among which Harvest House, corporation of growers ‘DOOR’, Dutch Fruit producer Association (NFO), the Royal FloraHolland Product Committees for Potted Orchids and for Roses. Feedback from Willy Baltussen and Koen Boone (Wageningen Economic Research) helped shape this report.

To ensure acknowledgement of this HFCR as an official PEFCR, a special process under the guidance from the Environmental Footprint Team of the European Commission is required. The call for joining this official process was open in spring 2019. Under the leadership of the Royal FloraHolland and the involvement of the extended Technical Secretariat the official process towards the development of the PEFCR ‘Cut Flowers and Potted Plants’ started in fall 2019. It is expected to run until mid-2022. This report is the main building block to develop the official PEFCR.

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Acronyms

Abbreviation	Explanation
CHP	Combined Heat and Power
CPA	Classification of Products by Activity
EF	Environmental Footprint
EFTA	European Free Trade Association
EU	European Union
FU	Functional Unit
GHG	Greenhouse Gas
GR	Geographical Representativeness
ha	hectare
HDPE	high density polyethylene
HFCR	Hortifootprint Category Rules
HHV	higher heating value
ILCD	International Reference Life Cycle Data System
K	potassium
kg	kilogram
km	kilometre
kWh	kilowatt-hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	low-density polyethylene
LHV	lower heating value
m	metre
m^2	square metre
m^3	cubic metre
MJ	megajoule
N	nitrogen
P	phosphorus
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
Qty	quantity
TS	Technical Secretariat

Definitions

Activity data - This term refers to information which is associated with processes while modelling Life Cycle Inventories (LCI). Examples of activity data include quantity of kilowatt-hours of electricity used, quantity of nitrogen used, output of a process (e.g. waste), number of hours the equipment is operated, distance travelled, floor area of a building, etc.

Acidification – EF impact category that addresses impacts due to acidifying substances in the environment. Emissions of NO_x, NH_3 and SO_x lead to releases of hydrogen ions (H^+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

Allocation – An approach to solving multi-functionality problems. It refers to 'partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems' (ISO 14040:2006).

Climate change - All inputs or outputs that result in greenhouse gas emissions. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale.

Company-specific data – It refers to directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It is synonymous to 'primary data'. To determine the level of representativeness a sampling procedure can be applied.

Comparison – A comparison, not including a comparative assertion, (graphic or otherwise) of two or more products based on the results of a PEF study and supporting PEFCRs or the comparison of one or more products against the benchmark, based on the results of a PEF study and supporting PEFCRs.

Cradle to Gate – A partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer's 'gate'. The distribution, storage, use stage and end of life stages of the supply chain are omitted.

Cradle to Grave – A product's life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Data quality – Characteristics of data that relate to their ability to satisfy stated requirements (ISO 14040:2006). Data quality covers various aspects, such as technological, geographical and time-related representativeness, as well as completeness and precision of the inventory data.

Ecotoxicity, freshwater – Environmental footprint impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

Elementary flow – Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.

Eutrophication – Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass. Three EF impact categories are used to assess the impacts due to eutrophication: Eutrophication, terrestrial; Eutrophication, freshwater; Eutrophication, marine.

Global warming potential – Capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance (for example, CO_2-equivalent units) and specified time horizon (e.g. GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years respectively). It relates to the capacity to influence changes in the global average surface- air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.

HortiFootprint Category Rules (HFCRs) - Life-cycle-based rules that complement general methodological guidance for PEF studies by providing further specification at the level of horticultural product categories: fresh fruits, fresh vegetables, cut flowers, potted plants, bulbs and seeds for consumers.

Human toxicity – cancer – EF impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer.

Human toxicity – non-cancer – EF impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non- cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

Input flows – Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products (ISO 14040:2006).

Intermediate product – Output form a unit process that is input to other unit processes that require further transformation within the system (ISO 14040, see ISO, 2006). An intermediate product is a product that requires further processing before it is saleable to the final consumer.

Ionising radiation, human health – EF impact category that accounts for the adverse health effects on human health caused by radioactive releases.

Land use – EF impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in quality multiplied by the area).

Life Cycle Inventory (LCI) – The combined set of exchanges of elementary, waste and product flows in a LCI dataset.

Life Cycle Inventory (LCI) dataset – A document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory. An LCI dataset could be a unit process dataset, partially aggregated or an aggregated dataset.

Material-specific – It refers to a generic aspect of a material. For example, the recycling rate of PET.

Multi-functionality – If a process or facility provides more than one function, i.e. it delivers several goods and/or services (‘co-products’), then it is ‘multifunctional’. In these situations, all inputs and emissions linked to the process will be partitioned between the product of interest and the other co-products according to clearly stated procedures.

Normalisation – After the characterisation step, normalisation is the step in which the life cycle impact assessment results are multiplied by normalisation factors that represent the overall inventory of a reference unit (e.g. a whole country or an average citizen). Normalised life cycle impact assessment results express the relative shares of the impacts of the analysed system in terms of the total contributions to each impact category per reference unit. When displaying the normalised life cycle impact assessment results of the different impact topics next to each other, it becomes evident which impact categories are affected most and least by the analysed system. Normalised life cycle impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impact. Normalised results are dimensionless, but not additive.

Output flows – Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases (ISO 14040:2006).

Ozone depletion – EF impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).

Practitioner of study – Individual, organisation or group of organisations that performs the study in accordance with the HFCR.

Primary data[1] – This term refers to data from specific processes within the supply-chain of the company applying the study. Such data may take the form of activity data, or foreground elementary flows. Primary data are site-specific, company-specific (if multiple sites for the same product) or supply-chain-specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the company applying the HFCR. In this Guidance, primary data is synonym of 'company-specific data' or 'supply-chain specific data'.

Product category – Group of products (or services) that can fulfil equivalent functions (ISO 14025:2006).

Product Category Rules (PCRs) – Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories (ISO 14025:2006).

Product Environmental Footprint Category Rules (PEFCRs) – Product category specific, life cycle-based rules that complement general methodological guidance for PEF studies by providing further specification at the level of a specific product category. PEFCRs help to shift the focus of the PEF study towards those aspects and parameters that matter the most, and hence contribute to increased relevance, reproducibility and consistency of the results by reducing costs versus a study based on the comprehensive requirements of the PEF method. Only the PEFCRs listed on the European Commission website2 are recognised as in line with this method.

Photochemical ozone formation – EF impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.

Reference flow – Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (based on ISO 14040:2006).

[1] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 2011).

[2] http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm

Representative Product (RP) Study – 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 HFCR.

Resource use, fossil – EF impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).

Resource use, minerals and metals – EF impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals).

Secondary data[3] – This refers to data not from specific process within the supply-chain of the company applying the HFCR. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third-party life-cycle-inventory database or other sources. Secondary data includes industry-average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and can also be based on financial data, and contain proxy data, and other generic data. Primary data that go through a horizontal aggregation step are considered as secondary data.

Supply-chain – This term refers to all of the upstream and downstream activities associated with the operations of the company applying the PEFCR, including the use of sold products by consumers and the end-of-life treatment of sold products after consumer use.

System boundary – Definition of aspects included or excluded from the study. For example, for a 'cradle-to-grave' EF analysis, the system boundary includes all activities from the extraction of raw materials through the processing, distribution, storage, use, and disposal or recycling stages.

Supply-chain specific – It refers to a specific aspect of the specific supply-chain of a company. For example, the recycled content value of an aluminium can produced by a specific company.

Supporting study – Study carried out on specific products following the exact guidance of the HFCR. This study is meant to put the validity and applicability of the HFCR to test by completing a full study for a specific product.

Unit process dataset – Smallest element considered in the life cycle inventory analysis for which input and output data are quantified (ISO 14040:2006). In LCA practice, both physically not further separable processes (such as unit operations in production plants, then called 'unit process single operation') and also whole production sites are covered under 'unit process', then called 'unit process, black box' (ILCD Handbook).

Waste – Substances or objects which the holder intends or is required to dispose of (ISO 14040:2006).

Water use – This term represents the relative available water remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived (see also http://www.wulca-waterlca.org/aware.html).

Weighting – Weighting is a step that supports the interpretation and communication of the results of the analysis. PEF results are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted EF results may be directly compared across impact categories, and also summed across impact categories to obtain a single overall score.

[3] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 2011).

Summary

This Hortifootprint Category Rules (HFCR) document provides technical guidance to the horticultural sector on how to perform Life Cycle Assessment (LCA) studies of horticultural products belonging to the following categories: fruits and vegetables, cut flowers, potted plants and bulbs and seeds for consumers. This report delivers a set of Category Rules applicable to horticultural products and is primarily meant for professionals with moderate knowledge of LCA. The HFCR is intended for practitioners to monitor their environmental impact, identify hotspots in the life cycle of their products and recognise areas for improvement of their environmental performance.

The goal of this HFCR is to provide a harmonised methodology after which consistent LCA studies can be performed for the European Horticultural sector. The development of the methodology follows as much as possible the most recent Guidance for developing Product Environmental Category Rules (PEFCR) published by the European Commission (Zampori and Pant 2019). The document is structured along the template as suggested by the PEFCR Guidance and thus documents how stakeholders and experts have been involved in the process and results of case studies as required by the PEFCR methodology. The first draft HFCR was released for stakeholder consultation in November 2018. Throughout the past two years, various workshops with growers of horticulture products took place. The aim of those workshops was to involve the sector and to review the feasibility of the data to be collected for such an important stage as cultivation.

At the start of the project, several topics were identified where additional guidance was needed for the horticulture sector next to the guidance currently available in the PEF. The following methodological challenges were identified: handling multifunctionality of combined heat and power systems used during cultivation; modelling of nitrate and phosphorous emissions; modelling pesticides emissions; and modelling of capital goods. The approaches that were developed to address these challenges were also tested in six representative product (RP) studies. The cases were selected based on a wide variety of applied technologies and origins of productions. These are:

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

The most relevant life cycle stages identified for any of the six RP studies were: Cultivation; Post-harvest handling; Packaging; Distribution; Storage; Use stage; and End-of-life. Climate change and acidification appeared the most relevant impact categories. The analysis of results of the six RP-studies shows that all life cycle stages except retail can be most relevant in a study of products within the scope of the HFCR. This implies that sufficient detail should be given to the data collection for all life cycle stages.

The HFCR suggests a ‘flexible’ approach, giving practitioners flexibility to 1) define the system boundaries of the study to be performed and 2) select the secondary data to be used as background to model the different life cycle stages in scope. Although this flexibility makes HFCR suitable for a broader set of use cases, it has as a drawback that it only allows for comparisons within the same study, provided that the same background data and scope definition is chosen.

Samenvatting

Dit document beschrijft de HortifootPrint-categorieregels (HFCR), technische richtlijnen voor de tuinbouwsector om Life Cycle Assessment (LCA)-onderzoek uit te voeren voor tuinbouwproducten uit de volgende categorieën: groente en fruit, snijbloemen, potplanten, bollen en zaden voor de consument. Dit verslag bevat een aantal categorieregels voor tuinbouwproducten en is met name bedoeld voor professionals met enige kennis van LCA. Met de HFCR kunnen mensen uit de praktijk hun milieu-impact monitoren, hotspots in de levenscyclus van hun producten identificeren, en zien op welke gebieden er milieuwinst te behalen valt.

Deze HortifootPrint-categorieregels zijn bedoeld als geharmoniseerde methode voor de Europese tuinbouwsector om consistent LCA-onderzoek uit te voeren. De ontwikkeling van de methode volgt zoveel mogelijk de recentste leidraad voor de ontwikkeling van milieufootprintregels voor productcategorieën (Product Environmental Footprint Category Rules Guidance; PEFCR Guidance) van de Europese Commissie (Zampori en Pant 2019). Het document is opgebouwd volgens het sjabloon uit de PEFCR-leidraad. Derhalve komt aan bod hoe stakeholders en deskundigen betrokken zijn bij het proces en wat de resultaten van casestudy's zijn, zoals vereist volgens de PEFCR-methode. De eerste conceptversie van de HFCR is in november 2018 vrijgegeven voor raadpleging van stakeholders. In de afgelopen twee jaar zijn er verschillende workshops gehouden met telers van tuinbouwproducten. Deze workshops waren bedoeld om de sector erbij te betrekken en om de haalbaarheid te onderzoeken van gegevensverzameling in de teelt, een uitermate belangrijke levenscyclusfase.

Aan het begin van het project werden verschillende onderwerpen geïdentificeerd waarvoor extra richtlijnen nodig waren in de tuinbouw, in aanvulling op de huidige leidraad in de PEF. Er bleken diverse uitdagingen te zijn bij het ontwikkelen van een methode, namelijk: gebruik van multifunctionele warmtekrachtkoppelingssystemen (WKK) in de teelt, modelleren van nitraat- en fosforemissies, modelleren van emissies van gewasbeschermingsmiddelen, en modelleren van kapitaalgoederen. De oplossingen die werden ontwikkeld om deze uitdagingen aan te pakken, zijn ook getest in zes representatieve productonderzoeken (RP-onderzoeken). De cases werden geselecteerd op basis van de grote verscheidenheid aan gebruikte technologieën en herkomst van de producties. Het gaat om:

- appels (gematigd meerjarig fruit, variërend qua energieverbruik bij opslag en wereldwijd transport);
- bananen (tropisch meerjarig fruit, variërend qua energieverbruik bij wereldwijd transport);
- Phalaenopsis (sierplant die in twee fasen wordt geteeld, op substraat en in de kas);
- rozen (vaste plant die bloemstelen produceert, geteeld in de grond in de kas, met en zonder luchttransport);
- tomaten (eenjarige groente, geteeld op substraat in de kas);
- tulpenbollen (eenjarig siergewas, in de vollegrond geteeld, niet in de kas).

De relevantste levenscyclusfasen die werden geïdentificeerd bij de zes RP-onderzoeken waren: teelt, behandeling na de oogst, verpakking, distributie, opslag, gebruik, en einde van de levenscyclus. Klimaatverandering en verzuring bleken de meest relevante impactcategorieën te zijn. Uit de analyse van de resultaten van de zes RP-onderzoeken blijkt dat alle levenscyclusstadia, behalve retail, het relevantst kunnen zijn in een HFCR-onderzoek op producten. Dit houdt in dat er in alle fasen van de levenscyclus voldoende gedetailleerde gegevens moeten worden verzameld.

In de HFCR wordt een 'flexibele' benadering voorgesteld, waarmee mensen uit de praktijk de vrijheid hebben om 1) de systeemgrenzen van het uit te voeren onderzoek vast te stellen en 2) de secundaire gegevens te selecteren als achtergrond voor het modelleren van de verschillende levenscyclusfasen binnen het toepassingsgebied. De HFCR is door deze flexibiliteit geschikt voor een breder scala aan gebruikssituaties. Het nadeel is echter dat alleen vergelijkingen binnen hetzelfde onderzoek mogelijk zijn, op voorwaarde dat dezelfde achtergrondgegevens en definitie van het toepassingsgebied worden gekozen.

1 Introduction

1.1 Background

In recent years, companies throughout the supply chain from growers to retailers and consumers are becoming more aware of the potential environmental impact of the cultivation, transport and packaging of cut flowers and potted plants. Therefore, the demand for sustainably produced cut flowers and potted plants is increasing. Consequently there is also a growing market for calculating the environmental footprints of these products. While consumers and retailers as well as the producers themselves want to know more about the sustainability credentials, there is as yet no standard methodology for calculating them. A specification was published in 2012 for carbon footprinting of horticultural products (PAS2050-1), but this does not include other environmental issues than climate change and its methodology is in some aspects outdated. To meet this growing demand the Hortifootprint project was launched to develop a uniform standard methodology that will be applicable to all horticultural products and that will be adopted across the whole horticultural value chain. The project was initiated by Royal FloraHolland, Fresh Produce Centre 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 advisory performed by Blonk Consultants and PRé Sustainability.

The result of the more than 2 years' work is presented in this document. The ambition was to make this document as concise and short possible and at the same time to ensure for its readability as a stand-alone version. The Hortifootprint Category Rules (HFCR) document provides technical guidance for the horticultural sector on how to perform environmental impact studies for their products. Using this HFCR, the European horticulture sector will be able to perform environmental impact studies in a harmonised and consistent way. The HFCR suggests a 'flexible' approach, giving practitioners flexibility to 1) define the system boundaries of the study to be performed and 2) select the secondary data to be used as background to model the different life cycle stages in scope. Although this flexibility makes HFCR suitable for a broader set of use cases, it has as a drawback that it only allows for comparisons within the same study, provided that the same background data and scope definition is chosen.

The development of the HFCR as well as the structure of this document, both follow the latest international Life Cycle Assessment (LCA) guidelines relevant to the sector, and have been developed (unless specified in the document) in alignment to the European Commission (EC) Suggestions for updating the Product Environmental Footprint (PEF) method (PEFCR Guidelines, Zampori and Pant 2019).

1.2 Report structure

The document consists of the main part that presents the methodology and is appended with an appendix. The structure of the report follows the template as suggested in the Guidelines (EC, 2018) as close as possible, and all following chapters are part of the HFCR, as summarised in Table 1. The appendix is intended to facilitate the readability of the document and replicates some of the key figures and assumptions as already documented in the PEFCR Guidelines (Zampori and Pant, 2019). Next, this document refers to several accompanying documents that can be consulted separately. These are six factsheets showing the key results of the six representative product (RP) studies that were performed to develop the methodology. The six cases were selected following a wide variety of applied technologies and origins of productions. These are:

- Tomatoes (annual vegetable cultivated in greenhouse, on substrate), see Ponsioen and Helmes, (2020b)

- Apples (temperate perennial fruit with variability in energy consuming storage and global transport), see Ponsioen and Helmes (2020a)
- Bananas (tropical perennial fruit with variability in energy consuming global transport), see Kan et al. (2020)
- Phalaenopsis (ornamental plant cultivated in two stages, in substrate and in greenhouse), see Helmes et al. (2020b)
- Roses (perennial plant yielding flower stems, grown in soil in a greenhouse, with and without air transport), see Helmes et al. (2020a)
- Tulip bulbs (annual crop in soil, grown without greenhouse protection, with ornamental function, see Goglio (2020).

Table 1 *Structure of the report*

Part of method	Description	Rules
General information & intended use (Goal)	Chapter 2	Paragraph 2.3
Scope	Chapter 4, paragraph 3.2	Chapter 3
Data collection, processing & modelling	Chapter 5	Chapter 6
Reporting		Chapter 7

There are several methodological challenges that are still considered immature for horticulture in the PEFCR Guidance (Zampori and Pant, 2019): handling multifunctionality of combined heat and power systems used during cultivation (see Ponsioen et al., 2020); modelling pesticides emissions (see Helmes, 2020); modelling of nitrate and phosphorous emissions (see Kool and Blonk, 2020); and modelling of capital goods (see Kan and Vieira, 2020). The methodological choices are described in the main part of the document under respective sections while the background information on the choices made is documented in separate reports as mentioned above and can be seen as on-going methodological work.

The main part of the HFCR presents the process, definitions and the Category Rules or calculation rules. Section 2 presents general information about the HFCR, describes the consortium that participated in the development of the methodology and the stakeholder engagement process.

Next, in Section 3 instructions are given for the scope definition in HFCR studies (i.e. functional unit, system boundaries and impact assessment method). A detailed description of the different life cycle stages relevant to horticultural products is provided (Section 4). These stages are cultivation, post-harvest handling, packaging, distribution, storage, retail, use and end-of-life.

Section 5 relates to the PEF results obtained from RP studies and lists the most relevant impact categories, life cycle stages, processes and elementary flows, as well as limitations and relationship of the EF results relative to the defined goal and scope of the RP studies. These findings are accounted for when presenting the Category Rules and instruction on data collection in Section 6 – the main part of this report.

The HFCR elaborates on sector-specific methodological rules (Section 6.1), providing practitioners with instructions on how to define the steady state in cultivation, deal with allocation in specific instances related to the horticultural life cycle, model electricity use, nitrate and phosphorous and how to deal with the end-of-life of different products. Additionally, the HFCR provides instructions on how to develop the inventory for each life cycle stage, providing instructions on primary and secondary data to be collected (Section 6.2).

Chapter 7 provides a checklist with minimum requirements for reporting the environmental footprint based on this HFCR.

1.3 Follow-up steps

While this document represents the methodology as it was developed, tested and made available in mid-2020, the work continues. First, the process of further testing of this methodology is encouraged outside of the writing team. The developers of the HFCR continue testing the methodology within the second phase of the project and are engaging with sector organisations to perform additional cases, especially for fruits and vegetables.

Second, the developers of the PEFCR 'Cut flowers and Potted plants' are looking forward to further exchanges on the methodology which will feed the development process of the PEFCR 'Cut flowers and potted plants'. The development process fully follows the guidance as presented in Zampori and Pant (2019).

2 General Information about HFCR

This section informs on the process that has been followed in the preparation of the Category Rules, including the stakeholder consultations. It also stipulates the conformance to other documents, additional to the PEF method.

2.1 How can you use this document?

This Hortifootprint Category Rules (HFCR) document provides technical guidance to the horticultural sector on how to perform Life Cycle Assessment (LCA) studies of horticultural products belonging to the following categories: fruits and vegetables, cut flowers, potted plants and bulbs and seeds for consumers. For the LCA professionals the use of the Guidelines (Zampori and Pant, 2019) is required when applying these Category Rules. To non-LCA professionals the document intends to present sufficient background information, including an Appendix, to follow the main choices while developing and testing the methodology. This main document is supported by ten supplementary documents: four documents on methodological choices (see Helmes, 2020; Kan and Vieira, 2020; Kool and Blonk, 2020; and Ponsioen et al., 2020) and six summaries of the representative product studies (RP studies, see Goglio, 2020; Helmes et al., 2020a, b; Kan et al., 2020; and Ponsioen and Helmes, 2020a, b).

Unless specifically indicated, this HFCR has been prepared in conformance with PEFCR Guidance (Zampori and Pant, 2019) and its earlier version (EC, 2018). Some key figures and assumptions from Zampori and Pant (2019) are referenced in the Appendix to ensure a stand-alone readability of this document by a non-LCA professional. These refer to definitions of the 16 environmental impacts, weighting and normalisation factors applied.

2.2 Conformance to norm documents and adopted terminology

Since the PEFCR Guidance (Zampori and Pant, 2019) is not well defined for the modelling of agricultural processes, the following three methodological documents have been extensively used that are specific for environmental footprints of horticultural products:

- PAS2050-1 Horticultural supplement (BSI, 2012)
- Horticulture CO_2-footprint methodology (Blonk et al., 2009)
- Benefits of Nature (Benefits of Nature, 2017).

These methodologies were compared to a hypothetical (and incomplete) PEFCR for horticultural products, based on the generic PEF Guide (EC, 2013) rules and the specifications in the PEFCR Guidance document (version 6.3; EC, 2018).

In line with the PEFCR methodology, the HFCR uses precise terminology to indicate the requirements, the recommendations and options that could be chosen when a study is conducted.

> The term 'shall' is used to indicate what is required in order for a study to be in conformance with this HFCR.
> The term 'should' is used to indicate a recommendation rather than a requirement. Any deviation from a 'should' requirement has to be justified when developing the study and made transparent.
> The term 'may' is used to indicate an option that is permissible. Whenever options are available, the study shall include adequate argumentation to justify the chosen option.

The terminology adapted in this document does not fully follow the terms as presented in Zampori and Pant (2019) concerning the representative product, representative product study and supporting study. In the HFCR, 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. 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’.

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 that were selected on the basis of a wide variety of applied technologies and origins of productions.

2.3 Limitations in using this method

There is a set of limitations when using this document:

- This HFCR enables the environmental assessment of individual horticultural products (environmental declarations, also called single studies) of sufficient data quality which are more reproducible and verifiable. This method still allows flexibility in terms of secondary data use and system boundary setting. Hence, the methodology does not support comparisons between products from different HFCR-compliant single studies or between products outside the scope of this HFCR. In theory, all comparisons can be made but not all comparisons make sense. The developers of this HFCR do not take responsibility for any comparison made with studies resulting from this HFCR. The responsibility for the quality of the comparison lies with the practitioner who relates the two single studies.
- Ecotoxicity, and more generally toxicity, is perceived as an important environmental aspect but during the development of the HFCR and following the PEFCR Guidance v6.3, it was excluded from the identification of the most relevant impact categories, according to the EF LCIA method as decided in the original PEF initiative. The RP studies do consider toxicity and we encourage for those implementing the HFCR to also include toxicity in their assessments.
- Emissions from fertilisers and plant protection products will vary depending on the site specific circumstances like slope of the terrain, soil type etc. This topic needs further attention.
- Water consumption and water return from irrigation needs to be further developed.
  This HFCR does not provide explicit guidance on which additional information may, should or shall be included in studies based on this HFCR, except that sufficient data should be provided to describe the product, the functional unit and the system boundaries, as stated in this chapter. Information regarding additional environmental impacts, biodiversity and technical information may be included, for example the items specified in PEFCR Guidelines (Zampori and Pant, 2019).

2.4 Technical Secretariat

The Technical Secretariat (TS) is the group of active members involved in the development of the HFCR for horticulture products. The members of the TS are shown in Table 2.

Table 2 *Technical Secretariat*

Name of the organisation	Type of organisation	Name of the members
Wageningen Economic Research *(TC coordinator):*	Research organisation, LCA consultancy	Irina Verweij-Novikova Tommie Ponsioen Roel Helmes Pietro Goglio
ABN AMRO Bank N.V.	Banking and financial	Jan de Ruyter
Blonk Consultants	LCA consultancy	Hans Blonk Paulina Gual Rojas
Dutch Ministry of Agriculture, Nature and Food Quality	Policy	Leo Oprel
Dutch Fresh Produce Centre (in Dutch: GroentenFruit Huis)	Trade association fruits & vegetables	Daan van Empel
Dutch sector organisation for greenhouse horticulture (in Dutch: Glastuinbouw Nederland)	Growers organisation	Quincy von Bannisseht
MPS	Developer of standards	Harold Beek
PRé Sustainability	LCA consultancy and software development	Marisa Vieira Daniël Kan
Coöperatieve Rabobank U.A.	Banking and financial	Arne Bac
Coöperatie Royal FloraHolland U.A.	Trade association cut flowers, garden plants & house plants	Piet Briët Albert Haasnoot
Foundation Benefits of Nature	Platform organisation	Karolien Tesselaar-van Tilburg Rick van der Linden

2.5 Consultations and stakeholders

Throughout the past two years, various workshops with growers of horticulture products were held. The aim of those workshops was to involve the sector of horticulture early on and to understand the feasibility of the data to be collected for such an important stage as cultivation. The first draft PEFCR was released for on-line stakeholder consultation in November 2018 and was concluded in a stakeholder workshop in January 2019.

An online consultation was done to discuss an initial draft of the HFCR 'Draft Methodology for Environmental-footprint for horticultural products' during the period between 5 November and 5 December 2018. The invitations to participate in the online consultation were sent to about 30 stakeholders. The following documents were made available on-line to the registered persons through the project website: the version of the HFCR from 22 October 2019, full reports of the RP studies on Tomato, Phalaenopsis, and Apples were also available during the above-mentioned period. The contacted persons were asked to review the HFCR document and the RP studies and to fill in the Stakeholder Consultation form in an Excel template. As a result, five complete evaluations have been received and processed by the TC. The form 'Replies to comments of stakeholders' was shared with respective stakeholders to inform them how their comments were dealt with. This form also served as a guiding document for the next revision round of the HFCR.

To facilitate the discussion of the findings during the on-line consultation, a stakeholder workshop was organised 29 January 2019. This workshop was attended by 22 external persons and consisted of a session with an extended group of Dutch stakeholders to discuss the project and the main findings. At the plenary session the project was introduced as well as the findings from the three RP studies were shared. Two parallel sessions focused on the following topics: 1) Modelling Energy allocation in LCA horticulture and 2) Pesticides Modelling. As a follow-up from this session, further developments around capital goods, toxicity issues and overall communication were advanced.

Next, the following focus group in-situ consultations took place in December 2018 - September 2019:
- 13 December 2018: session with Phalaenopsis growers about the project and the main findings from the case study 'Phalaenopsis: Life Cycle Assessment', see also Helmes et al. (2020b)

- 10 December 2018: session with Tomato growers about the project and the main findings from the case 'Greenhouse Tomatoes: Life Cycle Assessment', see also Ponsioen and Helmes (2020b)
- 22 January 2019: session with Roses growers about the project and the main findings of the case study 'Roses: Life Cycle Assessment', see also Helmes et al. (2020a)
- 29 March 2019: session with Fruit growers about the project and the main findings of the case study 'Apples: Life Cycle Assessment', see also Ponsioen and Helmes (2020a)
- 3 September 2019: session with greenhouse entrepreneurs (producers of flowers, fruits and vegetables) and greenhouse sector specialists to discuss the findings regarding the findings of HFCR in relation to handling multifunctionality of combined heat and power systems used during cultivation, see also Goglio et al. (2020).

Additionally, meetings with international associations took place in Brussels to seek international support in the methodology development. As a result of these working sessions, in August 2019 the TS of HFCR has prepared and submitted an application to the selection round as announced in the call by the PEF team of the EC. The application was selected and the official pathway towards developing PEFCR 'Cut flowers and Potted Plants' under the strengthened team of the TS, including

- UnionFleurs – the International Flower Trade Association and with the endorsement from
  - FSI2020- The Floriculture Sustainability Initiative
  - Foundation RHP as part of Growing Media Europe
  - Department Sustainability in Agrosystems of IRTA (Institute of Agrifood Research and Technology)
  - Dutch Association of Wholesalers in Floricultural Products (VGB).

3 HFCR scope

This chapter includes a description of the scope of the HFCR, lists and describes the sub-categories included in the HFCR based on the so-called Classification of Products by Activity (CPA) codes. Next, it includes a description of the representative products, i.e. products for which the footprints can be compared and of the functional unit, i.e. the unit that defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product under the assessment. The functional unit definition answers the questions 'what?', 'how much?', 'how well?', and 'for how long?' and is specified for each product sub-category: fruits and vegetables, cut flowers, potted plants, bulbs. The motivation for selecting representative products is also provided. Next, the Chapter also includes a system diagram clearly indicating the processes and life cycle stages that are included in the product category/sub-category. A short description of the processes and life cycle stages follows. Finally, following the EU Guidelines (Zampori and Pant, 2019), 16 environmental footprint impact assessment categories are named for which the analysis is to be performed in an HFCR-compliant study.

3.1 Product classification

The HFCR is valid for the following product categories (categorisation on the basis of the Classification of Products by Activity (CPA) codes, see EUROSTAT (2008)):

Non-perennials
- 01.11.6 Green leguminous vegetables (beans peas, etc.)
- 01.13 Vegetables and melons, roots and tubers
  Including all subcategories **excluding:**
  - 0.13.52/53/54 potatoes, sweet potatoes and cassava
  - 01.13.6 vegetable seeds, except beet seeds (they will be part of the lifecycle but not a specific product)
  - 01.13.8 truffles (however mushrooms are included)
- 01.19.2 Cut flowers and flower buds; flower seeds

Perennials
- 01.21.11 Table grapes
- 01.22 Tropical and subtropical fruits
- 01.23 Citrus fruits
- 01.24 Pome fruits and stone fruits
- 01.25.1 Berries and the fruits of the genus vaccinium

Planting material
- Only 01.3 bulbs

All production systems are included, also organic production.

The scope of this HFCR focuses on products from these categories that are marketed directly to the consumer, without processing (i.e. transformation of the product itself). Cutting, slicing and compiling of products is not seen as processing.

Practitioners may also use these guidelines to perform environmental impact studies of plant propagation materials.

3.2 Representative product(s)

To determine what to include in the Category Rules of a product group, the European Commission required performing an LCA study of the representative product. Such a study would enable a better understanding of the environmental impacts within a product group and guarantees a fair comparison between products. The European Commission provides two options for defining the representative product: a real product sold on the EU market or a virtual product, which does not exist in reality. This virtual product should be modelled on the average EU market share of all existing technologies and materials of the product group in question. The virtual product approach does carry the risk that technologies with relatively small market shares are overlooked. This is why it is so important to do a sensitivity analysis once the representative product is determined. The key purpose of a sensitivity analysis is to identify the data and assumptions that have the biggest influence on a result.
The choice made in this HFCR is on real products sold on the market.

Representative products were selected to create insight into the hotspots of the LCA of horticulture products. For the development of the HFCR six 'representative' products were selected with a relative high market share and a wide variety of applied technologies (see Table 3) and origins of productions. These are:

- Roses (perennial plant yielding flower stems, grown in soil in a greenhouse, with and without air transport),
- Phalaenopsis (ornamental plant cultivated in two stages, in substrate and in 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), and
- Apples (temperate perennial fruit with variability in energy consuming storage and global transport).

Alternative production technologies have been studied in several screening studies, e.g. CHP vs. geothermal heat, glass vs. plastic greenhouse, transport from different country of origin, etc. The screening studies conducted on these representative products were instrumental to define what is substantial and needs to be focused on during data collection. The results are as such not meaningful as a benchmark.

The summaries of these studies are available (see Goglio, 2020; Helmes et al., 2020a, b; Kan et al., 2020; and Ponsioen and Helmes, 2020a, b).

Table 3 *Cultivation properties of the products from the screening studies*

	Typology				
Study	**Food/ Ornamental**	**Annual/ Perennial**	**Soil/ Substrate**	**Protected/ Open**	**Post-harvest impacts**
Tomatoes	Food	Annual	Substrate*	Protected*	Limited
Apples	Food	Perennial	Soil	Open	Transport or storage
Bananas	Food	Perennial	Soil	Open*	Transport
Orchids	Ornamental	Annual	Substrate	Protected	Limited
Roses	Ornamental	Perennial	Soil*	Protected*	Transport
Tulip bulbs	Ornamental	Annual	Soil	Open	Storage

Asterisk (*) indicates that the product can also have the alternative property, but this was not included in the screening study.

3.3 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.
Thus the following four product sub-categories are defined in this HFCR:
1. Fruits and vegetables (products sold as potted plants excluded)
2. Cut flowers
3. Potted plants
4. Bulbs
These categories are used to determine the functional units, reference flows and data management in this guideline.

The functionality and thus functional unit (FU) differs for each defined sub-category. Table 4 shows the key aspects for defining the functional units for the sub-categories covered by this HFCR. A functional unit may differ per study and includes aspects on the use value of the product. This is not fully defined in this HFCR. However, to derive a meaningful FU and to organise the calculations in a consistent way the calculations shall use the reference flows defined in Table 3.

Table 4 *Key aspects of the functional units*

Aspect	For fruits & vegetables	For cut flowers	For potted plants	For bulbs to consumers
What?	To provide nutrition to humans	To provide decoration, sign of appreciation or gift.[4]	To provide decoration or nutrition	To provide decoration
How much?	1 kg of product consistent with system boundary defined (excluding packaging weight). Practitioners shall be mindful that the study correctly shows moisture losses and/or waste to correctly fulfil the functional unit at the defined system boundary. (See Section 3.4.)	1 stem	1 pot (inner pot only)	1 bulb
How long?	According to the specifications on consumer packaging or information otherwise known by the consumer related to the characteristics of the specific product. Variability of longevity innate to the product or storage method shall be communicated. *	According to the specifications on consumer packaging or information otherwise known by the consumer related to the characteristics of the specific product. Variability of longevity innate to the product or storage method shall be communicated. *	For one year	According to the specifications on consumer packaging or information otherwise known by the consumer related to the characteristics of the specific product. Variability of longevity innate to the product or storage method shall be communicated. *
How well?	According to the specifications of the producer or the retailer, and in accordance with the specific system boundary defined.	According to the specifications of the producer or the retailer, and in accordance with the specific system boundary defined.	According to the specifications of the producer or the retailer, and in accordance with the specific system boundary defined.	According to the specifications of the producer or the retailer, and in accordance with the specific system boundary defined.

* Considering duration (How long?): A lot of produce is sold unpacked and there is a high variation in longevity of produce related type of product, storage method and packaging.

[4] Decoration is the primary function of cut flowers; however, the value of a gift can be equally relevant. One stem was found to be the unit to best represent these two functions. This topic is further discussed in the PEFCR project for cut flowers and potted plants.

In this HFCR, the main function of the system is to produce a certain amount of an agricultural product (i.e. roses, tomatoes). The functional unit is represented by the amount of the specific agricultural product according to the specification on consumer packaging or information otherwise known by the consumer related to the characteristics of the specific product and with the specifications as defined by the growers and the retailers. The reference flow is the amount of product needed to fulfil the defined function. All quantitative input and output data collected in the study shall be calculated in relation to this reference flow.

The requirements to model the inventory for the same functional unit of the same horticultural product, will vary depending on the system boundary defined. This means that depending on where the practitioner sets the study system boundary, activity data for more or less life cycle stages will need to be collected. Practitioner shall make sure that the study reference flow correctly considers all necessary elements to fulfil the function of the study at the defined system boundary (See Section 3.4).

3.4 System boundary

The following life cycle stages have been identified for all horticultural products (see Table 5). Depending on the product subcategory, different activity data is applicable per life cycle stage. A more detailed and comprehensive overview of the life cycle stages is given in Section 4.

Table 5 *Life cycle stages*

Life cycle stage	Description of the process included
Cultivation	The cultivation stage encompasses activities related to farming and harvesting of the horticultural product. These include plot preparation, planting/sowing, growing, harvesting and all activities related to the handling of horticultural products after harvesting. (e.g. sorting, washing, phytosanitary treatment). Capital goods (including depreciation and maintenance) necessary for crop cultivation (e.g. greenhouse) shall be considered in this life cycle stage following the recommendations in Section 6.2.1.6.
Storage	The storage life cycle stage refers to the use of energy (e.g. in climate control) and chemicals used to store horticultural products. In practice, storage is rarely done for only one product. Therefore utility use shall be correctly attributed to the reference flow of the functional unit under study as per instruction given in Section 6.1.2.
Packaging	This life cycle stage considers the production of (primary and secondary) packaging material, utility use for product packing (attributed to the specific reference flow in the study), transport (if applicable) to packing location and end of life of packaging materials* (including transport for collection if applicable).
Distribution	Delivery of product to final user. This can take place by different modes of transportation and in different legs (e.g. from farm gate to retail and retail to final user).
Retail	This life cycle stage refers to utility use (e.g. electricity) for climate control during storage for retail.
Use stage	The use stage includes amongst others the emissions related to the oxidation of substrates added to potted plants, use of fertilisers and crop protection agents. This stage also includes the use of utilities for storage and when applicable preparation (by the consumer) of horticultural products.
End of life	The end of life of the horticultural product shall consider all activity data related to the management of the horticultural product as waste, including transport for collection, utility use and emissions related to incineration, landfill, composting or recycling, based on the local waste management system. Please note that the end of life of packaging materials shall be included in the 'Packaging' life cycle stage. Waste management of material losses at different life cycle stages shall be included in the stage where it occurs unless specifically indicated in this document.

The HFCR gives practitioners flexibility to define the system boundaries of the study to be performed, allowing users to select the life cycle stages that will be in scope of their own study. The chosen system boundary shall be likewise reflected in the functional unit and reference flow of the study to be performed.

Some rules shall apply to this flexible approach:
1. 'Cradle to farm gate' shall be the minimum scope of an HFCR study.
2. The practitioner shall clearly state the life cycle stages included and excluded from the HFCR study.
3. A system diagram shall always be provided to illustrate the defined system boundaries of the study.
4. The functional unit and reference flow shall be consistent to the chosen system boundaries and defined as per indications provided in section 3.3. The HFCR shall describe i) how the defined system boundary affects the FU, ii) how this FU may affect the environmental performance of the product and how to include this effect in the EF calculations and (iii) how an appropriate reference flow shall be defined.

Although a flexible system boundary is allowed in the HFCR, it is advised that the practitioner performs studies from cradle to farm gate as a minimum. The practitioner shall include all activities occurring before the product leaves the farm. These can widely vary between types of horticultural products. Figure 1 illustrates the different activities related to the identified life cycle stages of horticultural production. It shows how the product leaving the farm gate can undergo different stages in the life cycle depending on the particular product. Practitioner shall identify all the necessary activities to model 'cradle to farm gate' for its product based on the specific farm and product under study.

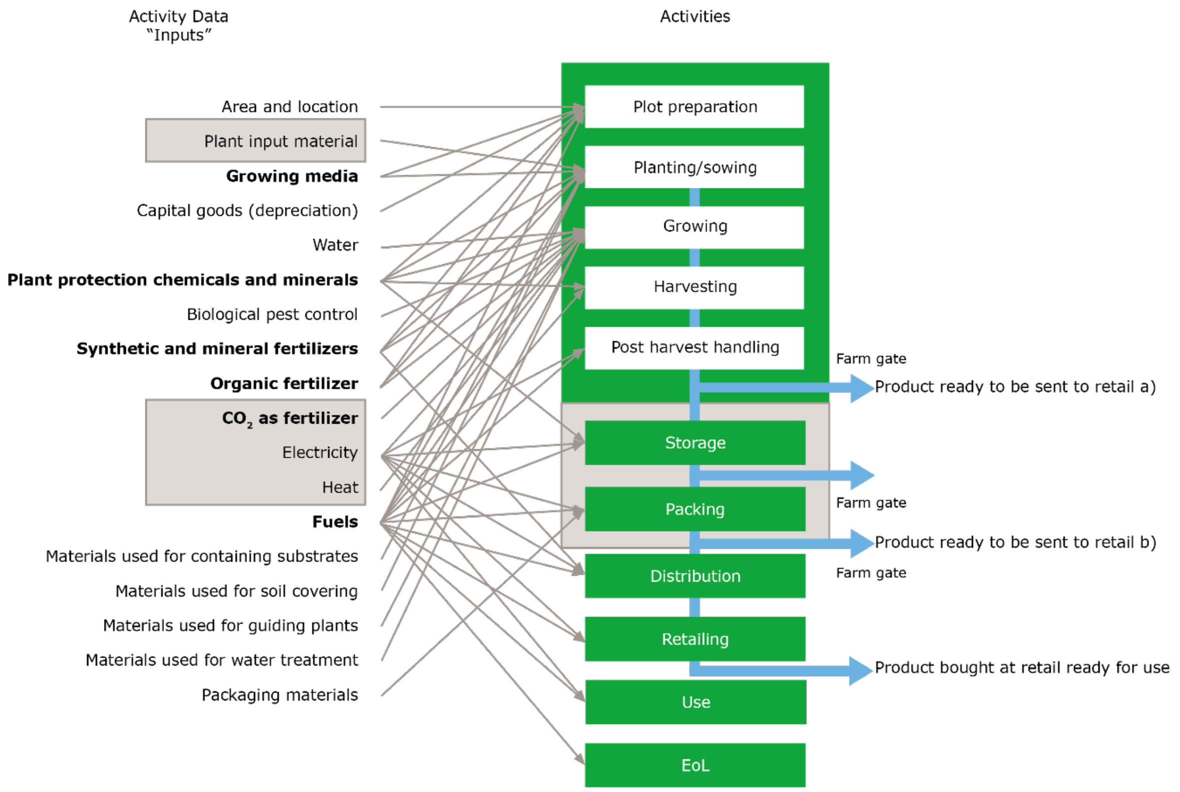

Figure 1 *Product system processes and elementary flows*
The life cycle stages (dark green) shall be presented in the results if occurring and when in scope. Cultivation at a farm always includes 5 subgroups of activities: plot preparation; planting or sowing; growing; harvesting and post-harvest handling. 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 at the left 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.

3.5 Impact assessment

Impact assessment methods are used to translate emissions and resource extractions of the Life Cycle Inventory into environmental impacts. Each study carried out in compliance with this HFCR shall calculate the environmental impact profile including all impact categories listed in the table below. This list was derived from the most relevant impact categories identified in the HFCR screening studies (Chapter 5), based on the most recent version available of the EF impact assessment method*.*

The full list of 16 EF impact categories, their definitions, normalisation factors and weighting factors are available in Zampori and Pant (2019) and at the PEF developer website (JRC, 2020). Normalisation and weighing factors are also listed in Appendix 1 to this report. Appendix 1 also provides the definitions of the 16 EF impact categories as provided at EC (2020).

Zampori and Pant (2019) provides a default list of EF impact categories and related assessment methods. For a HFCR study, all EF impact categories shall be applied, without exclusion (see Table 6). Following Zampori and Pant (2019), more details on how the CFs were calculated is available at: http://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml (see also Fazio et al. (2018a), Fazio et al. (2018b)). For the EF impact categories human toxicity, ‘cancer’, ‘human toxicity, non-cancer’ and ‘ecotoxicity, freshwater’, all CFs have been calculated with the USEtox 2.1 model using new input data for physicochemical properties, aquatic ecotoxicity and human toxicity (see Saouter et al. (2018).

Table 6 *List of the impact categories to be used to calculate the HFCR profile (following Zampori and Pant, 2019)*

	EF impact category	Impact category indicator	Unit	Characterisation model
1	*Climate change*	*Radiative forcing as Global Warming Potential (GWP100)*	*kg CO_2 eq*	*Baseline model of 100 years of the IPCC (based on IPCC 2013)*
2	*Ozone depletion*	*Ozone Depletion Potential (ODP)*	*kg CFC-11 eq*	*Steady-state ODPs as in (WMO 2014 + integrations)*
3	*Human toxicity, cancer*	*Comparative Toxic Unit for humans (CTU_h)*	*CTUh*	*USEtox model 2.1 (Fankte et al., 2017)*
4	*Human toxicity, non-cancer*	*Comparative Toxic Unit for humans (CTU_h)*	*CTUh*	*USEtox model 2.1 (Fankte et al., 2017)*
5	*Particulate matter*	*Impact on human health*	*disease incidence*	*PM method recommended by UNEP (UNEP 2016)*
6	*Ionising radiation, human health*	*Human exposure efficiency relative to U^{235}*	*kBq U^{235} eq*	*Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al., 2000)*
7	*Photochemical Ozone formation, human health*	*Tropospheric o zone concentration increase*	*kg NMVOC eq*	*LOTOS-EUROS model (Van Zelm et al., 2008) as implemented in ReCiPe 2008*
8	*Acidification*	*Accumulated Exceedance (AE)*	*mol H+ eq*	*Accumulated Exceedance (Seppälä et al. 2006, Posch et al., 2008)*
9	*Eutrophication, terrestrial*	*Accumulated Exceedance (AE)*	*mol N eq*	*Accumulated Exceedance (Seppälä et al. 2006, Posch et al., 2008)*
10	*Eutrophication, freshwater*	*Fraction of nutrients reaching freshwater end compartment (P)*	*kg P eq*	*EUTREND model (Struijs et al., 2009) as implemented in ReCiPe*
11	*Eutrophication, marine*	*Fraction of nutrients reaching marine end compartment (N)*	*kg N eq*	*EUTREND model (Struijs et al., 2009) as implemented in ReCiPe*
12	*Ecotoxicity, freshwater*	*Comparative Toxic Unit for ecosystems (CTU_e)*	*CTUe*	*USEtox model 2.1 (Fankte et al., 2017)*
13	*Land use*	- Soil quality index - Biotic production - Erosion resistance - Mechanical filtration - Groundwater replenishment	- Dimensionless (pt) - kg biotic production - kg soil - m3 water - m3 groundwater	*Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)*
14	*Water use*	*User deprivation potential (deprivation-Weighted water consumption)*	*m^3 world eq*	*Available WAter REmaining (AWARE) as recommended by UNEP, 2016*
15	*Resource use, minerals and metals*	*Abiotic resource depletion (ADP ultimate reserves)*	*kg Sb eq*	*CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.*
16	*Resource use, fossils*	*Abiotic resource depletion – fossil fuels (ADP-fossil)*	*MJ*	*CML 2002 (Guinée et al., 2002) and van Oers et al. 2002*

3.6 Limitations in the scope

The limitations in using the method in general have been described in paragraph 2.3. In addition to the main limitation of limited comparability of study results, the following limitations in the method related to the scope:

- The system boundary setting is flexible, as stated in paragraph 3.5: allowing users to select the life cycle stages that will be in scope of their own study, with a cradle-to-farm-gate scope as a recommended minimum.
- Emissions from fertilisers and plant protection products, water consumption and water returns need further attention.
- The waste resulting from human consumption is excluded. This is common practice in food Life Cycle Assessment studies.

4 Life Cycle Stages

This chapter provides a detailed description of the different life cycle stages relevant to horticultural products. The complete life cycle includes: cultivation, storage, packaging, distribution, retail, use and end-of-life. The cultivation stage as the most important production of the main product stage consists of 5 types of activities (plot preparation; planting or sowing; growing; harvesting and post-harvest handling) and refers to open field cultivation systems as well as protected cultivation systems. While this chapter is mainly descriptive, Chapter 6 elaborates on further details and presents the calculation rules (Category Rules).

4.1 Cultivation (plant material or final product)

Cultivation at a farm includes 5 types 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 (see Figure 1).

There is a wide variety of cultivation production systems globally which can be categorised for modelling of environmental impacts as follows:
- Open field in soil
- Open field outside soil (in a growing medium)
- Protected in soil
- Protected outside soil

This categorisation is relevant for the activities taking place and the emissions modelling, see Section 6.1.5.

A short description of the different cultivation activities and which activities shall be included in the study is given below.

1. Plot preparation

Open field farms
For open field farms where plants grow in the soil, plot preparation includes all activities necessary to start sowing or planting seedlings. These include all activities for soil preparation such as tillage, fertilisation and 'sterilisation' by using soil fumigants or other chemicals.
Depending on the crop, soil and climate conditions, several tillage management strategies can be adopted by the farmers. Three general types of tillage can be identified:
- no tillage: no tillage operation is carried out which is complemented with a chemical weeding treatment before seeding
- minimum tillage: only low depth implemented (<15cm) are used (i.e. Spring tine harrows, disk harrow; rotary harrow, hoeing)
- conventional tillage: both low and high depth operation (i.e. plough, rotary plough, subsoiler, disk harrow, spring tine harrows, rotary harrow, hoeing).

In many cases a part of the fertilisation takes already place before planting or sowing. This is especially the case for the use of organic fertilisers, such as manure in a crop rotation scheme.

There can also be 'Infrastructure products' in the soil such as water drainage systems or water irrigation systems. The material use for these shall be neglected. In this phase also the infrastructure for guiding plants during their growth phase is set up. These materials shall be accounted for.

For open field farms where plants do not grow in the soil all materials used for soil covering, growing media, containers that contain growing media and materials used to lift the plants from the ground shall be accounted for. The growing media are typically replaced every year while other materials can have a longer life span and the materials use should be depreciated over the years.

Protected farm systems
Plot preparation for protected farming (e.g. greenhouses) involves the cleaning of the production facility (the interior and/or the soil in the greenhouse) for instance by chemical or heat disinfection, bringing in the new growing media and other materials used to support the growth of the plant. In case of protected cultivation also the depreciation of the 'capital goods' (the housing) shall be included in the calculation.

Different materials can be used as a growing medium such as peat, vermiculite, stone wool, coconut fibre, perlite, and clay. Each has different growing characteristics. Often mixes are used depending on the crop requirements.

For the materials used for capital goods at greenhouse farming default data are derived. These involve the main materials used for building greenhouses (aluminium, steel, glass, plastics). More information on capital goods activity data modelling is available in Section 6.2.1.6.

2. Planting/sowing
After the preparation of the plot the planting or sowing can take place. Seeds or young plants are brought into soil or a growing medium. Energy use for machinery is the main input in open field farming. In protected farm systems there can be more labour involved. Sometimes the planting/sowing goes along with fertilisation or use of crop protection agents.

3. Growing
Growing is the entire phase between sowing/planting and harvesting. There are often multiple rounds of adding fertilisers and crop protection agents. Irrigation is important to ensure sufficient water availability during the growth stage.

4. Energy production
Energy can be produced by greenhouse farmers which use a boiler or combined heat and power plant (CHP) for heating and CO_2 production. In the market, there are different boilers and CHP units with a different degree of thermal and (for CHP) electricity efficiency.

5. CO_2 production
In greenhouse production additional CO_2 can be added into the greenhouse to improve efficiency of production. This can be sourced in three ways:
- Capture of CO_2 from CHP/gas-boiler on-site
- Capture or production off-site by another industry and transported to the greenhouse by pipes
- Capture or production off-site by another industry and transported to the greenhouse by truck.

6. Use of energy
Growers use fuels for farming machinery and irrigation and electricity for storage, equipment and light production. Electricity use can be high at greenhouses. Glasshouse systems can be connected to the grid and glasshouse growers sell their energy surplus from CHP production to the grid at the same time. Growers can also use exhaust heat from other industries to heat their glasshouse which is distributed through a pipe system. A large group of growers are provided with a boiler or CHP unit which use either gas or biomass to produce heat.

7. Use of agrochemicals/fertilisers

Emissions from agrochemicals shall be differentiated per active ingredient (AI) and cover:
- AI, to air
- AI, to water
- AI, to soil

Modelling of the AI emissions from agrochemicals shall include the following:
- Application method (e.g. spot application, spraying by small aircraft)
- Cultivation environment (e.g. open field, closed greenhouse)
- Relevant systems and technologies used (e.g. water recirculation, UV-treatment of wastewater)

8. Planting of seedlings

Depending on the crop the planting of seedling can be carried out using three different methods:
- with a transplanter attached to the tractor, especially in the case of open field crops
- manually
- using automatic electrical equipment in the case of glasshouse crops

9. Fertilisation

Fertilisation can be carried out in different ways depending on the type of crops. Also the difference between organic fertiliser application and mineral fertiliser application is relevant. Two types of manure application often occur:
- slurry spraying or injection: as slurry has a high water content, it is either sprayed or distributed on the surface or injected on the top-soil to avoid ammonia losses.
- manure spreading: as in the previous case the manure spreader is a machinery which is pulled and operated by tractors.

In the case of mineral fertiliser, we can distinguish two types of fertiliser application:
- open field spreading:
  - with centrifugal spreader, this equipment is attached and operated by the tractor
  - with pneumatic spreader, this equipment is also attached and operated by the tractor; it is more precise than the centrifugal spreader
  - with a sprayer, this is used in case the fertiliser forms a solution
- fertigation, in this case the fertiliser is dissolved in the irrigation water and applied during irrigation. This type of fertiliser application is very common in glasshouse crops.

10. Irrigation

Different types of irrigation can be identified:
- Flood irrigation, which is most often used in open field crops
- Sprinkler irrigation, which is most often used in open field crops
- Drip irrigation, which is most often used in horticultural crops both in glasshouse and open field
- Micro-sprinklers irrigation, which is most often used in horticultural crops both in glasshouse and open field
- Ebb-flow irrigation, which is used in glasshouse crops
- Sub-surface irrigation, which is used in open field
- Nutrient film technique, which is used in soilless systems to provide fertilisers and water to the crop

Often drip irrigation, micro-sprinkler and ebb-flow, nutrient film technique is used for fertigation.

11. Crop protection

Crop protection can be carried out with different type of sprayers. Most of the pesticides are sold as a solution which is subsequently diluted and sprayed. Some pesticides are used in dissolvable granules (against slugs). Sprayers can be distinguished in 3 main groups:
- Mechanical
- Pneumatic
- Air-flow

Some sprayers can be self-propelled.

Depending on environmental regulation sprayers can have nozzles that prevent drift to surface water. It is also common where high-standing crops are grown such as orchards, to use tree lanes for drift reduction.

12. Harvesting
Depending on the crop, a specific harvester can be used. However, for many horticultural crops, the harvest is mostly manual and mechanically assisted (i.e. mechanical platform, conveyer belt).

13. Post-harvest handling
Post-harvest handling considers all activities related to the handling of horticultural products after harvesting. These can include, sorting carried out mostly mechanically and operator assisted, washing and phytosanitary treatments. Several phytosanitary treatments are carried out after harvest to enhance storage duration and maintain the quality of the product.

4.2 Storage

Storage activities can occur at different stages in the life cycle of the horticultural product. The storage is often shared between different products. The main input of the storage is electricity consumption. The impact of the storage is dependent on the storage characteristics and the storage duration.

4.3 Packaging

Packaging considers packing activities and utility use in packing operations as well as the production and end of life of packaging materials used in the life cycle of the horticultural product under study. This includes primary secondary and tertiary packaging materials.

Packaging production and end of life shall be modelled using the circular footprint formula (CFF) as defined by Section 4.4.8 of the PEF method (Zampori and Pant, 2019). Further information on the CFF is provided in Section 6.2.8.

Packaging shall take into account the reuse of packaging materials if applicable (considering the number of trips/uses).

4.4 Distribution

The transport from storage to final client (excluding consumer transport, as the latter is part of the use phase) shall be modelled within this life cycle stage. The final client is defined as the user of the horticultural product.

Product losses during distribution shall be included in the modelling.

4.5 Retail

This life cycle stage groups all the activities happening at the retailers. Depending on the product, these may include storage at the retail, repackaging, cooling, heat use to maintain the required temperature, use of water to maintain the quality of the product. In the retail stage, as some of the product loses its commercial quality, waste is produced.

4.6 Use

The use stage describes how the product is (expected) to be used by the end user (e.g., the consumer). The use stage starts at the moment that the end user acquires the product, until it leaves its place of use and enters the end-of-life (e.g., recycling or final treatment).

The use phase is variable across products and consumers. For fresh fruits & vegetables the use phase encompasses (cool) storage, preparation and waste (during storage, preparation and eating).
For flowers & plants the use phase includes fertilisation, (re)potting related to oxidation of growing media and growth of plants, plant protection and watering.

4.7 End of life

The end of life (EoL) stage considers the waste management of the product in scope, such as the food waste, or the product left after use, including the necessary transports for waste management. The processes used to manage these wastes in accordance to local waste management systems, shall be accounted for.

The EoL shall also include the emissions related to the oxidation of peat carbon from the growing media (substrate) and fate of nutrients (if any) contained in the growing media mix.

Other waste (different from the product in scope) generated during the manufacturing, distribution, retail, use stage or after use shall be included in the life cycle of the product and modelled at the life cycle stage where it occurs.

The waste resulting from human consumption is excluded. This is common practice in food Life Cycle Assessment studies.

5 Most relevant impact categories, life cycle stages and processes

This chapter outlines the most important results as concluded on the basis of (representative product studies) RP studies for bananas, phalaenopsis, tomatoes, apples, roses and tulip bulbs. The purpose of performing RP studies was to identify the most relevant impact categories, life cycle stages, processes, elementary flows and data quality needs. The most relevant impact categories are defined as the impact categories that cumulatively contribute at least 80% of the total environmental impact. The classification "most relevant" for the other groups (life cycle stages, processes, etc.) is defined as the items within a group that contribute cumulatively to at least 80% of the total impact of one of the most relevant impact category of the group consistent with the Guidelines (EC, 2018). The RP studies' outcomes enabled a preliminary indication of major methodological requirements in the final HFCR and a definition of the benchmark for the product category/sub-categories in scope.

Individual summaries of the RP studies can be found under Goglio (2020), Helmes et al. (2020a, b), Kan et al. (2020), Ponsioen and Helmes (2020a, b). Each summary includes information about the scope of the study, describes functional unit, system boundaries, the data collection process and sources and key results (most relevant impact categories, life cycle stages, and processes, elementary flows and impact categories) and limitations. The idea behind identifying the most relevant results is to determine the data collection requirements, i.e. to intensify the data collection for the most relevant processes and simplify for less important processes. The RP studies have been performed as prescribed in the previous version of the Guidelines, namely EC (2018) where these studies are referred as 'screening studies'.

The **most relevant impact categories** for the product group in scope of this HFCR, which were identified on basis of the six RP-studies for bananas, phalaenopsis, apples, tomatoes, roses and tulip bulbs are the following (coloured in green in Table 7):

- Acidification
- Climate change
- Eutrophication, terrestrial
- Particulate matter
- Photochemical ozone formation
- Land use
- Resource use, fossils
- Resource use, minerals and metals

Table 7 *List of most relevant impact categories identified in the 6 RP studies (toxicity impacts excluded)*

Impact category	Bananas	Phalaenopsis	Tomatoes	Apples	Roses	Tulip bulbs*
Climate change	■	■	■	■	■	■
Ozone depletion						
Particulate matter	■		■	■		■
Ionising radiation, human health						
Photochemical ozone formation, human health	■			■		
Acidification	■	■	■	■	■	■
Eutrophication, terrestrial	■			■		■
Eutrophication, freshwater						
Eutrophication, marine						
Land use				■		
Water scarcity impacts						
Resource use, minerals and metals		■	■	■		
Resource use, fossils	■	■	■	■	■	■

*The screening study of tulip bulbs only considers cradle to farm gate (cultivation and post-harvest).

The **most relevant life cycle stages** (contributing cumulatively to 80% of one of the most relevant environmental impact categories) for the product group in scope of this HFCR, which were identified on basis of the six RP- studies (see Table 8) are the following:

- Cultivation
- Post-harvest handling
- Packaging
- Distribution
- Storage
- Use stage
- End-of-life

The analysis of results of the six RP studies shows that all life cycle stages except retail can be most relevant in a study of products within the scope of the HFCR. This implies that sufficient detail should be given to the data collection for all life cycle stages. Activity data collection is described in Section 6.2.

Table 8 *List of the most relevant life cycle stages identified in the 6 RP studies a)*

Life cycle stage	Bananas	Phalaenopsis	Roses	Tulip bulbs	Tomatoes	Apples
Cultivation	■	■	■	■	■	■
Post-harvest handling				■		■
Packaging		■		░		■
Distribution	■		■	░		■
Storage	■			░		
Retail				░		
Use stage		■		░		■
End-of-life	■	■		░		

a) The order of the life cycle stage is independent of the product system assessed. For some product systems the packaging can happen either before or after post-harvest handling. It is also not an indicator of the importance of each phase in relation to the product. A process that is relevant for an individual category can be irrelevant for the overall score due to a small contribution of that category to the overall environmental impact. The scope in the RP study tulip bulbs refers to 2 phases only (cultivation, post-harvest handling) because the storage of tulip bulbs in the downstream processes can be targeted for 3 separate products (bulbs, vase plants and cut-flowers) for which different product category rules apply. Therefore grey colour is used to indicate that the remaining processes were not considered.

The **most relevant processes** (contributing cumulatively to 80% of one of the most relevant environmental impact categories) for each product is presented in the Tables 9-12 below.

Table 9 *List of most relevant processes related to the most relevant impact categories for bananas*

Life cycle stage	Most relevant processes
Cultivation	Banana Production
	Fertiliser (ammonium nitrate) production
Distribution	Transport, freight, sea, transoceanic ship
Storage	Electricity
	Transport, freight, lorry
Packaging	Corrugated board box
End-of-life	Municipal waste collection service
	Sulphate pulp production

Table 10 *List of most relevant processes related to the most relevant impact categories for Phaleanopsis*

Life cycle stage	Most relevant processes
Cultivation	Heat from CHP
	Electricity from grid, low voltage
	Polypropylene
	Peat substrate
	Natural gas production
	Electricity from grid, medium voltage
	Deep well
	Heat from boiler
	Plastic waste processing
	Emissions during cultivation
	Transport in lorry, EURO5, Global
	Zinc coat in greenhouse
	Aluminium in greenhouse
	Electronics in greenhouse
	Steel in greenhouse
	Biowaste treatment
	Glass in greenhouse
	Moulding plastic
Packaging	Polystyrene
	Thermoforming plastic
Use	Emissions during use
	Transport with car by user
End of Life	Peat waste treatment

Table 11 *List of most relevant processes related to the most relevant impact categories for tomatoes (CHP)*

Life cycle stage	Most relevant processes
Cultivation	Aluminium production
	Electronics, for control units
	Flat glass, uncoated
	Steel, low-alloyed
	Zinc coat, coils
	Heat from CHP
	Natural gas
	Electricity from CHP
	Monoethanolamine
	Biowaste
	Nitrogen fertiliser production
	Tomato protection, at grower
Packaging	Corrugated board box
Distribution	Transport, lorry
Use	Transport, passenger car

Table 12 *List of most relevant processes related to the most relevant impact categories for apples (NL)*

Life cycle stage	Most relevant processes
Cultivation	Fertiliser (ammonium nitrate) production
	Apple production, at grower
	Electricity
	Establishing orchard
	Fertilising, by broadcaster
	Pesticide production
	Phosphate fertiliser production
	Planting tree
	Sulfate pulp
	Transport, passenger car
	Trellis system
Post-harvest handling	Absorption chiller
	Heat
Packaging	Corrugated board box
	HDPE, granulate
Distribution	Transport, lorry
End-of-life	Municipal waste collection
	Biowaste
	Waste Plastic incineration

Table 13 *List of most relevant processes related to the most relevant impact categories for roses*

Life Cycle Stage	Most relevant processes
Cultivation	Heat from CHP
	Electricity from CHP
	Natural gas production
	Emissions cultivation
	Biowaste treatment
	Glass (greenhouse)
	Roses pesticide use
	Municipal waste treatment
Distribution	Road transport
	Air transport

Table 14 *List of most relevant processes related to the most relevant impact categories for tulip bulbs*

Life cycle stage	Most relevant processes
Cultivation	Peat moss production
	Bulbs cultivation
	Wheat straw, at farm
	Polyethylene, high density, granulate
	Diesel (fuel)
	Pesticides production and transport
Post-harvest handling	Electricity,
	Heat, natural gas

6 Life Cycle Inventory

In this section the methodological rules are described that shall be applied during the Life Cycle Inventory LCI. LCI is the combined set of exchanges of elementary, waste and product flows. It is to be documented in a so-called LCI dataset. More specifically, this chapter elaborates on sector-specific methodological rules (Section 6.1), providing practitioners with instructions on how to define the steady state in cultivation, deal with allocation in specific instances related to the horticultural life cycle, model electricity use, nitrate and phosphorous and how to deal with the end-of-life of different products. Additionally, the HFCR provides instructions on how to develop the inventory for each life cycle stage, providing instructions on primary and secondary data to be collected (Section 6.2), and section 6.3 comments on which secondary datasets should be used.

6.1 Methodological Rules

The methodological rules here presented are the result of a careful consideration of the best approaches to tackle sector specific challenges. At the start of the project, several topics were identified where additional guidance was needed for the horticulture sector next to the guidance currently available in the PEF (Zampori and Pant, 2019). The following methodological challenges were identified and more extensively documented in the following documents:

- modelling nitrogen and phosphorus emissions (Kool and Blonk, 2020);
- modelling pesticides emissions (Helmes, 2020);
- handling multifunctionality of combined heat and power systems used during cultivation (Ponsioen et al., 2020) and
- modelling of capital goods (Kan and Vieira, 2020).

6.1.1 Average (steady state) definition

Cultivation data shall be collected over a time period which is sufficient long to provide an average representation assessment of the inputs and outputs of cultivation. The choice of such a time period will offset fluctuations due to seasonal differences. Table 15 gives an overview how this shall be implemented.

Table 15 *Implementation of the (steady state) average requirement (based on PAS 2050-1:2012, see BSI (2011)*

	Requirement
1.	For annual crops, an assessment period of at least three years shall be used (to level out differences in crop yields related to fluctuations in growing conditions over the years such as climate, pests and diseases). Where data covering a three-year period is not available e.g. due to starting up a new production system (i.e. new greenhouse, newly cleared land, shift to other crop), the assessment may be conducted over a shorter period, but shall be not less than 1 year. Crops/plants grown in greenhouses shall be considered as annual crops/plants, unless the cultivation cycle is significantly shorter than a year and another crop is cultivated consecutively within that year.
2.	For perennial plants (including entire plants and edible portions of perennial plants) a steady state situation (i.e. where all development stages are proportionally represented in the studied time period) shall be assumed and a three-year period shall be used to estimate the inputs and outputs. Where the different stages in the cultivation cycle are known to be disproportional, a correction shall be made by adjusting the crop areas allocated to different development stages in proportion to the crop areas expected in a theoretical steady state. The application of such correction shall be justified and recorded.
3.	For crops that are grown and harvested in less than one year (e.g. lettuce produced in 2 to 4 months) data shall be gathered in relation to the specific time period for production of a single crop, from at least three recent consecutive cycles.

6.1.2 Allocation

If a process or facility provides more than one function, i.e. it delivers several goods and/or services ('co-products'), it is 'multifunctional'. In these situations, all inputs and emissions linked to the process shall be partitioned between the product of interest and the other co-products according to fixed rules. Systems involving multi-functionality of processes shall be modelled in accordance with a decision hierarchy resulting in specific allocation rules. Allocation refers to partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. The HFCR defines which allocation rules shall be applied by the user of the HFCR and how the modelling/ calculations shall be made, following the template prescribed in PEFCR Guidelines (Zampori and Pant, 2019). The allocation rules are summarised in Table 16.

Table 16 *Allocation rules for activity data and elementary flows*

Process	Allocation Rule	Modelling Instructions
Allocating organic fertiliser use and green manure in annual open field crop rotation systems	Organic manure is divided over all crops in the crop rotation scheme on the basis of share in area, except for the mineral N fraction which is allocated solely to the crop of application.	If Organic fertiliser is applied in a crop rotation scheme the following calculation rules apply for fertilisation of N (BSI 2012). Formula 1 (Calculating N application to a crop as part of a crop rotation scheme) *Total N from Organic Fertiliser* $_{\text{applied to the plot where crop A stands}}$ = $NmO_A + Ncr_A + a_A/a_T \times (NoO_T + Ncr_T)$ • NmO_A = Mineral nitrogen from organic fertiliser applied to crop A (kg N/ area unit) • Ncr_A = Nitrogen from crop residues of crop A (kg N/ area unit) • a_A = area of crop A (area unit) • a_T = total area of crop rotation system (area unit) • NoO_T = Organic nitrogen from organic fertiliser applied on all area (kg N/ area unit) • Ncr_T = Nitrogen from crop residues of green manure on all area (kg N/ area unit) All other fertilizing elements supplied using organic fertilisers, including green manure, is calculated by Formula 2 (Calculating Fertiliser application to a crop as part of a crop rotation scheme) $F_{\text{applied to crop A}} = a_A/a_T \times (FO_T)$ Where • a_A = area of crop A (area unit) • a_T = total area of crop rotation system (area unit) • FO_T = Organic fertiliser applied on all area (kg F/ area unit)
Organic fertilisers	Manure used in conventional farming is considered as a zero-burden product unless farmers need to pay a price for the manure that exceeds transport costs. Manure is then treated as a co-product where economic allocation shall be used. Economic allocation shall be applied for all other organic fertilisers originating from industrial processes.	For manure as a zero-burden product all activities needed after storage at the animal farm to application on the horticulture crop are included (thus including transport and processing if occurring). If manure has a price then the price will be based on the revenues for the animal farmer (excluding transport costs) or the price will be based on a shadow price derived from equivalent quantities of artificial fertiliser needed.
Energy use, cleaning and other generic operations in Greenhouse Cultivation	Land occupation and economic allocation depending on the situation.	When multiple plant products are grown in a protected (and heated) system, the relative land occupation of each plant product shall be applied to allocate the interventions related to the inputs for which it cannot be specified. When possible, the system should first be broken down in sub-systems, for instance into separated compartments in within a greenhouse. Land occupation per product shall be obtained by specific data for the analysed time

Process	Allocation Rule	Modelling Instructions
		period (this will include any changes in land occupation due to differences with planning, differences in production, etc.). When not available, the average land occupation per plant product shall be used. This shall be calculated by adding together the land occupation per plant per phase using the following equation: *LO = Sum over phases (p)* $(GT_p * 1 / PD_p)$ With LO = Land occupation ($yr*m^2$) GT_p = Growing time of phase p (yr) PD_p = Plant density of phase p (numbers / m^2) There are cases known where potted plants are grown over a longer time period and leaves and/or flowers from those plants are sold as separate products during the cultivation period. The other way around is also possible: plants used for the production of cut flowers/leaves can be sold as potted plants after their useful life in flower/leaf production. In these cases, a final step of economic allocation between the pot plant and the cut leave/flower shall be used, after the step of allocation by land occupation.
Combined heat and power systems (CHP) in Greenhouse Cultivation	Energy content	The horticultural system should be subdivided into the heat and electricity production subsystem, the carbon dioxide capture and purification subsystem and the cultivation system. If the subdivision is feasible, the CO_2 output from the capture and purification system shall not receive the environmental impacts of the energy production, among which the CO_2 emission itself, and it shall receive the environmental impacts of the purification process. If only the subdivision between CHP and cultivation is feasible, the CO_2 output shall not receive the environmental impact of energy production nor purification. This impact goes to the energy production. If the subdivision between CHP and cultivation is not feasible, a theoretical subdivision shall be constructed by calculating all unknown energy inputs and output from the CHP from the known energy flows (see Section 6.2.2). Allocation between electricity and heat shall be carried out on energy content basis (see supplementary document on handling multi-functionality, Goglio et al. (2020)).
Crop co-product allocation	Economic	If a crop generates multiple outputs (e.g. fruit and trees; beans and straw) allocation will be done on the basis of relative revenue shares of the products using three years average prices sold at farm.
Transport (inbound and outbound)	Physical property defining load capacity	Allocation of transport emissions to transported products shall be done on the basis of physical causality, such as mass share, unless the density of the transported product is significantly lower than average so that the volume transported is less than the maximum load. Allocation of empty transport kilometres shall be done on the basis of the average load factor of the transport that is under study. If no supporting information is available, it shall be assumed that 100% additional transport is needed for empty return, which equals the utility rate of 50%. Further information on this allocation can be found in Section 4.4.3 (Zampori and Pant, 2019).
Storage to single product	Volume and time	Only part of the emissions and resources emitted or used at storage systems shall be allocated to the product stored. This allocation shall be based on the space (in m^3) and time (in weeks) occupied by the product stored. For this the total storage capacity of the system shall be known, and the product specific volume and storage time shall be used to calculate the allocation factor (as the ratio between product-specific volume*time and storage capacity volume*time). Further guidance on emission and resource allocation from storage can be found in (Zampori and Pant, 2019).

6.1.3 Electricity modelling

The HFCR follows the electricity modelling rules included in the PEF method (Zampori and Pant, 2019).

The following electricity mix shall be used in hierarchical order:

i. Supplier-specific electricity product shall be used if:
   a. available, and
   b. the set of minimum criteria to ensure the contractual instruments are reliable is met.
ii. The supplier-specific total electricity mix shall be used if:
   a. available, and
   b. the set of minimum criteria (see below) to ensure that the contractual instruments are reliable, is met.
iii. As a last option the 'country-specific residual grid mix, consumption mix' shall be used (available at JRC, 2020). Country-specific means the country in which the life cycle stage occurs. This may be an EU country or non-EU country. The residual grid mix characterises the unclaimed, untracked or publicly shared electricity. This prevents double counting with the use of supplier-specific electricity mixes in (i) and (ii).
iv. As a last option, the average EU residual grid mix, consumption mix (EU-28 +EFTA), or region representative residual grid mix, consumption mix, shall be used.

Note: if for a country, there is a 100% tracking system in place, case (i) shall be applied.

Note: for the use stage, the consumption grid mix shall be used as described in Section 6.2.7.

The environmental integrity of the use of supplier-specific electricity mix depends on ensuring that contractual instruments (for tracking) reliably and uniquely convey claims to consumers. Without this, the HFCR lacks the accuracy and consistency necessary to drive product/corporate electricity procurement decisions and accurate consumer (buyer of electricity) claims. Therefore, a set of minimum criteria that relate to the integrity of the contractual instruments as reliable conveyers of environmental footprint information has been identified. They represent the minimum features necessary to use supplier-specific mix within HFCR studies.

Please consult Zampori and Pant (2019) for further guidance on the following electricity modelling aspects:

- the set of minimum criteria to ensure contractual instruments from suppliers,
- how to model 'country-specific residual grid mix, consumption mix',
- a single location with multiple products and more than one electricity mix,
- multiple locations producing one product, and
- how to deal with on-site electricity generation.

6.1.4 Climate change modelling

Three main categories of greenhouse (GHG) emissions and removals shall be distinguished, each contributing to a specific sub-category of the impact category 'climate change':

1. Fossil GHG emissions and removals (contributing to the sub-category 'Climate change – fossil');
2. Biogenic carbon emissions and removals (contributing to the sub-category 'Climate change – biogenic');
3. Carbon emissions from land use and land use change (contributing to the sub-category 'Climate change – land use and land use change').

Credits associated with temporary and permanent carbon storage and/or delayed emissions shall not be considered in the calculation of the climate change indicator. This means that all emissions and removals shall be accounted for as emitted 'now' and there is no discounting of emissions over time (in line with ISO 14067:2018).

For a specific HFCR-compliant study, the sub-categories 'climate change – fossil', 'climate change – biogenic' and 'climate change - land use and land transformation', shall be reported separately if they show a contribution of more than 5% each to the total score of climate change.

6.1.5 Preferred Nitrogen and Phosphorus modelling

Nitrogen and phosphorus (N/P) emissions are calculated from N/P inputs into the cultivation system as, among others, synthetic fertiliser, manure and other organic fertilisers. In case of a rotation scheme organic N/P inputs shall be allocated to a specific crop based on guidance described in Section 6.1.2.
A preference level approach has been derived for the calculation of N/P related emissions.
The choice of preference level depends on data availability and the cultivation methods. We make a distinction in four types of cultivation:

- Open field soilless[5]
- Open field in soil
- Protected soilless
- Protected in soil

Requirements for use of preference levels and applicable system are given below, further details of N/P modelling can be found in the supplementary document (Memo on nitrogen and phosphorus emissions modelling, Kool and Blonk (2020)).

6.1.5.1 **Nitrate emissions**

Nitrate emissions shall be preferably calculated using either 'measurement' or the preferred modelling method. If insufficient data are available, then default EC PEF agricultural modelling may be applied. This shall be recorded and reported in the report of the HFCR study.

Table 17 *Measurement and modelling options for nitrate emissions*

Preference level	Open field soilless	Open field in soil	Protected soilless	Protected in soil
Measurement	**Measured nitrate releases,** if closed recirculation and measurements nitrate concentration and volume of discharged water available	**Non applicable**	**Measured nitrate emissions**, If closed recirculation and measurements nitrate concentration and volume of discharged water available	**Non applicable**
Preferred modelling*		**Runoff and leaching compliant to Miterra-Europe model** (Velthof et al. (2007, 2009)**)**		**Runoff and leaching compliant to Miterra-Europe model** (Velthof et al. (2007, 2009)**)**
Default modelling*	Based on **IPCC, Tier 1**	Based on **IPCC, Tier 1**	Based on **IPCC, Tier 1**	Based on **IPCC, Tier 1**

* Parameters for calculation provided in Sections 2.3 and 2.4 of the supplementary document (Memo on nitrogen and phosphorus emissions modelling, see Kool and Blonk (2020).

6.1.5.2 **Ammonia volatilisation**

Ammonia emissions shall be preferably calculated using the preferred modelling method. If insufficient data are available, then default EC PEF agricultural modelling may be applied. This shall be recorded and reported in the report.

[5] We assume a situation where the soil is completely covered by a material that prevents precipitation flowing to the soil and cultivation takes place in a substrate on top of this material.

Table 18 Measurement and modelling options for ammonia volatilisation

Preference level	Open field soilless	Open field in soil	Protected soillesss	Protected in soil
Preferred modelling*	Modelled NH_3 volatilisation from fertiliser use (Bouwman et al., (2002))	Modelled NH_3 volatilisation from fertiliser use (Bouwman et al., (2002))	Modelled NH_3 volatilisation from fertiliser use (Bouwman et al., (2002))	Modelled NH_3 volatilisation from fertiliser use (Bouwman et al., (2002))
Default modelling*	Based on **IPCC, Tier 1**	Based on **IPCC, Tier 1**	Based on **IPCC, Tier 1**	Based on **IPCC, Tier 1**

* Parameters for calculation provided in Sections 3.1 and 3.2 of the supplementary document (Kool and Blonk (2020)).

6.1.5.3 Nitrous oxide (direct)

As default modelling the IPCC 2006 Guideline (IPCC 2006) is followed. Parameters for modelling can be found in Section 4 of Kool and Blonk (2020).

6.1.5.4 Nitrous oxide (indirect)

Indirect nitrous oxide emissions are determined by ammonia volatilisation and nitrate leached (Sections 6.1.5.1 and 6.1.5.2). Default modelling for the indirect nitrous oxide emissions shall be based on these N-losses, following the IPCC Guidelines (IPCC 2006). Parameters for modelling can be found in section 5 of Kool and Blonk (2020).

6.1.5.5 Nitrogen oxides

The default modelling for Nitrogen oxides (NO_x) emissions depends on the way ammonia volatilisation is calculated. If ammonia volatilisation is calculated using IPCC Tier 1, nitrogen oxide emissions are not relevant because in the IPCC ammonia approach (IPCC 2006) the NO_x emissions are included.

If ammonia volatilisation is calculated using the preferred modelling TIER level, the approach to ammonia calculation shall follow the approach based on European Environmental Agency (2016). Section 6 in Kool and Blonk (2020) provides formulas and parameters to follow the latter approach.

6.1.5.6 Phosphate

Following PEFCR guide 6.3 (EC, 2018) the order of preference to model phosphate emissions is as follows:

1. 'The LCI should be modelled as the amount of P emitted to water after runoff and the emission compartment 'water' shall be used.'
2. 'The LCI may be modelled as the amount of P applied on the agricultural field (through manure or fertilisers) and the emission compartment 'soil' shall be used.'

In the case of measured amounts of phosphate discharged in wastewater to surface water or sewage system, the first option shall be used. Comparable with nitrate, phosphate measurements are only representative/accurate in completely closed recirculation systems, where all discharged water is monitored on phosphate content. In that case the phosphate emissions are calculated as volume discharged water times the measured phosphate concentration. This implies that for cultivations in the soil, regardless if it is protected, measurements of phosphate emissions are not applicable.

6.1.6 End-of-life modelling

The waste-related activities (transport, treatment, etc.) of products used during the manufacturing, distribution, retail, the use stage or after use shall be included in the overall modelling of the life cycle of the organisation. Overall, this shall be modelled and reported at the life cycle stage where the waste occurs.

The waste-related activities of the product studied shall be included and reported in the end-of-life life cycle stage. All modelled EoL processes shall be connected to the appropriate secondary data for municipal waste management processes.

6.1.6.1 **Circular footprint formula**

To model the end of life of products, this document aligns to PEF guidance using the circular footprint formula (CFF), integrating burdens and benefits of using and producing recycled materials in any stage of the life cycle under study. The CFF shall be applied in all cases where materials are recycled and shall be followed according to the prevailing situation at the point of substitution (i.e. where the recycled material is introduced).

The Circular Footprint Formula is a combination of three elements 'material + energy + disposal', i.e.:

Material

$$(1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times \left(E_{recyclingEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P}\right)$$

The material part of the CFF equation integrates the production and end of life of materials in the life cycle of a product. It calculates the burdens and potential benefits of the production of virgin and recycled materials in the manufacture of a product and the burdens and potential benefits of recycling the material at end of life.

Energy

$$(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

The energy part of the CFF refers exclusively to end of life activities. It deals with the specific emissions and resources arising from energy recovery and the potential benefits arising from recovering this energy.

Disposal

$$(1-R_2-R_3) \times E_D$$

The disposal part of the CFF refers exclusively to end of life activities where no recycling occurs, or energy is recovered. These refer to emissions and inputs related to the local waste management system.

A full description of the CFF parameters for each section of the formula is given in Table 19.

Table 19 *List of parameters of the Circular Footprint Formula*

Parameter	Description	Remarks
A	allocation factor of burdens and credits between supplier and user of recycled materials	Values between 0 and 1
B	allocation factor of energy recovery processes: it applies both to burdens and credits; it shall be set to 0	
Q_{Sin}	quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution	
Q_{Sout}	quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution	
Q_P	quality of the primary material, i.e. quality of the virgin material	
R_1	proportion of material in the input to the production that has been recycled from a previous system	
R_2	proportion of the material in the product that will be recycled (or reused) in a subsequent system	
R_3	proportion of the material in the product that is used for energy recovery at EoL	
$E_{recycled}$	specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process	LCI dataset
$E_{recyclingEoL}$	specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process	
E_v	specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material	
E^*_v	specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials	
E_{ER}	specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, …)	
$E_{SE,heat}$	specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted heat	
$E_{SE,elec}$	specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted electricity	
E_D	specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analyzed product, without energy recovery	
$X_{ER,heat}$	efficiency of the energy recovery process for heat	Values between 0 and 1
$X_{ER,elec}$	efficiency of the energy recovery process for electricity	
LHV	Lower Heating Value of the material in the product that is used for energy recovery	Value

If not all factors in the CFF are known, default parameters are available. Practitioner shall use default values available in the most recent version of Annex C of the PEF and OEF methods (see JRC, 2020).

6.1.6.2 **Growing media**

For the specific case of growing media (substrate), emissions occur during the life cycle due to the oxidation of carbon present in peat constituents. These emissions shall be accounted in all HFCR studies and shall be reported in the EoL stage of the horticultural product.

The following approach shall be used to calculate the emissions related to the growing media EoL.

Peat-based constituents
Carbon content of peat constituents shall be reported for the growing media used in cultivation. This shall be based on primary data.
Peat constituents carbon oxidation, shall be modelled as per guidance given in PAS 2050-1 (BSI 2012), summarised as below considering two cases:

a. Indoor use
   Peat oxidation shall be calculated by considering a default 1% oxidation per week until full oxidation of carbon present in peat (based on carbon content primary data in cultivation). If peat is transferred to a subsequent economic activity, the remaining carbon content of the peat shall be provided, and the same consideration of 1% oxidation per week shall be made until full oxidation, in which case the remaining CO_2 emissions shall be part of the subsequent economic activity.

If there is no additional economic application but the peat growing media is disposed at open field, then full CO_2 decomposition shall be attributed to the last economic activity considering the carbon content of peat as introduced to that particular economic activity.

b. Open field
   When peat constituents are applied in open field or for gardening, it shall be assumed that the peat carbon content (based on primary data in cultivation) is oxidised completely.

The mineralisation of nitrogen content of the growing media constituents is excluded from the EoL modelling as it is small compared with the added nutrients in cultivation and no good data to estimate the rate and proportion of decomposition was found.

Additives
Emissions related to the addition of nutrients to the growing media shall be accounted for. The full nutrient content and limestone content shall be reported.

Nitrate emissions are calculated according to the IPCC 2006 Guideline (IPCC 2006), in which 30% of the applied nitrogen is emitted as nitrate. Ammonia volatilisation is calculated according to the IPCC 2006 Guideline (IPCC 2006) whereas a fraction of the applied nitrogen is emitted to the air as ammonia. Both nitrous oxide (direct and indirect) emissions shall be calculated using IPCC 2006 Guideline (IPCC 2006).

CO_2 emissions from lime used directly as additive or lime containing additives shall also be modelled following IPCC guidance (IPCC 2006).

Due to the small input of nutrients in growing media compared to the use of fertiliser in the horticultural sector, nitrogen and CO_2 emissions from growing additives shall be assumed to be fully emitted and attributed to the first user of the growing media, regardless if the mix is reused later.

If growing media is reused, nutrient content shall be assumed exhausted and therefore no emissions shall be attributed to that the following economic activity.

6.2 Activity data collection

This section provides guidance on primary activity data collection and modelling for processes necessary to build the life cycle inventory of the different life cycle stages in this HFCR.

Primary activity data shall be collected if this is required according to the data needs matrix defined in the latest PEFCR guidance (Zampori and Pant, 2019). In summary, primary company-specific data is required if the process is run by the company, and data of sufficient quality, as assessed by the study practitioner, is required for all other processes. The data needs matrix could be used as a guideline for data quality assessment. The Data Quality Requirement criteria tables could be used as a guideline to optimise quality of primary and secondary data. Both tables and matrix are available in Zampori and Pant (2019). The following paragraphs and 'shall' provisions apply for the respective life cycle stages, only if the data needs matrix defines that primary data is required for a specific life cycle stage. In other cases, it is recommended to follow the 'shall' provisions in any case, for all life cycle stages.

6.2.1 Cultivation

The following activity data shall be collected for cultivation:
1. Historical data on area and plot use (needed for land use change)
2. Yield data
3. Crop rotation scheme data
4. Plant input material
5. Growing media
6. Capital goods depreciation

7. Water
8. Plant protection active ingredients use (chemicals and minerals)
9. Biological pest control
10. Synthetic and mineral fertilisers
11. Organic fertilisers
12. CO_2 as a fertiliser
13. Electricity
14. Heat
15. Fuels
16. Materials use
17. Waste

All data are collected per gross area of farm plots being part of the study. By combining yields, allocation data (e.g. prices of co-products) and the other data points, the data are transferred to data per unit of product.

For all cultivation data it is important to carefully define the average performance of the production system considering the variation in inputs and outputs related to climate variation. For perennial plants it is crucial to have a representative contribution of the different growth phases in the production system.

In most situations for annual and perennial plants it is preferable to have averages over three consecutive years for all data points.

6.2.1.1 **Historical data area on plot use**

For the farm plots where the crop(s) under study data are grown, data shall be collected on area use and on the history of the plot if a specific LUC calculation is done. If the farm (plots) have a proven history of no land use change for more than 20 years this means that there is no GHG impact of land use change. If no data on land use history are collected the default land use change data for the crop country combination shall be used according to the latest version of the land use change tool (Blonk Consultants, 2018).

6.2.1.2 **Yield data of main product and co-products**

Main crop products are the harvested products of the crop under study. Co-crop products are plant parts that are harvested for other use than the main product, e.g. bean straw or fruit tree wood.

Yields of main and co-products shall be collected in physical terms (weights or units depending on the functional unit) and economic terms (revenues of the yields for allocation) based on bookkeeping data that can be verified and comply to the requirements on steady state (Section 6.1.1).

6.2.1.3 **Crop rotation scheme data**

If crops are grown in a crop rotation scheme, data shall be collected and recorded for three subsequent years, concerning:
- The area of all plots being part of the crop rotation system (mostly equal to the crop land owned by the farmer)
- Per plot per year the application of organic fertilisers (in weight units)
- Per plot per year the yield of crops (per type of crop)
- Per plot per year the ‘yield’ of ‘green manure’ crops
- Per plot per year the gross area of the plot (so including the margins)

6.2.1.4 **Plant input material**

Plant input material can be seeds, seedlings or young plants. As activity data the number of seeds, seedlings and young plants needed per area is collected, next to the origin, the way of transport and the packaging, container and growing media use. For the production and logistics of plant input material secondary data may be used.

6.2.1.5 **Growing media**

For growing media data shall be collected on the quantity in volume/weight, origin and packaging material. Also, the share of carbon in the growing media that is considered as fossil shall be collected (peat constituent carbon content). The use of growing media materials shall be recorded per type of growing media on an annual basis. If growing media is used for a longer period than a year, then, the annual usage shall be defined. Growing media may contain nutrients. If that is the case the content shall be recorded. The following data shall be collected: N content, C content, P content, dry matter. For the production and logistics of growing media secondary data may be used. The end of life of growing media shall be modelled based on guidance given in Section 6.1.6.2.

6.2.1.6 **Capital goods in protected cultivation**

The greenhouse in protected cultivation shall be included in the life cycle inventory of HFCR studies. Practitioner may collect primary data when available. An overview of the data that needs to be collected is provided in the supplementary documents (Memo on capital goods modelling, see Kan and Vieira, 2020). In case no primary data is available, the practitioner shall use the default data provided in the same document. The default data in the capital goods memo are derived from (Montero et al., 2011).

Capital goods depreciation shall be taken into account in all cases. Linear depreciation shall be used. The expected service life of the capital goods shall be taken into account. By combining the material bill of the greenhouse, the total size, and the expected lifetime of the greenhouse, the material use in number of greenhouses is established. If there is no specific information on the lifetime of the greenhouse, the default lifetime of 15 years (Montero et al., 2011) shall be assumed. To calculate the input of greenhouse per unit of product (in mass), the total yield shall be divided by the size of the greenhouse, the expected lifetime of the greenhouse and, in case of different crops grown after each other, the share of cropping time it takes to grow the product. For a multi tunnel greenhouse, the same calculation shall be made.

$AGH_p = (AGH_T * CT_p / CT_T) / (LTGH * YGH)$

In which
AGH_p = the area of the greenhouse per mass of crop p (ha / t)
AGH_T = the total area of the greenhouse (h)
CT_p = the cropping time (length of the cropping period) of crop p (weeks)
CT_T = the total cropping time (weeks)
LTGH = the life time of the greenhouse (yr)
YGH = the yield of the product for the entire greenhouse (t/yr)

For instance, in a greenhouse of 5 ha that has an expected lifetime of 15 years, 1,500 tonnes of tomatoes are grown, and the cropping period is 52 weeks out of 52 weeks total cropping period. In that case the area of greenhouse per tonne of tomatoes is:

$AGH_{tomatoes} = (5 * 52 / 52) / (15 * 1500) = 2.2E\text{-}04\ ha / t$

For instance, in a greenhouse of 1 ha that has an expected lifetime of 15 year, 200 tonnes of tomatoes and 50 tonnes of lettuce are grown, and the cropping period of tomatoes is 36 weeks out of a total cropping period of 48 weeks. In that case the area of greenhouse per tonne of tomatoes is:

$AGH_{tomatoes} = (1 * 52 / 52) / (15 * 200) = 2.5E\text{-}04\ ha / t$

6.2.1.7 **Water**

The following water flows shall be monitored:
- Irrigation water
- Other blue water use

Irrigation water is crop specific (except for green manure which is distributed over all crops). The flow of irrigation water can be measured/estimated with several methods. This shall be recorded as well as the source of the irrigation water.

Table 20 *Water use activity data collection*

Activity data	Unit per gross area per year per crop	Quantity	Water source (well, canal/river, lake, tap water)	Source and method of measurement
Irrigation water	m^3/ha			
Other water use	m^3/kg crop			

If irrigation water is measured over the season continuously so that the balance of evapotranspiration and irrigation water can be calculated, then a higher Tier level nitrate emission calculation can be conducted (Section 6.1.5.1).

6.2.1.8 **Plant protection active ingredients data**

Data shall be collected on all use of plant protection ingredients such as herbicides, insecticides, fungicides, biocides, soil fumigants in all stages of cultivation and storage. This data involves the specific active ingredient and its CAS number, the application rate in grams per year per area unit or per crop weight unit for the crop under study. The active ingredients can be organic or inorganic chemicals such as S and Cu compounds.

The impact of crop protection active ingredients depends on the farm system, climate conditions, the distance to surface area, the spraying technology etc. In this version of the HFCR, no specific emission model is recommended that differentiates to these parameters so there is no need to collect this information. Further details are provided in the supplementary document (Memo on transfer fractions of plant protection products, Helmes (2020)). The distribution percentages of the active ingredients may be improved beyond the default of 9% to soil, 9% to air and 1% to freshwater from Zampori and Pant (2019).

6.2.1.9 **Biological pest control**

Since secondary data on biological pest control are not available, no data collection is needed here.

6.2.1.10 **Synthetic and mineral fertilisers**

For synthetic and mineral fertilisers data shall be collected on the application of N, P, K, $CaCO_3$ and other Calcium compounds. Data on N fertilisers shall be split in ureum and other N compounds. For N, P, K compounds preferably also data on compounds use shall be collected for more precise calculations. The data shall be specified in weight per area for the crop under study.

Table 21 *Fertiliser use activity data collection table for default modelling*

Activity data	Unit per gross area per year	Quantity	Source and method of measurement
Fertiliser brand or type name and composition	Kg /ha		
Calculated N use	Kg N/ha		
Calculated P use	Kg P/ha		
Calculated K use	Kg K/ha		
CaO use	Kg CaO/ha		
$CaCO_3$ use	Kg $CaCO_3$/ha		

The impact of N fertiliser use depends on several parameters. To apply the preferred modelling for calculating nitrate emissions from run-off, leaching and for calculating ammonia emission as mentioned in Section 6.1.5, the following additional data shall be collected on the farm situation

(Table 22), including slope, precipitation, soil properties and temperature. N compound use (Table 23) and way of application of N compounds (Table 24).

Table 22 *Farm situation classification to be used for more detailed modelling of N emissions to air and water*

Parameter	Relevant for	Classification	Fill in your situation
Slope	Nitrate, runoff; formula 2, Annex II	0<8%	
		8<15%	
		15<25%	
		≥25%	
Precipitation surplus	Nitrate, runoff; formula 2 Annex II Nitrate leaching; formula 5 Annex II	<50 mm	
		50<100 mm	
		100<300 mm	
		≥300 mm	
Mineral soils, clay content	Nitrate, runoff; formula 2 Annex II	<18%	
		18<35%	
		35<60%	
		≥60%	
		Peat soils	
Soil organic C content	Nitrate leaching; formula 5 Annex II	<1%	
		1%<2%	
		2%<5%	
		≥5%	
Depth soil to rock	Nitrate, runoff; formula 2 Annex II	≤25 cm	
		>25 cm	
Acidity of soil pH	Ammonia volatilisation; formula 6 Annex II	<5.5	
		5.5≤7.3	
		7.3≤8.5	
		>8.5	
CEC[a]	Ammonia volatilisation; formula 6 Annex II	≤16	
		16≤24	
		24≤32	
		>32	
Average annual temperature	Nitrate leaching; formula 5 Annex II Ammonia volatilisation; formula 6 Annex II Nitrous oxide (direct); formula 9 Annex II	<5 ºC	
		5<10 ºC	
		10<15 ºC	
		15<18 ºC	
		18<20 ºC	
		>20 ºC	

[a] CEC = cation exchange capacity of the soil/substrate.

Table 23 *Differentiation of N compounds for more detailed ammonia emissions calculation*

Type of N Compound	Amount in kg N
Ammonium sulfate (AS)	
Urea	
Ammonium nitrate (AN)	
Calcium Ammonium nitrate (CAN)	
Anhydrous Ammonia (AA)	
Other straight N	
Nitrogen solutions	
Ammonium phosphates (mono-ammonium and diammonium phosphate)	
other compound NP	
compound NK	
compound NPK	
Ammonium Bicarbonate	

In the case that no information is available on which N-fertilisers are used (as described in Table 23) country specific defaults based on the average N-fertiliser use may be used (see supplementary document, Kool and Blonk (2020)).

Table 24 *Differentiation in way of application of N compounds for more detailed ammonia emissions calculation*

Way of application	Fill in your situation
broadcast	
broadcast to floodwater	
incorporated	
solution	
broadcast and then flooded	
incorporated and then flooded	
broadcast to floodwater at panicle initiation	

6.2.1.11 **Organic fertilisers**

Organic fertilisers are products originating from a wide range or sources, such as animal manure, co-products from industry and compost. The following data shall be collected on organic fertilisers:

- Fertiliser type (animal type, from conventional or organic farming)
- Fertiliser composition: water, Total N, organic bound N, mineral N, P, K, Cd, Zn, Cu
- Transport distance

For the production of organic fertiliser and the composition of trace elements Cd, Zn and Cu secondary data may be used. For the composition of N, P and K, fertiliser type and the transport distance primary data shall be used.

6.2.1.12 **Nitrogen and Phosphorous balance**

To get the full picture of N and P use, the fate of the nutrients and the environmental impact modelling, a balance per area unit shall be made according to Table 25.

Table 25 *N and P nutrient application balance per area unit*

	Nutrient application on the field during cultivation of the crop	Nutrient application due to crop rotation related fertiliser application	Nutrient uptake by the crop (main product plus co-product)	Nutrient uptake by crop residues	Nutrients discharged to surface or sewage water system after recirculation	Remaining nutrients
N						
P						

If a recirculation system is in place farm system emissions to surface water shall be calculated directly from the discharged quantities.

6.2.1.13 **CO_2 as a fertiliser**

CO_2 is used as a fertiliser in greenhouses. It can be produced by farmers themselves in a CHP (see Section 6.2.2 for the calculation of the environmental impact at CHP production). Data shall be collected on the quantity in weight unit per area unit for the area where the crop under study is grown.

For the purification and logistics of CO_2 as a fertiliser from a third party supplier, secondary data may be used.

In most cases, CO_2 is a waste product and thus shall be modelled as such: only the inputs required to capture, process, store and transport the CO_2 to the greenhouse shall be included. The resulting CO_2 emissions shall be allocated to the original process, e.g. heat and electricity when produced on-site.

The source of CO_2 used in greenhouse crops should be clearly defined in the HFCR study together with at least basic assessment of the uncertainties related to the impact of CO_2 production and handling of CO_2 used during crop growth.

6.2.1.14 **Electricity**

Electricity data shall be collected according to the generic PEF methodology explained in Section 6.1.3, which implies that a specific consumption mix can be accounted for if the conditions on validation are met. Electricity flows from a CHP to a greenhouse of the same owner may be calculated from the CHP efficiency and external electricity deliveries (e.g. to the grid).

6.2.1.15 **Heat**

For heat, data shall be collected on the energy content use per hectare. For the production of heat from a CHP at a farm (own or neighbour) primary data of suppliers shall be used under the condition that the data is generated according to the allocation rules described in Section 6.1.2. Heat flows from a CHP to a greenhouse of the same owner may be calculated from the CHP efficiency and external heat deliveries. For heat from other sources secondary data may be used.

6.2.1.16 **Fuels**

For fuel use data shall be collected per area unit and shall include:

- Fuel type
- Energy content of the fuel specified in HHV or LHV
- Fuel mix (for instance if biogenic fuels are mixed in) in relative shares of fuels
- Quantity of the fuel in weight and energy units
- Origin of the fuel

This information will be used to match the most adequate secondary datasets for production of fuels and combustion of fuels.

6.2.1.17 **Materials use**

There can be a wide variety of material use at a farm. The following types shall be added in the inventory, whenever occurring:

Materials used for containing substrate (growing media)

The use of substrate material as a growing media goes along with material use for containing the substrate. These can be foils or more rigid packaging such as containers for pot soil. Pots can come with the young plant material and can be added at a later during the growing phase. All materials used (both incoming with young plant material and added later) shall be recorded in weight units per hectare and per product.

Materials used for soil covering

Materials used for soil covering may be relevant in open field and protected farm systems. It concerns the use of natural materials such as mulch or straw and synthetic materials such as plastics.

Materials used for guiding plants

Many fruit containing plants are led and supported. For this purpose, a wide variety of constructions are developed consisting of a range of materials, such as wood, steel and plastics.

Materials used for lifting plants to ease handling

Potted plants and plants grown in substrate systems such as strawberries are mostly lifted from the ground to make handling easier. These materials shall also be included.

For all the materials used, the quantities shall be recorded in weight units per year per hectare and per unit of product if that is needed for the calculations to product units. The following data points shall be recorded.

- Type of material
- Origin of production
- Share of recycling
- Type of waste processing

This information shall be used to match the most adequate secondary datasets for production of materials and waste processing.

6.2.1.18 **Waste**

Farm waste consists of plant and crop remains (organic) and of wasted materials. Since organic farm waste quantities are mostly not excessive there is no need to quantify this. For materials waste the waste scenario is included in the Circular footprint formula detailed in Section 6.1.6.1.

6.2.2 Heat and electricity systems

A combined heat and power (CHP) system can provide heat and electricity for a horticultural producer. The practitioner shall gather activity data from the operation inputs and outputs of the CHP system. Activity data shall be collected, dividing the CHP unit to the smallest unit possible, being 1) the cultivation activities, 2) the CHP system and 3) the flue gas cleaning system (**Error! Reference source not found.**).

If the subdivision is not feasible, activity data shall be collected on the CHP including the flue gas cleaning system and the cultivation separately. If the subdivision between CHP and cultivation is not feasible, a theoretical subdivision shall be constructed by calculating all unknown energy inputs and output from the CHP from the known energy flows.

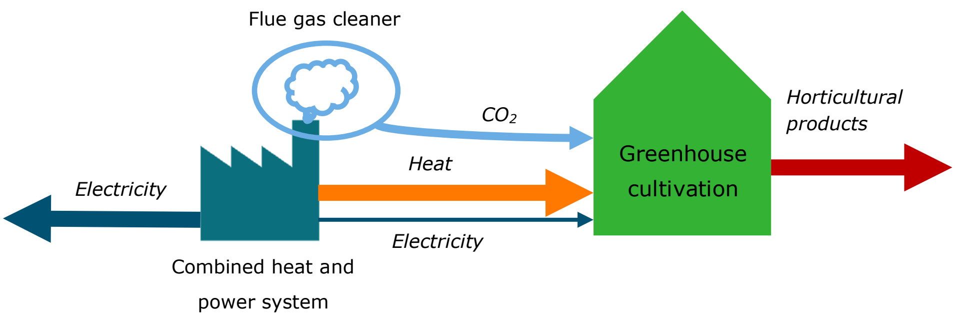

Figure 2 *Graphical representation of the heated greenhouse processes, subdivided into three unit process and the product flows*

Activity data for the CHP unit shall include:

i. The type and quantity of fuel used by the CHP per unit of energy produced. The amount and type of fuel shall be connected to appropriate secondary data for fuel production.

ii. The environmental interventions related to the CHP unit, shall be calculated. This shall be done applying the following provisions:
   - Carbon dioxide (CO_2) emissions to air shall be determined in the following order of preference:
     - The emission shall be collected from direct measurement or a documented prior measurement of the CHP unit considered.
     - If direct measurement is not available, the emission shall be collected from a data source specific to the installation, such as a technical specification document.

- If a technical specification is not available, a public source, clearly stating average emissions from CHPs in general representative for the country of cultivation shall be used.
- If a public source is not available, secondary data from scientific papers or LCA databases are accepted.

- All emissions for different cases within the same study shall be from the same type of data source. Note that CO_2 may be used in the cultivation process, however CO_2 is considered a direct emission of the CHP heat and electricity production and shall not be attributed to any other stage in the cultivation process. As per Section 6.1.2, if CO_2 is used as fertiliser, the flue gas cleaning activities for the purification of CO_2 can be attributed to the production of CO_2 and its use as fertiliser in the cultivation process.
- Methane (CH_4) emissions to air from natural gas should be directly measured from CHP unit operation considering mg of C loss per m^3 of natural gas, assuming all C lost is CH_4. If no measurement is available, a default worst case scenario of 2.8% of fuel loss shall be assumed. Methane emissions from combustion of fuels other than natural gas shall be determined using the specific fuel heating value and carbon emission factors per energy unit.
- Nitric oxide (NO_x) emissions to air shall be calculated using the EMEP/EEA Tier 1 approach mg emission per MJ of fuel.
- Sulphur dioxide (SO_2) emitted to air shall be calculated using the EMEP/EEA Tier 1 approach mg emission per MJ of fuel.

iii. Electricity and heat output per unit of fuel used shall be recorded. The activity data and environmental interventions from CHP shall be allocated to the heat and electricity outputs as per indication provided in Section 6.1.2.

6.2.3 Packaging

If packing is a separate operation the fuel and electricity use shall be collected. Electricity use data shall be collected according to the generic PEF methodology explained in Section 6.1.3, which implies that a specific consumption mix can be accounted for if the conditions on validation are met.

The use of packaging material for the products being distributed to the customer shall be quantified for primary (having direct contact with the product), secondary (packing the packed products for transport) and tertiary packaging materials. The weight of material used to fulfil the functional unit, shall be recorded.

The end of life of packaging materials shall be considered in this life cycle stage. The production and EoL modelling of packaging materials shall follow the formula and method explained in Section 6.1.6 of this document.

For primary packaging materials at least the parameter information for recycling, reuse and waste handling shall be collected. For secondary and tertiary packaging, default parameter settings according to the PEFCR guidance shall be used. These are provided per material and country in Annex C of the PEF guidance document (Zampori and Pant 2019).

6.2.4 Storage

Electricity use for climate control is the main activity data that shall be collected.

Electricity use data shall be collected according to the generic PEF methodology explained in Section 6.1.3, which implies that a specific consumption mix can be accounted for if the conditions on validation are met. If the storage operation takes place at the farm no specific electricity use data needs to be collected. Often storage is not used for a single product, when this is the case, emissions and resource use from storage shall be allocated to the product under study based on guidance provided in Section 6.1.2.

6.2.5 Distribution

Outbound transport is a mandatory company-specific process. Primary data shall be collected for distribution operations to final client (either B2B or B2C).
This may be done with different levels of accuracy, as indicated in the hierarchy below from the most accurate to the least accurate, depending on data availability:

1. Fuel consumption for producer means of delivery and transport to user.
2. Producer specific delivery distance and means of transportation.
3. Average fuel consumption per m^3 delivered and means of transport.
4. Average distance from cultivation to final user and transport means.

If actual fuel use data of outbound transport can be collected, because there is a suitable accounting system in place, these data shall be used. Fuel use data shall be connected to secondary data of fuel production and combustion. Actual fuel use data shall be collected following Table 26.

Table 26 *Data collection table for fuel use in outbound transport (when fuel data available)*

Activity data	Unit *	Quantity	Technology (EURO class 1,2,4,3,5, or 6)	Source and method of measurement
Fuel (type 1)	unit/ tonne delivered product (specify unit)			
Fuel (type 2)	unit/ tonne delivered product			
Fuel (type 3)	unit/ tonne delivered product			
Fuel (type 4)	unit/ tonne delivered product			

If data on actual fuel use are not available, then the outbound transport shall be assessed through distances according to steps 2 or 4 of the hierarchy indicated above and connected to appropriate secondary datasets for the corresponding means of transportation.

6.2.6 Retail

Activity data for the retail stage shall be modelled using default data as provided in (Zampori and Pant 2019).

Section 4.4.5 of the PEFCR guidance document (Zampori and Pant, 2019) provides default energy and refrigerant gas consumption for food and non-food products in the retail stage. These data shall be coupled to appropriate secondary data on fuel/energy production and consumption.

The wastage of products during distribution and retail shall be included in the modelling. Annex F of the PEFCR guidance (Zampori and Pant, 2019), provides default loss rates per type of product. The default loss rate (incl. broken products but not products returned to manufacturer) during distribution (overall consolidated value for transportation, storage and retail place) for fruits and vegetables is 10% as prescribed in the Annex F of Zampori and Pant (2019). This shall be reflected in the study reference flow (e.g. 1 kg of apples at consumer means 1.1 kg of packed apples prior to storage (weight exclude the packaging waste)).

To model the EoL of waste product in the distribution and retail (see Section 6.1.6), default assumptions shall be considered for the fate of losses at the distribution centre, during transport and at retail place, (Zampori and Pant 2019):

- Food products are assumed to be 50% trashed (i.e., incinerated and landfilled in municipal waste management system), 25% composted and 25% methanised.
- Product losses (excluding food losses) and waste from packing/repacking/unpacking at distribution center, during transport and at retail place: all waste is assumed to be 100% recycled.
- Other waste generated at the distribution centre, during transport and at the retailer (except food and product losses) such as repacking/unpacking are assumed to follow the same EoL treatment as for home waste.

6.2.7 Use

One of the most important aspects of the use phase of fruits and vegetables is the mass balance. How much of the product is actual used and what does that mean for the amount of product to be sold to fulfil the functional unit. 'Losses' can be intentional (peeling an apple, removing the pit) or unintentional (losses from storage or preparing too much). A part of the 'loss' is also due to evaporation of fruits and vegetables.

Electricity use is important for cooling and electricity and fuels use for preparation. For this specific data may be collected or default data from the JRC guidance document used.

Unless more detailed data are collected for preparation, cooking secondary data may be used. The waste of products during the use stage shall be included in the modelling. User specific information may be used. If real losses are unknown, default values for fruits and vegetables losses shall be used: 19% for fruits and vegetables and 0% for cut-flowers, potted plants, bulbs and seeds, as available in Annex F of Zampori and Pant (2019). This means that if in the scope of an HFCR study, the use phase is considered, the reference flow shall be adapted to consider these losses.

For example, in a study where the functional unit is 1 kg of apples to be consumed, and the system boundary is set from cradle to grave, the reference flow shall be 1.19 kg of apples. Considering the losses in the use phase, 1.19 kg is necessary to deliver 1 kg of apples to be consumed.

Following Zampori and Pant (2019), for the use stage the consumption grid mix shall be used. The electricity mix shall reflect the ratios of sales between EU countries/regions. To determine the ratio a physical unit shall be used (e.g. number of pieces or kg of product). Where such data are not available, the average EU consumption mix (EU-28 + EFTA) or region representative consumption mix, shall be used.

6.2.8 End of life

The end of life of horticultural products shall be modelled following instructions given in Section 6.1.6. For this, the carbon (peat origin) and nutrient content of growing media shall be collected as per guidance given in Section 6.1.6.2.

6.3 Which secondary datasets to use?

Processes not modelled using primary activity data shall be connected to secondary (background) data. This HFCR provides no direct recommendation on what data sources to use as background data. Practitioner is free to choose a suitable life cycle inventory database to perform its LCA in accordance to this HFCR.

7 HFCR results and reporting

This chapter provides the template for HFCR studies that should be used in documenting and communicating the results.

Results of a HFCR studies shall be communicated, using the following checklist:

ITEM	Included in the study (Y/N)	Section	Page
Summary			
General information about the product			
General information about the company			
Diagram with system boundary and indication of the situation according to DNM			
List and description of processes included in the system boundaries			
List of co-products, by-products and waste			
List of activity data used			
List of secondary datasets used			
Data gaps			
Assumptions			
Scope of the study			
(sub)category to which the product belongs			

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Appendix 1 Methodological background from PEFCR Guidelines (Zampori and Pant, 2019), selected

This appendix presents most relevant methodological assumptions as stipulated in PEFCR Guidelines (Zampori and Pant, 2019). These are repeated here on the basis of discussions with professionals from the horticultural sector who are considered non-LCA professionals. This repetition is solely meant to improve the readability of the document for non-LCA professionals.

DEFINITIONS OF ENVIRONMENTAL FOOTPRINT IMPACT CATEGORIES
While Table 5 in the main text refers to 16 Impact Categories (IC) that are to be assessed when performing a PEF study, the previous version of the guidelines (EC, 2018) referred to 15 ICs.

The following definitions of 15 EF impact categories are considered in RP-studies and are copied from the EU PEF website (EC, 2020).

CLIMATE CHANGE
All inputs or outputs that result in greenhouse gas emissions. The greatest contributor is generally the combustion of fossil fuels such as coal, oil and natural gas. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale.

Unit of measurement: Kilogram of Carbon Dioxide equivalent (kg CO2 eq). During the calculations, the global warming potential of all greenhouse gas emissions are compared to the amount of the global warming potential of 1 kg of CO_2.

OZONE DEPLETION:
The stratospheric Ozone (O3) layer protects us from hazardous ultraviolet radiation (UV-B). Its depletion can have dangerous consequences in the form of increased skin cancer cases in humans and damage to plants. The stratospheric ozone depletion is an impact which affects the environment on a global scale.

Unit of measurement: kilogram of CFC-11 equivalent (kg CFC-11 eq). During the calculations, the potential impacts of all relevant substances for ozone depletion are converted to their equivalent of kilograms of Trichlorofluoromethane (also called Freon-11 and R-11).

HUMAN TOXICITY – CANCER EFFECTS:
Potential impacts on human health caused by absorbing substances through the air, water and soil. Direct effects of products on humans are currently not measured. Cancer in humans is an impact which predominantly affects people at local and regional scale.

Unit of measurement: Comparative Toxic Unit for humans (CTUh). This is based on a model called USEtox.

HUMAN TOXICITY – NON-CANCER EFFECTS:
Potential impacts on human health caused by absorbing substances the air, water and soil. Direct effects of products on humans are currently not measured. Human toxicity is an impact which predominantly affects people at local and regional scale.

Unit of measurement: Comparative Toxic Unit for humans (CTUh). This is based on a model called USEtox.

ECO-TOXICITY – FRESH WATER ACQUATIC:
Potential toxic impacts on an ecosystem, which may damage individual species as well as the functioning of the ecosystem. Some substances have a tendency to accumulate in living organisms. Eco-toxicity is an impact which predominantly affects the environment at local and regional scale.

Unit of measurement: Comparative Toxic Unit for ecosystems (CTUe). This is based on a model called USEtox.

PARTICULATE MATTER – RESPIRATIRY INORGANICS
The adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx, SO_2). Usually, the smaller the particles are, the more dangerous they are, as they can go deeper into the lungs.

Unit of measurement: kilogram of Particulate Matter 2.5 equivalent (kg PM 2.5 eq). The potential impact of respiratory inorganics is converted into the equivalent of a kilogram of particulate matter of a diameter of 2.5 micrometres or less.

IONISING RADIATION
The exposure to ionising radiation (radioactivity) can have impacts on human health. The Environmental Footprint only considers emissions under normal operating conditions (no accidents in nuclear plants are considered).

Unit of measurement: Kilogram of Uranium 235 equivalent (kg U235 eq). The potential impact on human health of different ionising radiations is converted to the equivalent of kilobequerels of Uranium 235.

PHOTOCEMICAL OZONE FORMATION
While stratospheric ozone protects us, ozone on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog ('summer smog') is present in cities. Photochemical ozone formation is an impact which affects the environment at local and regional scale.

Unit of measurement: kilogram of Non-Methane Volatile Organic Compound equivalent (kg NMVOC eq). The potential impact of substances contributing to photochemical ozone formation are converted into the equivalent of kilograms of Non-Methane Volatile Organic Compounds (e.g. alcohols, aromatics, etc.).

ACIDIFICATION
Acidification has contributed to a decline of coniferous forests and an increase in fish mortality. Acidification can be caused by emissions getting into the air, water and soil. The most significant sources are combustion processes in electricity, heating production and transport. The contribution to acidification is greatest when the fuels contain a high level of Sulphur. Acidification is an impact which mainly affects the environment on a regional scale.

Unit of measurement: Mole of Hydron equivalent (mol H+ eq). Hydron is general name for a cationic form of atomic Hydrogen. Mole is a common unit of measurement used in chemistry, expressing amount of substance. The potential impact of substances contributing to acidification is converted to the equivalent of moles of Hydron.

EUTROPHICATION - TERRESTRIAL
Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and limit growth in the original ecosystem. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: Mole of Nitrogen equivalent (mol N eq). Mole is a common unit of measurement used in chemistry, expressing amount of substance. The potential impact of substances contributing to terrestrial eutrophication is converted to the equivalent of moles of Nitrogen.

EUTROPHICATION – AQUATIC FRESH WATER

Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). If algae grows too rapidly, it can leave water without enough oxygen for fish to survive. Nitrogen emissions into the aquatic environment are caused largely by fertilisers used in agriculture, but also by combustion processes. The most significant sources of Phosphorus emissions are sewage treatment plants for urban and industrial effluents and leaching from agricultural land. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: kilograms of Phosphorus equivalent (kg P eq). The potential impact of substances contributing to freshwater eutrophication is converted to the equivalent of Kilograms of Phosphorus.

EUTROPHICATION – MARINE

Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). As a rule, the availability of one of these nutrients will be a limiting factor for growth in the ecosystem, and if this nutrient is added, the growth of algae or specific plants will be increased. For the marine environment this will be mainly due to an increase of nitrogen (N). Nitrogen emissions are caused largely by the agricultural use of fertilisers, but also by combustion processes. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: kilogram of Nitrogen equivalent (kg N eq). The potential impact of substances contributing to marine eutrophication is converted to the equivalent of kilograms of Phosphorus.

LAND USE

Use and transformation of land for agriculture, roads, housing, mining or other purposes. The impacts can vary and include loss of species, of the organic matter content of soil, or loss of the soil itself (erosion).

Unit of measurement: kilograms of carbon deficit (Kg C deficit). This is an indicator of loss of soil organic matter content, expressed in kilograms of carbon deficit.

RESOURCE DEPLETION - WATER

The withdrawal of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. The impact category considers the availability or scarcity of water in the regions where the activity takes place, if this information is known.

Unit of measurement: cubic metres (m^3) of water use related to the local scarcity of water.

RESOURCE DEPLETION – MINERAL, FOSSIL AND RENEWABLE

The earth contains a finite amount of non-renewable resources, such as metals, minerals and fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. For example, the depletion of fossil fuels may lead to the non-availability of fossil fuels for future generations.

Unit of measurement: kilogram of Antimony equivalent (kg Sb eq). The amount of materials contributing to resource depletion are converted into equivalents of kilograms of Antimony.

NORMALISATION AND WEIGHTING

Normalisation and weighting are applied to select the most relevant impact categories in agreement with the ISO standard related to life cycle assessment (ISO, 2006). In order to obtain aggregated results for a PEF, the value calculated for each impact categories is then multiplied for a normalisation factor and a weighting factor. The first takes into account all impact scores of a functional unit in the impact score profile to a reference situation, while the latter contribute in combining each impact factor in one single score as set in the PEFCR Guidelines (Zampori and Pant, 2019).

Table A1.1 *Normalisation and weighting factors per impact category, following PEFCR Guidelines (Zampori and Pant, 2019)*

	Normalisation	Weighting
Climate change	0.000129	0.2219
Ozone depletion	42.82	0.0675
Ionising radiation, HH	0.000237	0.0537
Photochemical ozone formation, HH	0.02463	0.051
Respiratory inorganics	1571	0.0954
Non-cancer human health effects	2106	0
Cancer human health effects	25969	0
Acidification terrestrial and freshwater	0.018	0.0664
Eutrophication freshwater	0.3918	0.0295
Eutrophication marine	0.03536	0.0312
Eutrophication terrestrial	0.005652	0.0391
Ecotoxicity freshwater	8.46E-05	0
Land use	7.49E-07	0.0842
Water scarcity	8.72E-05	0.0903
Resource use, energy carriers	1.53E-05	0.0892
Resource use, mineral and metals	17.28	0.0808

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