Comparative life cycle assessment of horticultural growing media based on peat and other growing media constituents

Final Report

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EPAGMA

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This report has been prepared by Quantis, a team of world-leading experts in the field of environmental life cycle assessment. Quantis works with companies, governments and other decision makers to identify and implement the right actions for minimizing the environmental footprint of products and services. Founded in 2006, the firm maintains its global headquarters in Lausanne, Switzerland with branches in Boston, Montréal, and Paris. Quantis provides the highest level of proficiency in delivering state-of-the-art analysis and solutions for organizations striving to be leaders in the global sustainability effort.

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This report is associated with the electronic file presenting the results of this project.

PROJECT INFORMATION	
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EXECUTIVE SUMMARY

Comparative life cycle assessment of horticultural growing media based on peat and other growing media constituents

Context and objectives

EPAGMA represents a large part of the peat and growing media industry at the European level. The 18 member companies are located in: Belgium, Denmark, Estonia, Finland, Germany, Ireland, Latvia, Lithuania, The Netherlands, Poland, and Sweden.

EPAGMA has commissioned Quantis to carry out this study. The objective of this life cycle assessment was to compare the environmental impacts of peat-based growing media, media composed of peat in combination with other constituents, and one peat-free medium.

The constituents other than peat assessed in this project were: bark, coir pith, green compost, mineral wool, perlite, rice hulls, and wood fibre.

EPAGMA is eager to better understand the environmental impacts associated with the composition of growing media for various applications for both internal and external communication.

As the results of this comparative LCA are intended for public disclosure by EPAGMA, an independent critical review was performed by a third party panel of experts to ensure that this study meets the ISO 14040 and ISO 14044 requirements for comparative assertion disclosed to the public.

Functional unit

The functional unit (FU) is a reference for comparing all growing media for a given application area on a common basis. The chosen functional unit is the following: “To provide 1 m^3 (EN 12580) of growing media for each of the following five areas of application: fruity vegetables, pot plants, young plant production using loose-filled trays, tree nursery stock, and hobby market.”

For each area of application, different mixes were defined in collaboration with EPAGMA experts. All mixes related to a specific application were required to be comparable from a functional point of view (the same function for all the mixes).

System boundaries

The LCAs comprise all processes from raw material extraction to the end-of-life stage of all product constituents. As shown in Figure I, the product system is divided into six principal life cycle stages: (1) Production, (2) Delivery, (3) Processing, (4) Distribution, (5) Use, and (6) End of Life.

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Production
Activities on the growing or extraction site
(e.g. for peat it includes equipment and infrastructure production for peat extraction, peat bog draining, terrain arrangement, cleaning, drying, peat harvesting and after-uses; for coir pith it includes the coconut harvesting; for bark wood harvesting, etc.)

Delivery
Transportation from production sites to processing and mixing sites (train, truck, ship)

Processing and mixing
Activities at the processing plant - Energy and water consumption
Lime and fertilizer additions to the mixes
(e.g. peat sieving, bark production, coir pith retting, etc.)

Distribution
Distribution of the growing media to the customers (train, truck, ship)

Use
Degradation of the growing media during consumption

End-of-life
Degradation of the growing media post-consumption

Figure I: System boundaries

Results

The document reports results across the 5 areas of application for 4 indicators: Climate change, Resources, Ecosystem quality, and Human health.
In general, for all the areas of application, the growing media that have the highest impact on the **Climate change** and **Resources** indicators are the mixes containing peat. This is due to land use changes during peat harvesting and after-use Production stage) as well as GHG emissions during peat decomposition in the use and end-of-life stages. For example, Mix 1.1 with 100% white peat has higher Climate change impacts than Mixes 1.2 (100% mineral wool) and 1.3 (100% compressed coir pith), as shown in Figure II.

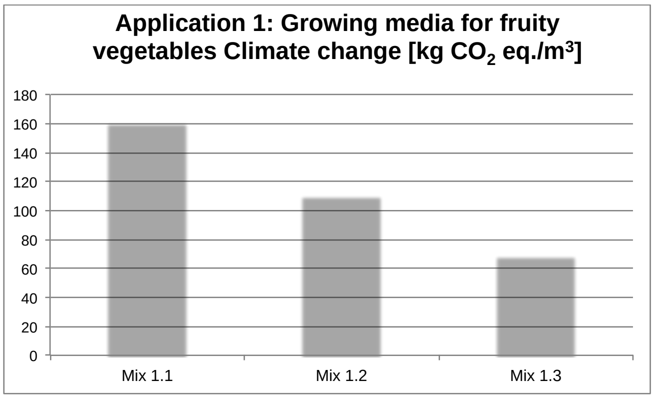

Figure II: Results for the Climate change indicator (expressed as kg CO_2 eq/m^3) for growing media within area of application 1.

For the **Human health** indicator, the most impacting mixes are growing media containing coir pith (Mix 1.3 – 100% coir pith) and growing media containing green compost. For example, for area of application 2 mix with the greatest Human health impact is Mix 2.3 (50% white peat, 30% green compost, 20% coir pith), as shown in Figure III. Transport of coir pith (freight shipment from Sri Lanka to Europe and transport of decompressed coir pith in Europe to the mixing plant) and processing emissions for the green compost contribute to increased impacts on Human health.

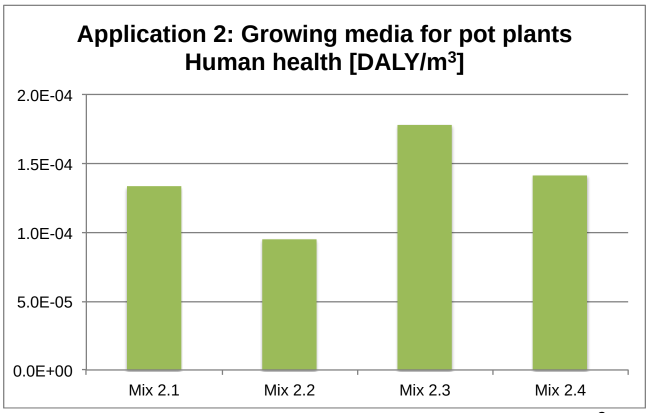

Figure III: Results for the Human health indicator (expressed as DALY/m^3) for growing media within area of application 2.

For the **Ecosystem quality** indicator, growing media containing coir pith generally have the highest impact due to of land occupation during the coconut harvesting stage. For example, for the area of application 1, the coir pith (Mix 1.3) is the most impacting; for area of application 5, Mix 5.4 (10% bark, 30% coir pith, 30% green compost, 10% rice hulls, 20% wood fibres) has the highest impact, as shown in Figure IV.

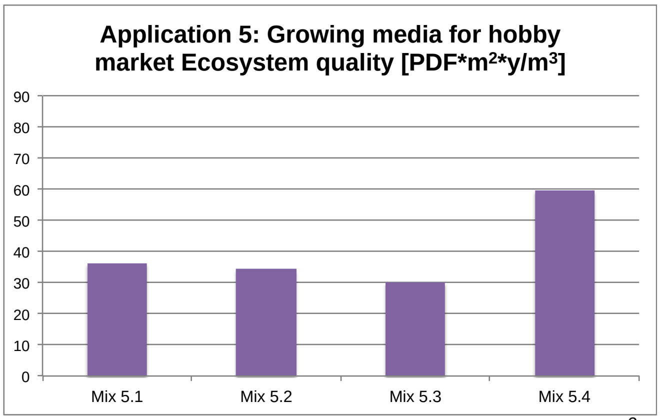

Figure IV: Results for the Ecosystem quality indicator (expressed as PDF.m^2.y/m^3) for growing media within area of application 5.

Conclusions of the study

The analysis of the results shows that in general it is not possible to clearly identify any among the growing media as the least or the most impacting across all the indicators. This is true for all the areas of application 1 (fruity vegetables), 2 (pot plants), 3 (young plant production using loose-filled trays) and 5 (hobby market), but not for area of application 4 (tree nursery stock). For this latter, it is worth noting that Mix 4.2 (50% white peat, 30% bark, 20% wood fibres) has lower impacts than all other alternatives for all the indicators presented in this study.

For all the growing media, the following general tendencies can be observed:

- Growing media containing a relatively large share of peat have a higher impact on Climate change;
- Growing media containing a large share of green compost have a higher impact on Human health;
- Growing media containing a large share of coir pith have the highest impact on Ecosystem quality.

For growing media constituents that are functionally equivalent, we observe that:

- Coir pith has the highest impacts on Ecosystem quality;

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- Mineral wool has the highest impacts on Human health;
- Peat has relatively the highest impacts on Climate change and Resources.

Outlook

To reduce the impacts of a growing medium one could imagine changing the growing media composition, substituting one constituent for another. It is, however, important to consider that this may influence the functionality of the mix, and growing media are comparable only if they fulfil the same function.

The choice of a growing media composition is limited by technical considerations (e.g. growing medium characteristics, crop requirements, safety, reliability, availability of constituents, price). In substituting a peat-based mix for a peat-free mix, it is essential for the grower to consider whether the crop quality and yield remain the same. If this is not the case, the growing media will not be comparable because they will not be functionally equivalent.

Evaluation of growing media quality is out of scope of this study although this aspect must be taken into account during the analysis and interpretation of the results of this study.

Another way to reduce the impacts of growing media is to optimise the impacts of individual constituents over their respective life cycles, particularly the distribution of growing media to the final customer. In this study we assumed the same transportation distances for all of the growing media. The higher the density of the growing medium, the higher the transportation impact will be, and therefore the shorter the distribution distance should be if possible.

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Abbreviations and Acronyms

CO_2	Carbon Dioxide
CH_4	Methane
N_2O	Nitrous oxide
DALY	Disability Adjusted Life Years
GWP	Global Warming Potential
GHG	Greenhouse gases
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PDF.m².year	Potentially Disappeared Fraction of species over a certain area and a certain period of time

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Glossary

Area of application	There are 5 different areas of application identified in this study. They are related to the use of the growing media.
Climate change	Global warming is considered to be a stand-alone endpoint category with units of kg CO2-equivalent. By default in IMPACT 2002+, the assumed time horizon is 500 years (GWP500) to account for both short-term and long-term effects (as opposed to GWP20 and GWP100) as there is little evidence that global warming effects will decrease in the future. However, in this study a 100 year time horizon is used (GWP100) and the 500 year time horizon is presented in a sensitivity study. The greater the impact, the higher the indicator value will be.
Ecosystem quality	This indicator quantifies the impact of anthropogenic processes on the natural development and occurrence of species within their habitats. The damage can directly be determined as a Potentially Disappeared Fraction of species (PDF) over a certain area (m2) and during a certain time (y). The greater the impact, the higher the indicator value will be. Aquatic ecotoxicity, terrestrial ecotoxicity, acidification, eutrophication, terrestrial acidification/nitrification, land occupation all contribute to this indicator.
Growing media	They are materials, other than soil in situ, in which plants are grown (CEN Report 13456:1999). In this study, different growing media with similar (but not identical) properties are compared for the same area of application. In practice growth results would vary. In this report, the term ‘growing media’ is synonymous for of ‘growing media mixes’ or ‘mixes’.
Growing media constituents	Materials which are suitable as ingredients of growing media (CEN Report 13456:1999) The constituents considered in this study are added to a mix by %-volume. In this study the following growing media constituents are analysed: bark, coir pith, green compost, mineral wool, perlite, rice hulls, and wood fibres.

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Haku-Peco systems	These are peat harvesting systems. In the Peco system, the ridge on the fifth field from the stockpile is picked up by a harvesting machine, passed along a conveyor and dropped on top of the ridge on the fourth field from the stockpile. This process is repeated in “leap frog” fashion until all of the peat is harvested onto the stockpile located in the middle field of the eleven-field unit. In the Haku system, each ridge is picked up by the same type of harvester and loaded onto a trailer in an adjoining field. This trailer of peat is then taken to the central stockpile while another trailer moves into position under the harvester. The operations of milling, harrowing, ridging and harvesting are repeated for each harvest and are collectively described as a cycle.
Human health	Human toxicity (carcinogenic and non-carcinogenic effects), respiratory effects (inorganics and organics), ionizing radiation, and ozone layer depletion all contribute to the damage to human health. The damage is measured in disability adjusted life years (DALY), or the number of years of life lost (mortality and morbidity). The greater the impact, the higher the indicator value will be.
IMPACT 2002+	This is the peer-reviewed and internationally-recognized LCIA method used to assess the environmental impacts in this study (Jolliet et al. (2003), as updated in Humbert et al., (2009)).
Mixes	These are the growing media selected by a professional working group and confirmed by the expert panel. Although the exact properties of the mixes have not been determined, within an area of application they would have similar but not identical properties to the extent that they could replace each other in practical use The general assumption is therefore that growing media are comparable within same area of application. In the case of mineral wool slabs, the properties would differ considerably from those of peat and coir pith. In this report, mixes are synonymous with growing media mixes or growing media.

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Resources	The two midpoint categories contributing to this damage indicator are mineral extraction and primary non-renewable energy consumption. The greater the impact, the higher the indicator value will be.
Upper heating value	Higher heating value (HHV) or gross energy takes into account the latent heat of vaporization of water in combustion products and assumes all water is in liquid state at the end of combustion (in the products of combustion).
Volumes (for constituents and growing media)	All volumes for constituents and growing media are expressed according to the standard EN 12580 :1999.

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1 Introduction

1.1 Life cycle assessment

The increasing awareness of the importance of sustainability and the potential environmental consequences associated with products and services has sparked the innovation of methods to better understand, measure and reduce these negative consequences. The leading tool for achieving this – and the only tool that can make a full evaluation of all sources and types of impact over the entire life cycle of a product – is life cycle assessment (LCA), a method defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 14040 2006; ISO 14044 2006).

LCA is an internationally recognized approach that evaluates the potential environmental and human health impact associated with products and services throughout their life cycles, from raw material extraction through including transportation, production, use, and end-of-life treatment. Among other uses, LCA can identify opportunities to improve the environmental performance of products at various points in their life cycle, inform decision-making, and support marketing and communication efforts.

1.2 Context and background

EPAGMA represents a large part of the peat and growing media industry at the European level. EPAGMA acts as the interface for peat and growing media companies with the EU institutions since its members represent 18 European peat and growing media companies who wish to be informed of political decisions that affect their day-to-day business.

EPAGMA aims to contribute to the socio-economic development of regions and communities where peat is sourced and used, and it is committed to high environmental standards and practices in peat extraction.

This study has been conducted according to the requirements of ISO 14040 and 14044 for comparative assertion disclosed to the public and is in line with LCA good practices established by international organizations such as the UNEP/SETAC Life Cycle Initiative and the European Commission ILCD Handbook.

Appendix A contains details regarding the reference flows, unit processes, impact scores and data sources. Appendix B and C present the IMPACT 2002+ and ReCiPe LCA methodologies, respectively. Appendix D reports the results per constituent. Appendix E contains the critical review report. Appendix F reports system boundaries for the constituents, and Appendix G reports a summary of GHG emissions for black and white peat.

2 Goal and scope definition

2.1 Objectives and intended application

The present project is focused on understanding the environmental impacts of black and white peat and comparing popular growing media made partially or totally of black and white peat with the following constituents: bark, coir pith, green compost, mineral wool, perlite, rice hulls, and wood fibres.

More specifically, the **objectives** of the study are:

I. To **characterize the environmental impacts** over the life cycle **of the chosen growing media constituents**;

II. To **compare the environmental impacts** over the life cycles of the chosen and defined **growing media** within the same areas of application;

III. To identify the key parameters of the study and provide an **assessment of their overall environmental impact** through a sensitivity analysis.

EPAGMA is eager to better understand the environmental impacts associated with the different growing media areas of application for both internal and external purposes. As the results of this comparative LCA are intended for public disclosure by EPAGMA, an independent critical review is performed by a third party panel of experts to ensure that this study meets the ISO 14040 and ISO 14044 requirements for comparative assertion disclosed to the public (see critical review report in Appendix E).

2.2 General description and context

Growing media include all such products that are used in the professional and hobby markets, whether produced by the growing media industry or by growers (privately-developed mixes). Media for all types of plant cultivation, usually in containers, are included in the definition given above, as well as fertilized planting media (e.g., for trees and shrubs) and casing soil for mushrooms.

Growing media constituents are the basic components of mixes, which are generally formulated on a volume percentage basis.

From the comprehensive CO CONCEPT survey “Socio-economic impact of the peat and growing media industry on horticulture in the EU” (Altmann, (2008)), it is estimated that peat

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represents 86% of all constituents used in the professional horticultural sector and 69% of the constituents used for the hobby growing media market.

A short description of each growing media constituent analysed in this LCA study is presented in Table 1.

Table 1: Growing media constituents analysed[1]

Growing media constituent	General description	Use as a growing media constituent
Bark 	Bark from one or more tree species. (Non-composted bark is used in this study.)	Used as the sole constituent in orchid cultivation or as a constituent in potting mixes for tree nurseries and floriculture.
Coir pith 	Product obtained by mechanical processing of the mesocarp of coco palm fruits. It is primarily imported from the Far East (Sri-Lanka, India, Philippines). The material is locally pressed into sheets, blocks or briquettes and then shipped in containers.	Esteemed for its good wettability and peat-like colour. Mixed with other constituents in mixes for sowing, propagating and potting; also as the sole constituent of grow bag mixes in vegetable and flower cultures.
Green compost 	Solid particulate matter resulting from controlled decomposition, by thermophyllic microorganisms, of biodegradable materials such as arboreal wastes, grass clippings and other material from gardening and landscaping maintenance activity.	Used in mixes for all segments of horticulture; important constituent of growing media for organic growing.

[1] Source of pictures: Klasmann-Deilmann GmbH company

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Mineral wool (picture shows mineral wool flakes) 	Product obtained by melting basalt and limestone after addition of coke at 1600°C followed by spinning and granulation. Binders for firmness and wetting agents are added for the production of mineral wool mats, which are referred to in this study.	Mineral wool mats are used in the production of fruity vegetables (e.g. tomatoes or egg plants), cut flowers, etc.
Black Peat 	Strongly humified (decomposed) peat (H6-10 on the Von Post scale) sedentarily accumulated in bogs consisting mainly of peat moss residues and residues of cotton grass, shrubs and other typical bog plant species with hardly to non-recognizable plant structure and dark brown to almost black in colour.	Used in all horticultural segments. Second most important constituent of growing media throughout Europe.
White Peat 	Weakly to moderately humified (decomposed) peat (H1-5 on the Von Post scale) sedentarily accumulated in bogs consisting mainly of peat moss residues and residues of cotton grass, shrubs and other typical bog plant species with visible plant structure and yellowish brown to dark brown in colour	Used in all horticultural segments. Main constituent of growing media throughout Europe.
Perlite 	Manufactured from naturally occurring hydrated volcanic rock (perlit), expanded by heat to form a cellular structure.	Usually mixed to improve the flowability, increase the air content and improve the water uptake of mixtures.
Rice hulls 	Residue obtained in the rice manufacturing industry and mainly consisting of rice paleae; steamed.	Can be added to mixes to improve air capacity. Constituent of less importance.

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Wood fibres 	Fibres obtained by mechanically or mechanically-thermally fraying of untreated wood and/or wood wastes.	Increasingly important constituent in mixes for pot plants, trees, shrubs, etc. Used in combination with peat and other constituents.

2.3 System function and functional unit

The functional unit (FU) is a reference for comparing all growing media within an area of application on a common basis. It is therefore critical that this parameter is clearly defined and measurable.

The functional unit is a quantified representation of the function and for this study it is:

To provide 1 m^3 *(acc. to EN 12580) of growing media for each of the following five areas of application:*

- *fruity vegetables*
- *pot plants*
- *young plant production using loose-filled trays*
- *tree nursery stock*
- *hobby market.*

For each area of application different growing media mixes were defined in collaboration with EPAGMA experts. All mixes related to a specific area of application were required to be comparable from a functional point of view (with the same function for all the mixes). The comparability of the mixes has been approved by the growing media expert on the review panel, Prof. Elke Meinken. For more details related to the mixes, please refer to section 2.6.

2.4 System boundaries

The determination of system boundaries identifies the stages, processes and flows considered in an LCA and should include: 1) all activities relevant to the attainment of the study objectives and therefore necessary to carry out the studied function; 2) all the processes and flows that significantly contribute to the potential environmental impacts.

This chapter describes the life cycle stages of the studied products and determines which processes and flows shall be included within the LCA, i.e., what is considered to be in the product system (and therefore analysed), and what is outside the system (and hence not included in the assessment).

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This study assesses the life cycles of different growing media composed of the constituents listed and described in Table 1. The LCAs comprise all processes from raw material extraction to the end-of-life stage of all product constituents. The system is divided into six principal life cycle stages: (1) Production, (2) Delivery, (3) Processing, (4) Distribution, (5) Use, and (6) End of Life.

The product systems to be studied are summarized in Figure 1. This figure shows a simplified process diagram including the six life cycle stages, each of them covering a whole cradle-to-gate sub-system.

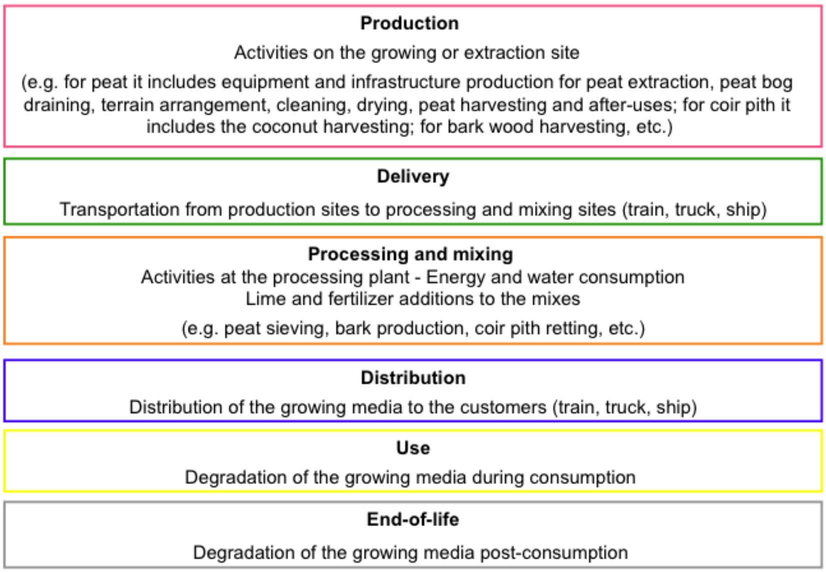

Figure 1: Product system description for the LCA of the systems studied. Common processes (excluded in the growing media comparison) are not included in this figure.

The « **Production** » sub-system takes into account all production activities related to the production of the growing media constituents and their raw materials. More specifically, this step includes all the activities in situ.

The « **Delivery** » sub-system takes into account all intermediate transportation of the growing media constituents up to the mixing plant.

The « **Processing** » sub-system takes into account all activities at the mixing plant or processing plant. It includes the addition of other materials and the production of infrastructure for the processing activities. We assume in this study that the mixing activities (required energy and packaging) are the same for all growing media, and consequently they can be excluded from this comparative LCA. In the section related to the detailed peat results (section 3.3), we include the energy used for packaging and mixing in the «Processing» sub-stage in order to assess independently the total impacts for the two peat constituents.

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In order to reach functionally comparable mixes within each area of application, different quantities of lime and fertilizers need to be added. They are therefore taken into account in the analysis.

The « **Distribution** » sub-system takes into account the transportation of the growing media to the final customers.

The « **Use** » sub-system includes the emissions related to the decomposition of the growing media. Plant cultivation is taken into account in the study, but as plant growth is considered equivalent for all areas of application, it can be neglected in this comparative LCA. Consequently, we did not consider plant growth or plant decomposition.

The « **End of life**» sub-system takes into account the final management of the growing media post-consumption. Here the assumption is that growing media are not reused.

In the present project, all product components and production processes for which the necessary information is readily available or a reasonable estimate can be made are included. In cases where important information is unknown, uncertain or highly variable, sensitivity analyses are performed to evaluate the potential significance of the data gap(s).

2.5 Life cycle inventory data, sources and hypothesis

The quality of LCA results is dependent on the quality of data used in the study. Every effort has been made in this investigation to implement the most credible and representative information available. Information regarding production, transformation and distribution of the different growing media constituents, including manufacturing processes, distances of immediate suppliers, distribution distances and transportation modes, is collected directly from EPAGMA members via questionnaires, email, phone calls, or in person. In some instances, approximations are made based on the best judgment of the appropriate staff members.

The LCI data describing background processes (e.g., electricity generation) source mainly from the *ecoinvent* inventory database (version 2.2) or are based on adapted *ecoinvent* processes. *Ecoinvent* is a particularly robust, transparent and complete database, both in terms of technological and environmental coverage (Althaus, Doka and Dones (2007); The ecoinvent center (2007); Frischknecht, Jungbluth and Althaus (2005)). It is one of the best commercial databases from a quantitative (number of included processes) and qualitative (quality of the validation processes, data completeness, etc.) perspective and it is internationally recognized by experts in the field.

In some cases, sufficiently representative data are not available in *ecoinvent* and are therefore taken from our own database, which includes data from ten years of LCA activity

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and adapted for the specific purpose of this paper. Each unit process and its data source is documented in Appendix A.

The SimaPro 7.1 software, developed by PRé Consultants (www.pre.nl), was used to assist the LCA system modelling, link the reference flows with the life cycle inventory database and compute the complete life cycle inventory of the systems.

2.5.1 Data collection

Concerning black and white peat production, 18 companies within EPAGMA were contacted by emails and phone calls, and they contributed their data by completing a questionnaire. Five companies did not participate, but the other 13 signed confidentiality agreements and provided us with data. Visits at 3 different companies were organized. The aim of these visits was to collect data directly on site, to see peat extraction and processing, and to speak in-person with the experts of the companies. The companies were proposed and chosen directly by EPAGMA as a representative sample of the EPAGMA companies.

Not all growing media constituents considered in this study are produced by the companies that are members of EPAGMA. For the constituents other than peat, we contacted the suppliers directly. In total we contacted about 20 suppliers in addition to the 18 EPAGMA companies. Four suppliers provided us with the requested data. Data for the remaining growing media constituents are derived by applying expert judgment to available data sources (e.g. information from publications, websites, and literature review of existing LCAs).

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Table 2: Source of data collected per growing media constituent other than peat

Growing media constituents	Source of data
Bark	Wood harvesting: primary data, wood chips production: secondary data, bark production: primary data from one supplier
Coir pith	Coconut cultivation: secondary data from literature
	Coir pith extraction: primary data from 1 supplier + secondary data from literature
	Coir pith processing: primary data from 1 EPAGMA company
Green compost	Primary data from 2 EPAGMA companies
Mineral wool	Mineral wool: primary data from 1 supplier, basalt extraction: secondary data
Perlite	Primary data from 5 sites in Europe from 2 suppliers
Rice hulls	Rice cultivation: secondary data (scientific paper)
	Rice hulls production: primary data from one supplier
Wood fibres	Wood chips production: secondary data Wood fibres production: primary data from 2 EPAGMA companies

2.6 Areas of application

2.6.1 General description of the areas of application

It is important to note that the different growing media constituents are not mutually exclusive: different growing media constituents considered separately don't have identical properties. Consequently they may have complementary functions in some cases.

Following ISO 14040, comparisons between systems shall be made on the basis of their fulfilment of the same functions. In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results. Given these considerations, we decided to compare the growing media constituents on the basis of their

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use in horticulture, that is, on the basis of *their application*. The following 5 areas of application were identified:

1. Growing media for fruity vegetables (e.g. eggplant, tomato, pepper, cucumber)
2. Growing media for pot plants (i.e. green plants)
3. Growing media for young plant production using loose-filled trays
4. Growing media for tree nursery stock (i.e. container-grown plants)
5. Growing media for the hobby market (potting mix)

For each area of application, different *mixes* were defined in collaboration with EPAGMA experts. All mixes related to a specific application were required to be comparable from a functional point of view (the same function for all the mixes). *The choice of the mixes has been conducted by the EPAGMA experts on the basis of their years of experience in the sector and approved by the growing media expert of the review panel, Prof. Elke Meinken.* Every effort has been made by the EPAGMA experts and Quantis to create comparable growing media within each area of application in order to follow ISO requirements, and the review panel (external) has accepted them as equivalent.

The mixes for each area of application are presented in Table 3.

Table 3: Chosen mixes for the 5 areas of application (Values in % v/v)

Area of application 1: Growing media for fruity vegetables			
Constituents	**Mix 1.1**	**Mix 1.2**	**Mix 1.3**
Compressed coir pith			100
Mineral wool		100	
White peat	100		

Area of application 2: Growing media for pot plants				
Constituents	**Mix 2.1**	**Mix 2.2**	**Mix 2.3**	**Mix 2.4**
Bark				20
Coir pith			20	
Green compost			30	10
Black peat	50			30
White peat	50	80	50	
Perlite		20		
Rice hulls				10
Wood fibres				30

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Area of application 3: Growing media for young plant production using loose-filled trays				
Constituents	**Mix 3.1**	**Mix 3.2**	**Mix 3.3**	**Mix 3.4**
Coir pith		50	30	
Black peat	25			
White peat	75	30	50	80
Perlite				20
Wood fibres		20	20	

Area of application 4: Growing media for tree nursery stock				
Constituents	**Mix 4.1**	**Mix 4.2**	**Mix 4.3**	**Mix 4.4**
Bark		30		20
Green compost	30		20	
Black peat				40
White peat	50	50	60	40
Rice hulls	20			
Wood fibres		20	20	

Area of application 5: Growing media for the hobby market				
Constituents	**Mix 5.1**	**Mix 5.2**	**Mix 5.3**	**Mix 5.4**
Bark		20		10
Coir pith				30
Green compost	40			30
Black peat		80	60	
White peat	60		40	
Perlite				
Rice hulls				10
Wood fibres				20

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2.7 Data and assumptions for black and white peat

The main hypotheses and data used for black and white peat are given in detail in this section. The exact reference flows considered are presented in the Appendix A.

2.7.1 Black and white peat production and processing

In this study we analysed only peat extraction by milling (sod peat and other means of extraction were excluded). Primary data were collected from 13 EPAGMA companies through a questionnaire and they are related to the production, processing and delivery stages. Each company provided data for different sites. In particular, primary data were collected from 18 extraction sites for white peat and 14 different extraction sites for black peat. We created a model in SimaPro specific to each company and for each stage of the black and white peat life cycle. Each company also provided information for different processing plants. To calculate the final results, we computed a weighted average of the impacts of the different companies. To calculate the weights we used:

- For the extraction sites: the extracted peat quantity in 2009.
- For the processing plants: the processed peat in 2009.

Black and white peat products differ in terms of carbon content, bulk density and moisture content. In this study we used the values reported in Table 4. The two kinds of peat are extracted in different countries of Europe and using different technologies of peat milling. To capture these differences, we collected primary data on peat extraction for each of the two kinds of peat.

The steps of:

- bog opening (including drainage of the peatland) after any of the four possible pre-uses (pristine, agriculture, forestry, degraded) (classified as “Non-ordinary operations”)
- bog closing (that is, preparation for after-use – classified as “After-use objectives realization”)

depend on the peatland and are equal for both kinds of peat (black and white). Peat processing activities (sieving and mixing of the peat) can be considered the same for both black and white peat. Details about the peat production stage are provided in Figure 2.

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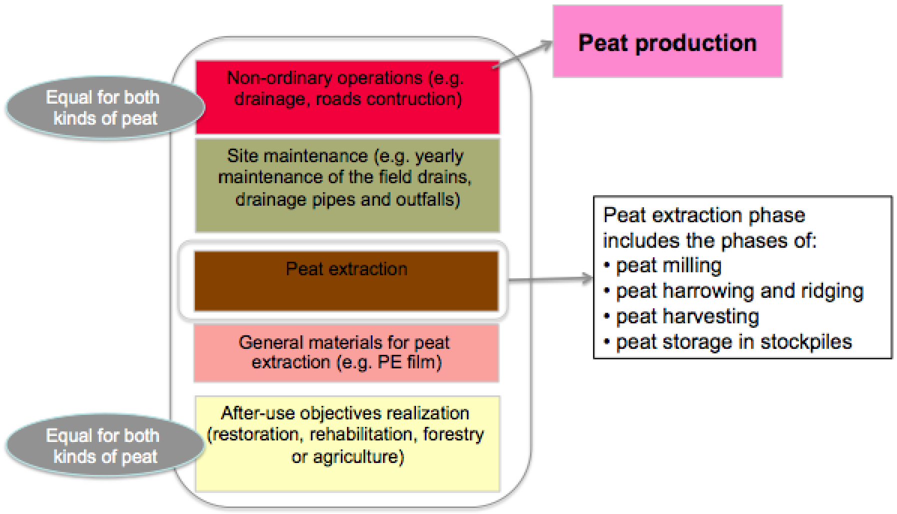

Figure 2: Details of the peat production stage. This stage includes the sub-stages of: non-ordianry operations, site maintenance, peat extraction, general materials production and after-use objectives realization.

Table 4: Characteristics of black and white peat

	Black peat	White peat	Source
Dry bulk density [kg/m^3]	100	72	EPAGMA primary data
Fresh density [kg/m^3]	400	180	EPAGMA primary data
Moisture content (% m/m)	75	60	EPAGMA primary data
C content (% dry matter)	55	50	Personal communication Dr. Heinrich Höper[2]
C quantity per m^3 [kg/m^3]	55	36	Calculation
Upper heating value (MJ/kg)	5	8.8	EPAGMA primary data

2.7.2 Dynamic GHG emission profiles for peat

In this section, the assumptions concerning uptake and emissions of greenhouse gases (carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4)) during the different stages of peat production are presented.

The emission stages are described by the equation below:

Total emissions for peat production = (harvesting stage + after-use stage) – reference scenario

[2] State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover

Where:

Harvesting stage — Period in which peat is being harvested. All emissions from the drained harvesting area and stockpiles, harvesting equipment and transports are included. The emissions depend on harvesting time and the production technology used.

After-use stage — Emissions/uptake at the peatland after harvesting depends on the after-treatment of the cutaway peatland. In this study four options are included: restoration, rehabilitation, afforestation and agriculture. Emissions from equipment and transports are included.

Reference scenario — This is the scenario represented by the pre-harvesting conditions at the peatland. Emissions from this stage are considered to be avoided (hence the subtraction in the equation). The type of peatland will determine the magnitude of the emissions in the reference scenario. This approach is in line with the latest studies conducted in Europe (Hagberg and Holmgren (2008); Holmgren et al. (2006)). Four reference scenarios have been considered in this study:

- pristine bogs (mires): bogs which have not been disturbed by human activity;
- drained forested peatland: peatland that has been drained, partially extracted and afforested in the past;
- drained cultivated peatland: peatland that has been drained, partially extracted in the past and then cultivated;
- degraded peatland: peatland that has been drained and partially extracted in the past, for which the original ecosystem has been disturbed and damaged by human activity.

2.7.2.1. Reference scenarios – before site preparation

This chapter gives an overview of the main peatland scenarios (before a site is prepared for peat extraction) that are analysed in this study.

a) Pristine bogs

Emissions and uptake of greenhouse gases from pristine bogs (not subject to human impact, such as drainage) can differ significantly between different bog types but also vary substantially with climatic conditions, according to Hagberg and Holmgren (2008). In this study one main type of pristine bogs has been considered: nutrient poor, ombrotrophic mire. Studies of CO_2 fluxes from pristine bogs indicate that they can be either net sources or net

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sinks of CO_2, and the measurements show great variability between sites and years. In this study, according to Hagberg and Holmgren (2008), the values of 55 g CO_2 /(m^2 .y) and 7 g CH_4 /(m^2 .y) are used.

In accordance with Hagberg and Holmgren (2008), in this study the N_2O emissions from pristine mires are assumed to be negligible.

b) Drained forested peatland

i) Emissions

The net flows of greenhouse gases at drained forested peatlands vary widely between different sites. The CO_2 emissions from decomposition of peat vary with climate, drainage effectiveness, and fertility of the peatland. N_2O emissions may be significant at sites with high fertility (low C/N-ratio) and are lower in coniferous forests than in deciduous forests (von Arnold (2004); von Arnold et al. (2005)).

In this study, only one type of forested peatland is considered: peatland with high fertility as described by Alm et al. (2007) and Hagberg and Holmgren (2008).

- CO_2 emissions from the peatland soil are assumed to be 818 g CO_2 /(m^2 .y) (Hagberg and Holmgren, (2008); von Arnold (2004); von Arnold et al., (2005)).
- N_2O emissions are assumed to be 0.5 g N_2O/(m^2 .y), (Hagberg and Holmgren (2008) based on Alm et al. (2007); Klemedtsson et al., (2005)).
- CH_4 emissions are assumed to be negligible for high fertility sites (Hagberg and Holmgren (2008) based on Alm et al. (2007)).

ii) Carbon sequestration in forest and in the soil

The carbon uptake in living biomass depends on the forest productivity of the drained forested peatland.

In a growing forest, Hagberg and Holmgren (2008) consider a constant uptake of 820 g CO_2 /(m^2 .y) and 416 g CO_2 /(m^2 .y), for peatlands with high and low fertility respectively. We considered in this study a carbon accumulation equal to 820 g CO_2 /(m^2 .y) for a drained forested peatland as the reference scenario.

c) Drained cultivated peatland

Emissions vary with land use, so soil management practices associated with different crops have a very important influence on the emissions.

In this study we used the average values from Hagberg and Holmgren (2008) for the different crop categories of 1780 g CO_2 /(m^2 .y) and 1.5 g N_2O/(m^2 .y). CH_4 emissions are assumed to be negligible according to Hagberg and Holmgren (2008).

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d) Degraded peatland

Following Höper (2007), in this study we assumed emissions of 1382 g CO_2 /(m^2 .y) and 0.67 g CH_4/(m^2 .y). N_2O emissions are assumed to be negligible according to Höper (2007).

Table 5 summarizes the emissions and carbon sequestration values assumed for the peatland reference scenarios used in this study.

Table 5: Summary of the emissions and carbon sequestration values assumed for the reference scenarios in this study

Reference scenario	CO_2 [g /(m^2 .y)]	CH_4 [g /(m^2 .y)]	N_2O [g /(m^2 .y)]	Source
Pristine bogs	55	7	negligible	Hagberg and Holmgren (2008)
Drained forested peatland - emissions	818	negligible	0.5	Hagberg and Holmgren (2008) based on Olsson (2006); von Arnold (2004); von Arnold et al. (2005) Hagberg and Holmgren, (2008) based on Alm et al. (2007); Klemedtsson et al. (2005)
Drained forested peatland – carbon sequestration	820	-	-	Hagberg and Holmgren (2008) (for peatlands with high fertility)
Drained cultivated peatland	1780	negligible	1.5	Hagberg and Holmgren (2008)
Degraded peatland	1382	0.67	negligible	Höper (2007)

2.7.2.2. Harvesting stage

According to Alm et al. (2007), the annual average emission of CO_2 due to peat oxidation from milled peat harvesting areas in southern Finland is 980 g CO_2 /(m^2 .y). This value is based on measurements and simulations with 30 years weather data.

According to Alm et al. (2007) the average emission of CH_4 from the harvesting areas (including ditches) is 7.2 g CH_4 /(m^2 .y), while emission of N_2O from the harvesting area is 0.3 g N_2O/(m^2.y).

The CO_2 emissions from stockpiles have been estimated to be 250 ± 125 g CO_2 /(m^2 .y) (per peat harvesting area) according to Kirkinen et al. (2007) based on Finnish measurements in Nykänen et al. (1996). This is also in accordance with Alm et al. (2007). In this study, 250 g CO_2 /(m^2 .y) has been used for all peatland types that use milling.

The CH_4 emissions from stockpiles are 19.5 g CH_4 /(m^2 .y) (per stockpile area) according to Alm et al. (2007). Since the area of the stockpiles is very small compared to the harvesting

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area, the CH_4 emissions are assumed to be negligible in the study, in accordance with Hagberg and Holmgren (2008).

N_2O emissions from stockpiles are assumed to be negligible, based on Alm et al. (2007).

Table 6 summarizes the emissions assumed for the peat harvesting stage in this study.

Table 6: Summary of the emissions assumed for the peat harvesting stage in this study

Stages	CO_2 [g /(m^2 .y)]	CH_4 [g /(m^2 .y)]	N_2O [g /(m^2 .y)]	Source
Harvesting	980	7.2	0.3	Alm et al. (2007)
Stockpiles	250	negligible	negligible	Alm et al. (2007) Hagberg and Holmgren (2008)

2.7.2.3. After-uses of extracted peatlands

This chapter gives an overview of the different peatland after-uses scenarios.

Four after-use scenarios have been considered in this study:

- Forestry: the process of creating a forested ecosystem on a peatland that has been degraded or damaged.
- Agriculture: the process of creating a cultivated area on a peatland that has been degraded or damaged.
- Peatland rehabilitation: The restoration of ecosystem processes, productivity and services of the former peatland. This does not, however, imply the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure (Clarke et al. (2010)).
- Peatland restoration: The process of assisting the recovery of peatland that has been degraded or damaged to as near as possible its original natural condition (Clarke et al., 2010).

a) Forestry

i) Emissions

In this study, we assumed that of the total carbon left in cutaway previously-forested peatlands, half is stable in the soil[3] (never degraded). Following Hagberg and Holmgren (2008), we assumed that the CO_2 emissions in the afforested cutaway peatland decrease exponentially from 1100 g CO_2 /(m^2 .y).

[3] Source: Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.

The CO_2 release is reported in Figure 3. The carbon content in the soil has been calculated with the assumption that a bottom peat layer of 25 cm remains. With a density in situ (the density of peat when it is intact in the peatland) of 100 kg/m^3 and 50 kg C/m^3, we have 12.5 kg C/m^2.[4]

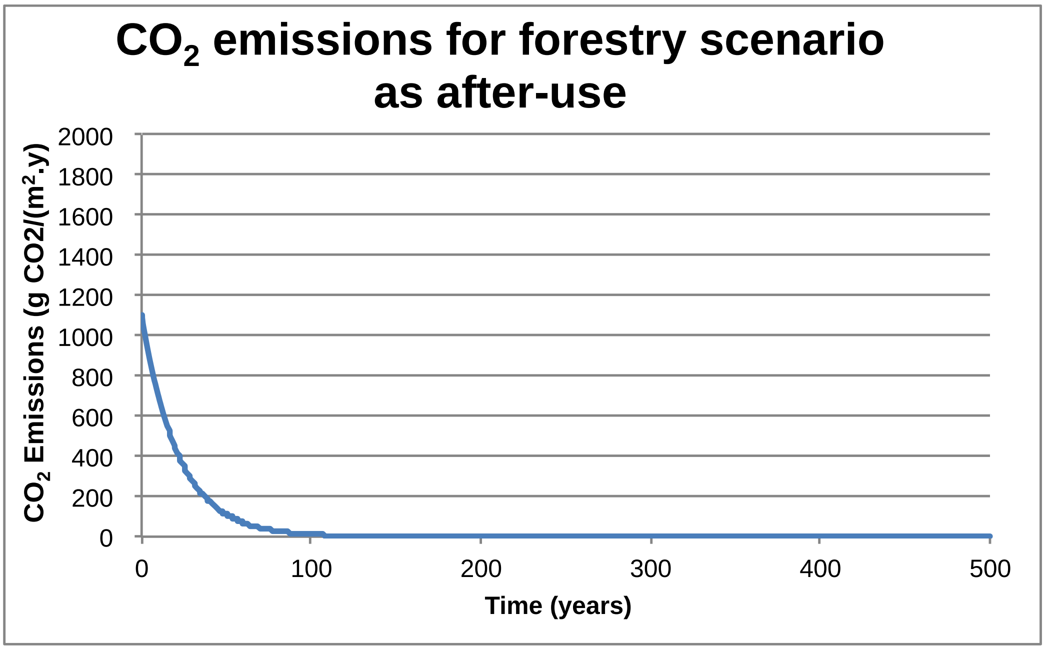

Figure 3: CO_2 emissions for the forestry after-use scenario (quantitative chart)

It is assumed that N_2O emissions will be 0.15 g $N_2O/(m^2 .y)$ after afforestation. They then decrease linearly to 0.06 g $N_2O/(m^2 .y)$ after 45 years and remain constant at that level throughout a reference 100-year time horizon (Hagberg and Holmgren (2008); Alm et al. (2007)). Please note that there is great variation in literature concerning N_2O emissions from a cutaway peatland.

[4] Source: Dr.Kari Minkkinen. Personal communication, September 14, 2011.

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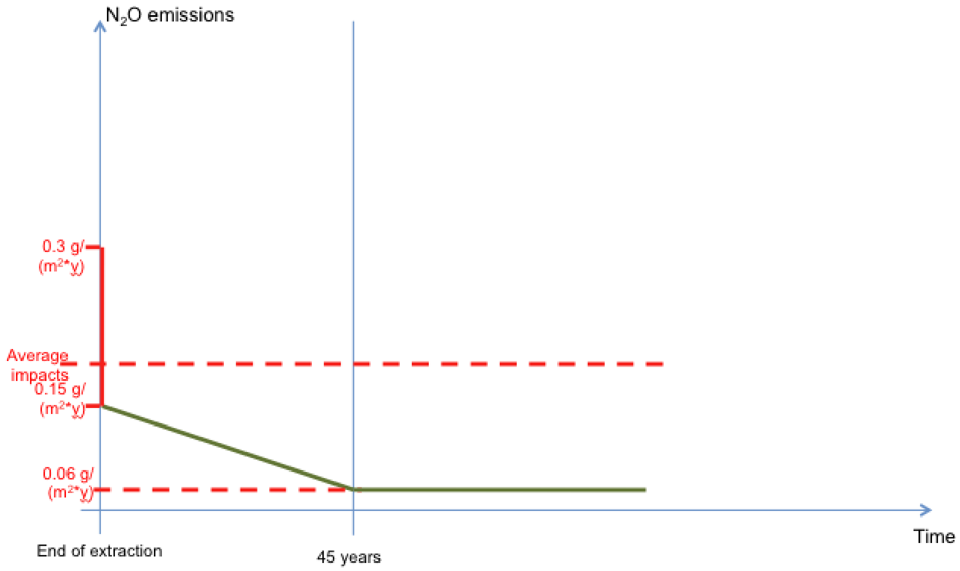

Figure 4: N_2O emissions for the forestry after-use scenario (qualitative chart)

In accordance with Hagberg and Holmgren (2008), the CH_4 emissions in afforested cutaway peatlands are assumed to be negligible.

ii) Carbon sequestration in growing forest and in the soil

In this forestry scenario, we also considered the carbon sequestration in growing forest and in the peat soil.

In this study we decided to follow the approach taken by Masera et al. (2003) because it better reflects the dynamic approach of this analysis.

Masera et al. (2003), study accumulation in a Norway spruce forest stand in Central Europe by using the CO2FIX Model. Masera et al. consider a turnover every 100 years in which previous land use was assumed to be Norway spruce with 142 t C/ha initial humus content.

Figure 5 shows the evolution of carbon stocks studied by Masera et al. (2003).

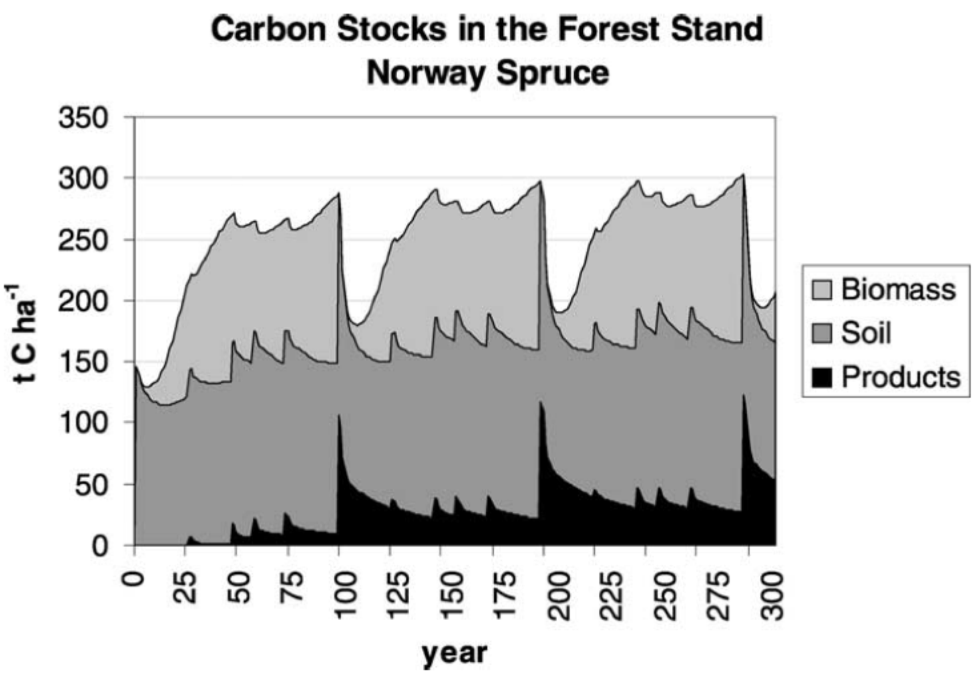

Figure 5: Evolution of carbon stocks in a Norway spruce forest stand in Northern Europe (Source of the figure: Masera et al. (2003)). “Products” listed in the legend are meant to be wood products (i.e. wood furniture)

The linear approximation of Masera’s model used in this study is presented in Figure 6.

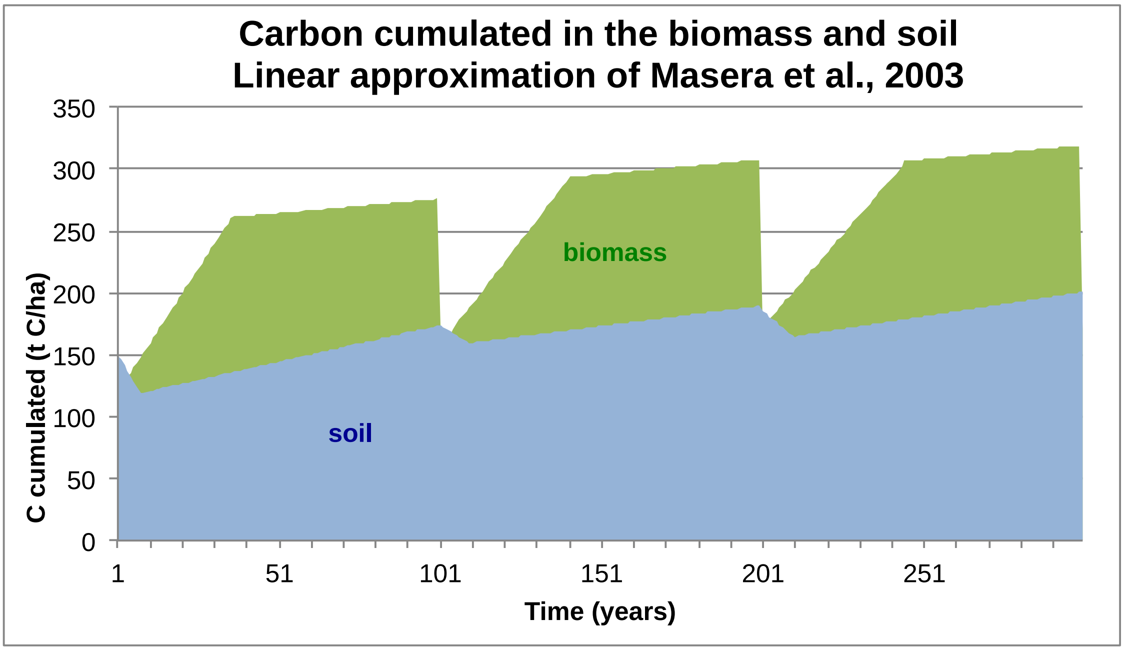

Figure 6: Carbon stocked in biomass and soil in the model adopted in this study.

The use of wood for furniture temporarily stocks CO_2. In this study, we considered that the wooden products credit is out of scope and cannot be attributed to peat extraction.

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b) Agriculture

In this study, we considered that, of the total carbon left in the cutaway peatland, half is stable in the peat soil[5] (never degraded - as for the afforestation scenario). We assumed that the CO_2 emissions from the cultivated cutaway peatland decrease exponentially from 1780 g CO_2 /(m^2 .y) (Hagberg and Holmgren (2008)). Figure 7 reports CO_2 emissions for the agriculture after-use scenario.

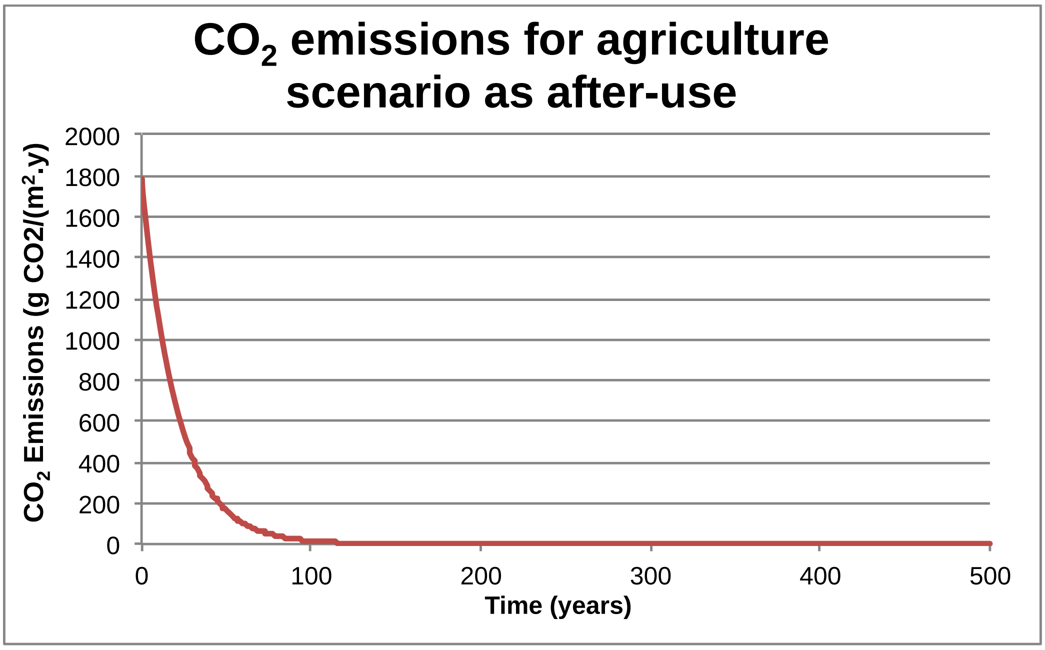

Figure 7: CO_2 emissions for the agriculture after-use scenario (quantitative chart)

N_2O emissions have been considered equal to the afforestation scenario, while CH_4 emissions have been considered negligible (Alm et al. (2007), Hagberg and Holmgren (2008)).

c) Restoration

There are few studies concerning the emissions and uptake of greenhouse gases that will be relevant for a cutaway peatland after it has been re-wetted and restored. Extended measurements over time are lacking, and there are great uncertainties in the values.

In this study, we assumed that after 10 years, CO_2 emissions reach a value of 100 g CO_2 /(m^2.y) (Dr. Höper[6]). The average uptake of the restored peatland is assumed to be 120 g

[5] Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.

[6] Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.

CO_2 /(m^2 .y) (mainly based on Kirkinen et al. (2007) and Hagberg and Holmgren (2008)) after 25 years (Dr. Höper[7]).

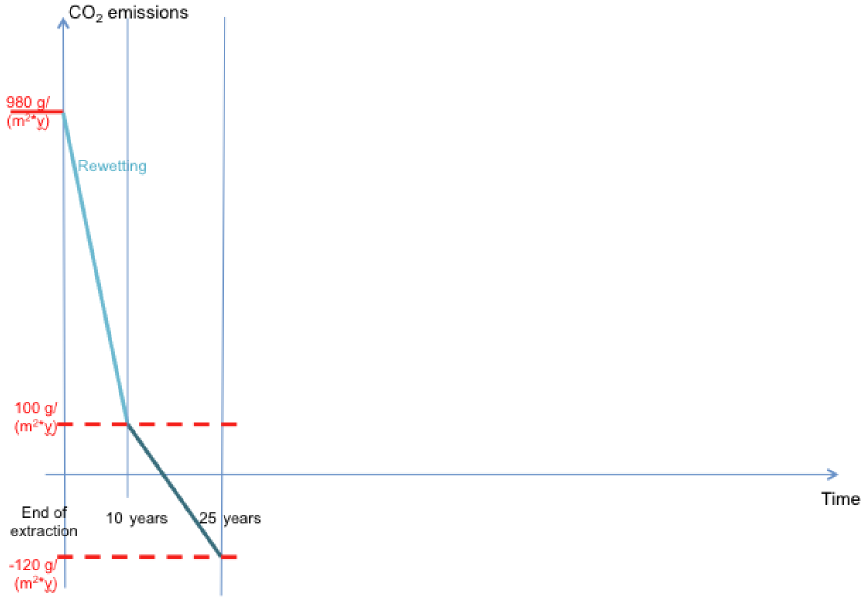

Figure 8: CO_2 emissions for the restoration after-use scenario (qualitative chart)

We assumed the CH_4 emissions to be 17 g CH_4 /(m^2 .y) after 10 years, based on Alm et al. (2007) and Hagberg and Holmgren (2008).

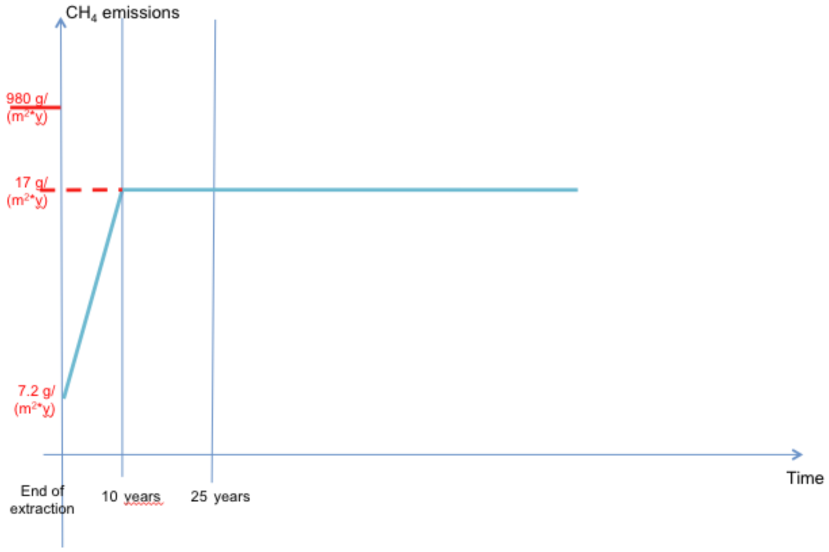

Figure 9: CH_4 emissions for the restoration after-use scenario (qualitative chart)

No studies of N_2O emissions from restored peatlands were found but, in similar treatment to the pristine bogs, the N_2O emissions are assumed to be negligible. This assumption has

[7] Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.

been used in previous studies by Hagberg and Holmgren (2008), Nilsson & Nilsson (2004), Zetterberg et al. (2004) and Kirkinen et al. (2007).

d) Rehabilitation

No data on GHG emissions were found in the literature for the rehabilitation scenario. In accordance with Dr. Höper[8] we assumed that for CO_2 emissions, the trend is quite similar to the restoration scenario, except that the sink is not reached and after 25 years emissions are equal to 0.

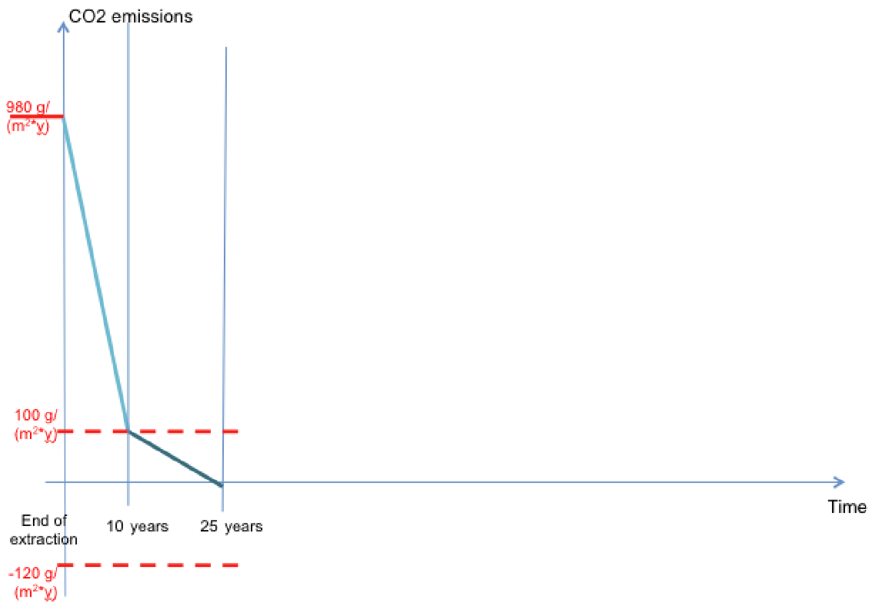

Figure 10: CO_2 emissions for the rehabilitation after-use scenario (qualitative chart)

For CH_4 and N_2O emissions, we made the same assumptions used in the restoration scenario.

[8] Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.

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Table 7 summarizes the emissions and carbon sequestration values assumed for the after-use stages in this study.

Table 7: Summary of the emissions assumed for the peat harvesting stage in this study

Stages	CO_2 [g /(m^2.y)]	CH_4 [g /(m^2.y)]	N_2O [g /(m^2.y)]	Source
Forestry - emissions	Exponentially decrease from 1100 g CO_2 /(m^2.y)	Negligible	Linear decrease from 0.15 g N_2O/(m^2.y) to 0.06 after 45 years and then remain constant at that level.	Hagberg and Holmgren (2008)
Forestry – carbon sequestration	Please refer to Figure 6 for more information	-	-	Masera et al. (2003)
Agriculture	Exponentially decrease from 1780 g CO_2 /(m^2.y)	Negligible	Equal to forestry	Hagberg and Holmgren (2008) Alm et al. (2007)
Restoration	120 g CO_2 /(m^2.y) after 25 years	17 g CH_4 /(m^2 .y) after 10 years	Negligible	Kirkinen et al. (2007) Hagberg and Holmgren (2008) Alm et al. (2007)
Rehabilitation	Same trend as restoration, but sink is not reached	Same as restoration	Same as restoration	Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.

2.7.2.4. Use and end-of-life stage

The first year of the peat degradation is assumed to take place while plants are growing, and it was included in the use stage. Emissions occurring during the subsequent years were included in the end-of-life stage.

Cleary et al. (2005) state that aerobic degradation rates of peat in the first year range from 0% to 6% for moderately to well-humidified peat. In this study, we assumed a degradation rate equal to 5%, and we included the first year of degradation in the use stage. Assuming carbon quantities for black and white peat as shown in Table 4, we obtained the CO_2 degradation shown in Figure 11.

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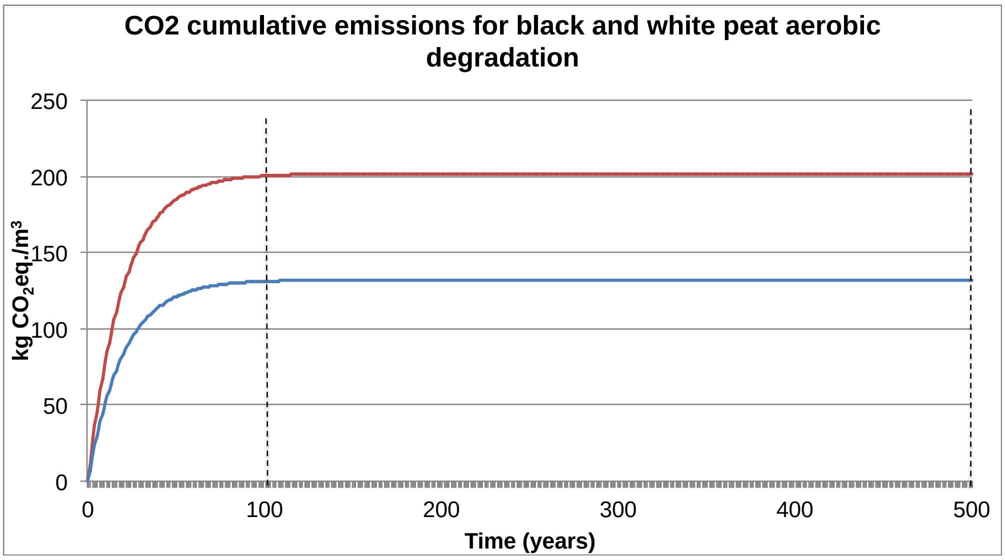

Figure 11: CO_2 cumulative emissions for black and white peat end-of-life, for 100 year and 500 year time horizons, respectively. The first year is included in the use stage. The degradation rate assumed is from Cleary et al., (2005).

Concerning N_2O emissions during degradation, we assumed that 1.5% of nitrogen content is emitted as N_2O (Schmid et al., 2000) and that peat has a nitrogen content equal to 1% of the peat mass (www.peatmoss.com). We assumed the same degradation rate as CO_2. N_2O degradation trends for black and white peat are reported in Figure 12.

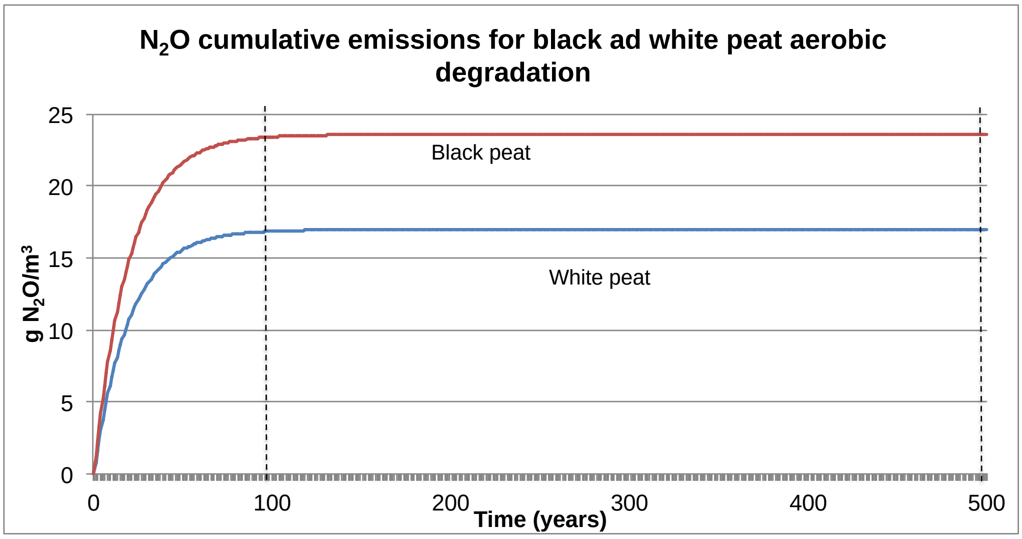

Figure 12: N_2O cumulative emissions for black and white peat end-of-life, for a 100 years and 500 years time horizons. The first year is included in the use stage. The degradation rate assumed is from Cleary et al. (2005).

2.7.3 Dynamic LCA and current LCA methodology

Current LCA methodology does not consider the timing of when emissions occur. In the inventory phase, all the emissions of a given pollutant are summed up into a single

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aggregated value. The global warming impact is then calculated by multiplying the aggregated emission of each gas by the respective global warming potential (GWP) for a given time horizon (20, 100 or 500 years). Finally, the life cycle impact for the global warming category in kg CO_2 -eq is given by the sum of the impact of each GHG[9].

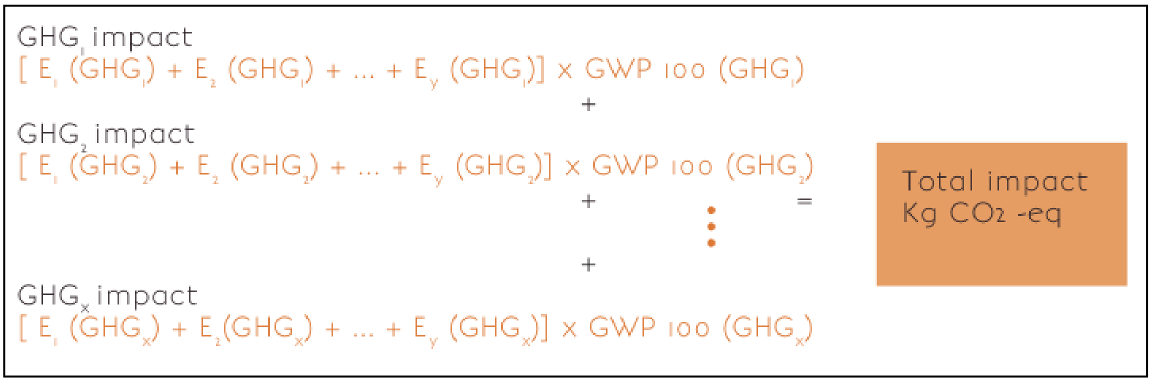

Figure 13 : Global warming impact assessment with current LCA methodology for a 100-year time horizon. GHG1 to GHGx represent each greenhouse gas identified by the IPCC. E1 to Ey represent the different emission sources (source: http://www.ciraig.org/dynCO_2 _en/).

According to Levasseur et al. (2010), the lack of consideration for the temporal distribution of GHG emissions in current LCA methodology leads to:

1) an inconsistency in temporal boundaries in relationship to the chosen time horizon
2) the inability to assess the impact of temporarily storing carbon or delaying GHG emissions.

The first issue is inherent to using GWPs for a fixed time horizon. Indeed, by choosing a 100-year time horizon for GWPs, one considers only the radiative forcing occurring during the 100 years following the emission. For a product system where the life cycle emission inventory occurs over a long period of time such a building with a 75-year lifetime, the GHG emissions occurring at end-of-life (year 75) are assessed over a time period 175 years following the construction. If LCA results from two products or projects with different temporal profiles are compared, the time frame over which the global warming impact is calculated would not be the same for both systems. To compare products or projects consistently, one must use a flexible time horizon to assess the impact of each GHG emission, which would begin when the emission occurs and would finish at the end of the time horizon chosen for the analysis.

The second issue is related to the inability of current LCA methodology to value temporary carbon storage as it considers neutrality between carbon flows to and from the atmosphere if the temporal aspects are not considered. The increasing number of climate mitigation

[9] http://www.ciraig.org/dynco2_en/

projects using forestry, and other types of projects related to bioenergy, for example, also raise issues regarding the temporal aspects of GHG emissions. The principle of biomass carbon neutrality is increasingly questioned, particularly for wood, since carbon sequestration in trees can extend over several decades. One also has to be aware that temporary carbon storage has a value if and only if a time horizon is chosen over which impacts are calculated, so that delayed emissions have a lower impact over this time period, which the current LCA methodology cannot evaluate.

It is therefore preferable to use the dynamic LCA approach instead of the traditional LCA approach to compare the impacts of different product systems over a consistent time frame as soon as they involve GHG emissions dispersed over several years. A dynamic LCA approach is also recommended to assess the impact on global warming of any product system or project where GHG flows (emission and sequestration) occur on different timelines.

Dynamic LCA takes into account the temporal distribution of the emissions using a dynamic inventory. The life cycle inventory is collected separately in one-year time steps for each GHG. This dynamic inventory is then assessed with dynamic characterization factors (DCF), which consist of the integral of the absolute radiative forcing expression (AGWP) for every time step (Levasseur et al. (2010)):

$$DCF_i(t)_{instantané} = \int_{t-1}^{t} a_i\left[C_i(t)\right]dt$$

To develop a dynamic inventory, temporal boundaries must be defined in addition to the usual system boundaries that determine which processes will be considered in the inventory. The first thing to do is to set the initial time limit (time zero), i.e. the moment when the first life cycle emission occurs. Then, it is necessary to determine when each emission occurs relative to this initial time and the time horizon. A 100-year time horizon is used in the vast majority of applications, often justified by the fact that it is consistent with the Kyoto Protocol. However, Shine, one of the lead authors of the IPCC's First Assessment Report, wrote an editorial paper questioning the widespread use of GWP100, which he calls an "inadvertent consensus" (Müller-Wenk, 2010). By choosing a 100-year time horizon for GWPs, one considers only the radiative forcing occurring during the 100 years following the emission. After that timeframe the radiative forcing of each gas is implicitly considered to be zero.

In a dynamic LCA, all emissions from fossil or biogenic sources are valued with respect to the radiative forcing generated until the selected time frame. In that respect, choosing a 100-year timeframe meaning the radiative forcing of an emission occurring at time zero is calculated over 100 years, but the emission occurring at year 30 is calculated over the timeframe of the remaining 70 years. Each flow of CO_2 entering or leaving the atmosphere (independently if from fossil or biogenic origin) is accounted for in the inventory as a positive emission (entering the atmosphere) or a negative emission (leaving the atmosphere, e.g. (temporary) sequestration).

2.7.3.1. *Application of the dynamic LCA to the EPAGMA study*

Dynamic LCA is very relevant for correcting the temporal inconsistencies between the inventory and impact assessment with respect to the choice of an LCA time frame. In some cases, this temporal inconsistency can lead to a shift in the results/conclusions between traditional and dynamic LCA. This is particularly the case if the life cycle emissions of the product analysed occur over a period of time similar to the time horizon chosen for the analysis. In our study, if we consider a scenario of afforestation/reforestation for example, the dynamic LCA becomes more relevant than the traditional LCA because the (positive and negative) emissions over the life cycle of the forest are comparable to the chosen time horizon of the analysis (100 years). According to Levasseur et al. (2010), in afforestation and reforestation projects, the dynamics of sequestration significantly influence the temporal profile of the global warming impact, and therefore it is crucial to account for the time frame in order to properly assess any proposed projects.

The application of dynamic LCA is less relevant when the process of peat generation takes thousands of years. Carbon fixed by peat during this time horizon is almost negligible when compared to the extracted quantity, and the results of a dynamic LCA will be the same as the results of a traditional LCA. The same consideration may apply when the life cycle emission occurs over a very short timeframe. In the case of compost, for example, where emissions are taking place during the first few years, results from dynamic LCA and traditional LCA will be very similar. Additionally, if the growing medium degradation will be the same as its natural degradation speed (abandoned in the forest, for example), the difference in terms of results between traditional and dynamic LCA will not be so relevant.

Given these considerations, we decided to use a dynamic LCA approach for peat as the life cycle of extraction (with its after-use scenario) becomes comparable to the chosen time horizon of 100 years (in particular for the afforestation scenario).

In this study, to calculate the GHG impacts we used the DYNCO_2 tool. DYNCO_2 is a dynamic LCA software tool used to calculate temporal carbon footprinting developed by the CIRAIG (http://www.ciraig.org/dynco2_en/). More specifically, in this study we used a modified version of this tool that also takes into account the degradation of the methane into CO_2 in the atmosphere (traditionally not accounted for in the IPCC characterization factors). The characterization factors developed consider that when the methane is degraded, it is converted immediately into CO_2.

More specifically, we considered that the peat extraction starts in year 0. The peat extraction occurs over 50 years (this period is the average of the harvesting time of all the extraction sites considered in this study). Several after-use scenarios (presented in section 2.7.5.2) are considered at the end of the extraction period. Figure 14 presents CO_2 emissions for peat extraction and after-use scenario, with a time horizon of 100 years, using the example of forestry as the after-use scenario. For the end-of-life of peat and the use stage, degradation starts at the time 0 (see Figure 15). The time horizon considered is 100 years, a 500-year time horizon is considered in the sensitivity analysis.

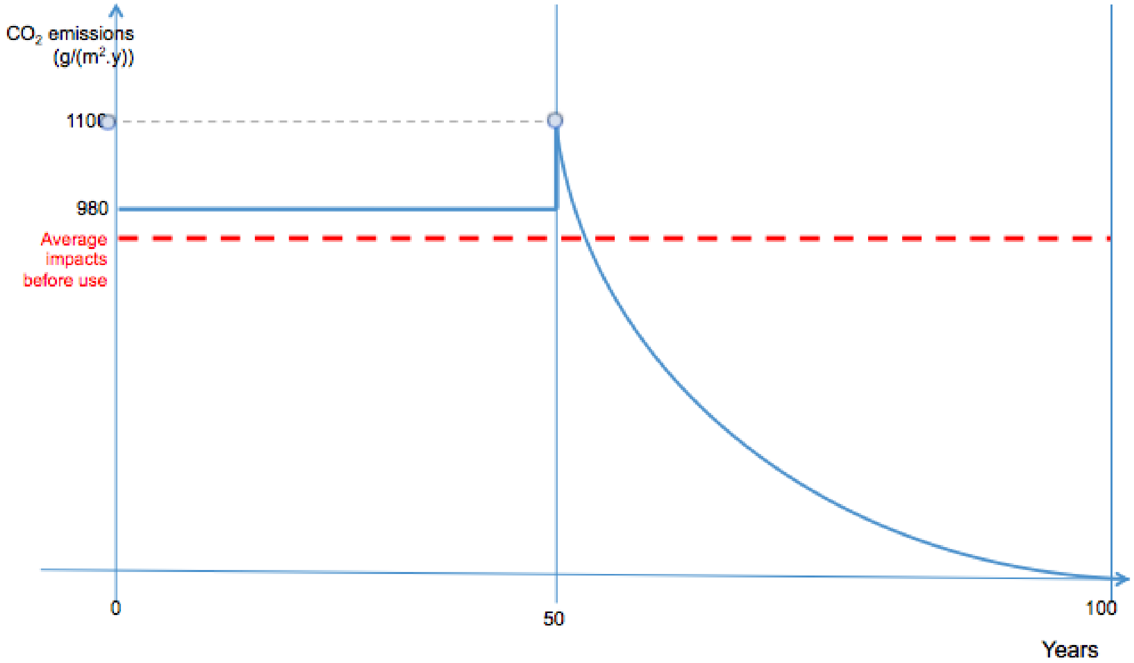

Figure 14: CO_2 emissions for peat extraction and after-use scenario with a time horizon of 100 years using the example of forestry as the after-use scenario. The blue line represents the CO_2 emissions trend during extraction and after-use, while the red line represents the impacts before harvesting (weighted average for the different sites).

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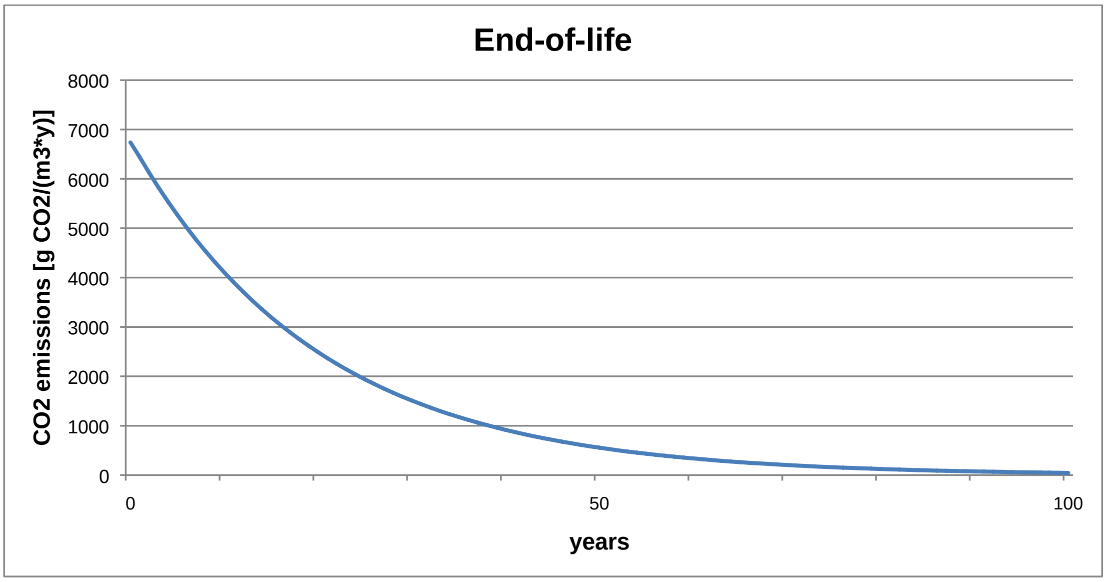

Figure 15: CO_2 emissions for end-of-life of white peat with a time horizon of 100 years. The model is based on Cleary et al. (2005)

2.7.4 Peat resource degradation in situ

GHG emissions are caused by an oxidation of the peat in situ that causes a degradation of the peat resource. This degradation has been calculated beginning from the upper heating value of black and white peat reported in Table 4 (an average value for black and white peat of 10.55 MJ/kg CO_2 has been assumed).

2.7.5 Ecosystem quality impacts

In this section, the assumptions concerning Ecosystem quality impacts during the different stages of peat production are presented.

We used here the same approach applied for the peat GHG calculations. Therefore, impact calculations are described by the equation below:

Total Ecosystem quality impacts for peat production = (harvesting stage + after-use stage) – reference scenario

Where:

Harvesting stage	Period in which peat is being harvested. Harvesting causes a decrease of the biodiversity of a peatland and consequently an increase of the Ecosystem quality impact indicator. Impacts from equipment and transports are included.
After-use stage	The after-treatment potentially contributes to an increase in the biodiversity. This increase depends on the after treatment of the cutaway peatland. In this study four options are included: restoration,

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	rehabilitation, afforestation and agriculture (see section 2.7.2.3). Impacts from equipment and transports are included.
Reference scenario	This is the scenario represented by the pre-harvesting conditions of the peatland. Impacts from this stage are considered to be avoided (hence the subtraction in the equation). The type of peatland will determine the level of biodiversity in the reference scenario.

So far, no publication in the literature specifically addresses the Ecosystem quality indicator in LCA for peatland. Consequently, we chose to adapt the IMPACT 2002+ method for the case of peatland. The following approach (based on expert judgment) has been developed internally at Quantis by the experts that have co-authored the IMPACT 2002+ methodology, integrating inputs from discussions with Dr. Heinrich Höper[10].

This remains however a first attempt to assess Ecosystem quality for peatland in LCA. A more detailed and robust analysis should be conducted in the future bringing together LCA experts, ecologists, and experts in peatlands. This is out of the scope of this study, but could be part of another project.

2.7.5.1. IMPACT 2002+ adaptation

The unit used to express the Ecosystem quality indicator in IMPACT2002+ is PDF.m^2.y. PDF stands for Potentially Disappeared Fraction, and the indicator represents the number of species disappeared times the area affected (m^2) and the duration of the disappearance (year). The Ecosystem quality indicator represents the sum of the damage scores calculated for the midpoint categories "aquatic ecotoxicity", "terrestrial ecotoxicity", "terrestrial acid/nutrification" and "land occupation". Characterization factors for land occupation (m^2 eq organic arable land/(m^2.y)) have been calculated from land use impact scores estimated for each reference scenario.

Figure 16 shows the land use impact scores estimated on the basis of the biodiversity levels assigned to each reference scenario (working assumptions). Biodiversity scores are expressed as a % of pristine bog biodiversity. If we assume that a pristine bog has the highest level of biodiversity of any peatland (100%, which corresponds to a 0 land use impact score) while a peatland under extraction has the lowest biodiversity level (0%, which corresponds to 1 land use impact score), we can collocate the other scenarios between these values. Consequently, we assumed that:

- Degraded peatland has a biodiversity equal to 10% of the pristine bog biodiversity;

[10] Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover).

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- Drained cultivated peatland has a biodiversity equal to 25% of the pristine bog biodiversity;
- Drained forested peatland: there are two possible scenarios. A forest that is exploited by man can reach a biodiversity level very different from a natural forest. We assumed that a man-forested peatland has a biodiversity degree equal to 60% of the pristine bog biodiversity. In order to be consistent with the scenario chosen for carbon accumulation in a forest as after-use (harvesting every 100 years according to Masera et al. (2003)), *we considered here only the man-forested scenario.*

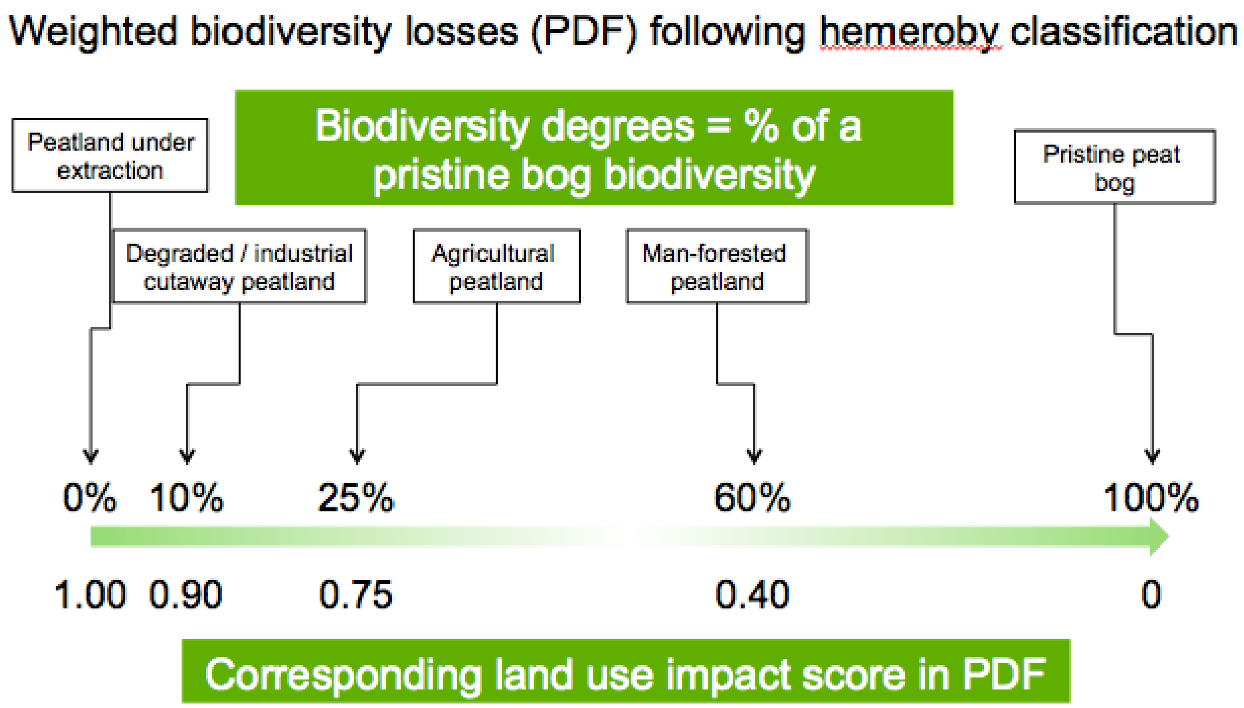

Figure 16: Conversion from the reference scenario biodiversity level to land use impact scores. These are working assumptions.

Table 8 reports the conversion from land use impacts scores to IMPACT2002+ characterization factors. According to IMPACT 2002+, the conversion factor from land use impact scores is equal to 1.09 PDF.m^2 .yr/m^2 org.arable[11].

[11] Organic arable land. Unit used in IMPACT 2002+ to express land use impact scores

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Table 8: Characterization factors calculated for each reference scenario. The conversion factor from land use impact scores is equal to 1.09 PDF.m^2 .yr/m^2 org. arable (IMPACT 2002+).

EPAGMA study specific land occupation flows for peatland		Estimated land use impact score		Characterization factors	
Peatland under extraction	0%	1.00	PDF = PDF.m^2.y/m^2y	0.917	m^2 org.arable/m^2y
Degraded / industrial cutaway peatland	10%	0.90	PDF = PDF.m^2.y/m^2y	0.826	m^2 org.arable/m^2y
Agricultural peatland	25%	0.75	PDF = PDF.m^2.y/m^2y	0.688	m^2 org.arable/m^2y
Man-forested peatland	60%	0.40	PDF = PDF.m^2 .y/m^2y	0.367	m^2 org.arable/m^2y
Nature-forested peatland	90%	0.10	PDF = PDF.m^2.y/m^2y	0.092	m^2 org.arable/m^2y
Pristine bog peatland	100%	0.00	PDF = PDF.m^2.y/m^2y	0	m^2 org.arable/m^2y

2.7.5.2. After-use stage

This chapter gives an overview of the different peat after-uses scenarios. For a short description of the after-use scenarios chosen, see section 2.7.2.

To be consistent with GHG emissions, we considered here a timeframe of 100 years (after the start of the extraction, so 50 years after the end of extraction; this is the same approach used for the GHG calculations). 500 years is used in sensitivity analysis.

a) Forestry

For forestry, we assumed that the land use impact score decreases from 1 (value attributed to a peatland under extraction) to 0.1 PDF (value assumed for a nature-forested peatland). If the forest is not exploited, the impact stays constant at this value. If the forest is harvested (on average every 70 years) the impact increases instantaneously to a value approaching 1 and then decreases from it again, cyclically. Figure 17 shows this cycle. For simplicity, we assumed that impact decreases to 0.4 PDF (the average value of each cycle, assumed for a man-forested scenario) and then stays constant at this value.

In order to be consistent with the scenario chosen for carbon accumulation in a forest as after-use (harvesting every 100 years according to Masera et al. (2003)), we considered here only the approximation of the man-forested scenario (excluding the nature-forested scenario).

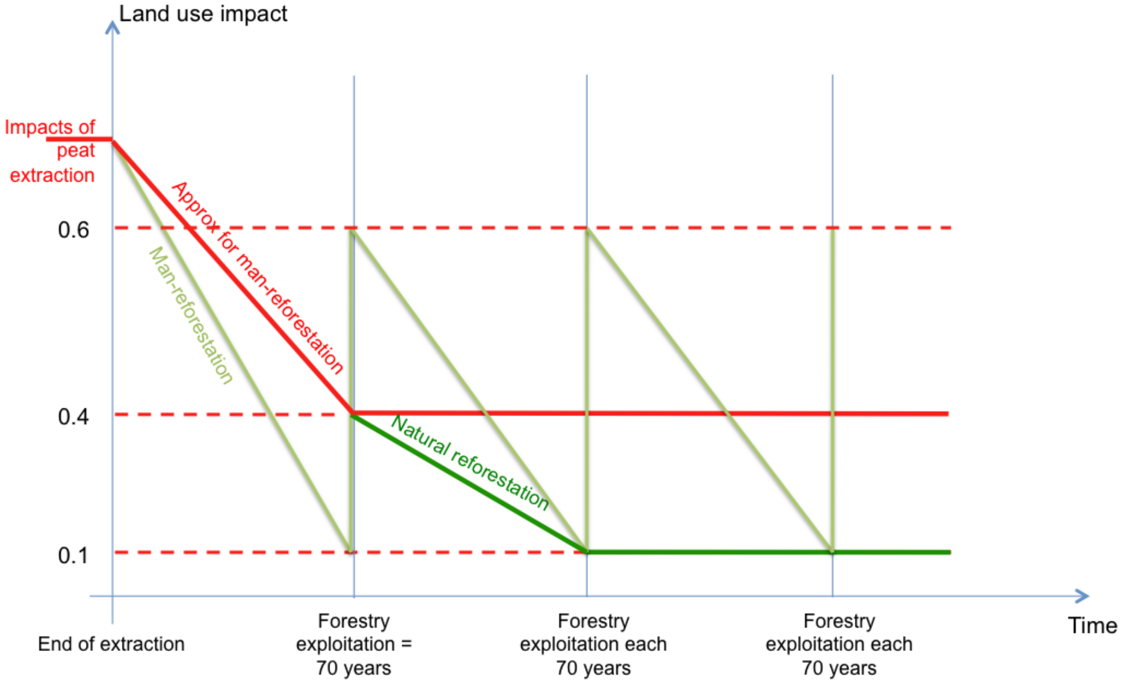

Figure 17: Land use impact scores trends for forestry. Qualitative chart based on experts judgement. Working assumptions.

b) Agriculture

We assumed that the ecosystem is influenced by the previous peat extraction for about 10 years after the end of extraction, after which the land use impact score reaches 0.75 PDF (the score assumed for a drained cultivated peatland reference scenario) and is maintained constantly for the next years. Figure 18: shows the land use impact score trends for agriculture.

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c) Restoration

For the restoration after-use scenario, we assumed that the land use impact score decreases from 1 (value attributed to a peatland under extraction) to 0.8 in the first 10 years[12]. After this time, the score continues to decrease linearly until the value equals 0, reached after 25 years. Figure 18 shows the land use impact scores trends for restoration.

d) Rehabilitation

For rehabilitation, we assumed a trend very similar to restoration. The only difference is that, by the definition of the term itself, with rehabilitation it is not possible to reach a score equal to 0 (i.e., it is not possible to reach a biodiversity degree equal to a pristine bog). We assumed that after 25 years a score equal to 0.1 is assumed and maintained for subsequent years. Figure 18 shows the land use impact scores trends for rehabilitation.

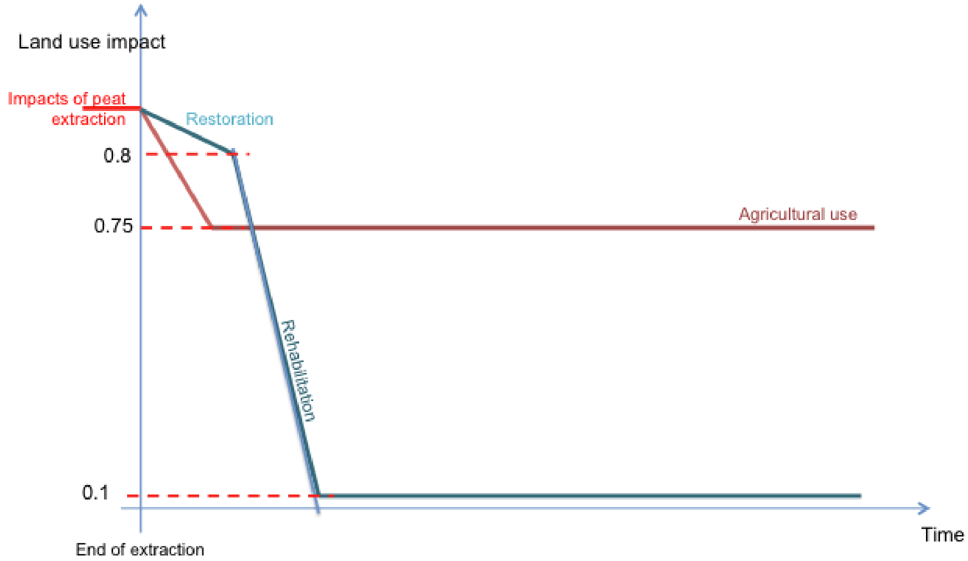

Figure 18: Land use impact score trends for restoration, rehabilitation and agriculture after-use scenarios. This qualitative chart is based on available literature on GHG emissions from a peatland and experts judgement (working assumptions.)

2.7.6 Black and white peat transport to mixing plant

To model the distances to the mixing plant and the transportation modes we used primary data collected through the completed questionnaires from EPAGMA members. For volume-limited transports we assume that a 40 t truck transports 25 t in a volume of 102 m^3. Therefore, 245 kg/m^3 has been considered the density threshold below which transport is volume-limited.

[12] Dr. Heirich Höper, expert judgment, personal communication.

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2.8 Data and assumptions for the other growing media constituents

The main hypotheses and data used for the other growing media constituents analysed in this study (those other than peat) are described in this chapter.

The exact reference flows considered are presented in Appendix A.

Bulk densities (fresh and dry) and the moisture content of each constituent are summarized in Table 9.

Table 9: Bulk densities (fresh and dry) and the moisture content of the different growing media constituents analysed in this study

Constituents	Bulk density (kg/m^3) fresh	dry	Moisture content (% m/m)	C content (% m/m dry matter)
Bark	280	196	30%	50%
Coir pith	350	70	80%	46%
Green compost	600	330	45%	29%
Mineral wool	70	70	negligible	negligible
Black peat	400	100	75%	55%
White peat	180	72	60%	50%
Perlite	105	105	negligible	negligible
Rice hulls	110	100	9%	47%
Wood fibres	120	66	45%	50%

2.8.1 Bark production and processing

Bark used in growing media is a by-product of forestry operations. The main products of sawmills are sawn timbers and wood chips, whose economic values are higher than the sawdust and bark values.

The approach used in this study was to complete the primary data coming from one supplier and one EPAGMA member with ecoinvent data.

More specifically, for wood harvesting, we used primary data related to diesel consumption, machinery and transport to sawmill from one supplier complemented by data from ecoinvent. Secondary data are related to land use for the trees to grow.

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For sawing activities we used secondary data from ecoinvent (Sawing/debarking softwood at plant from Sawdust, Scandinavian softwood (plant-debarked), dry matter content=70%, at plant/NORDEL). The allocation factors reported in Table 15 were used for the different by-products.

For bark processing (diesel and energy consumption for bark screening and breaking) we used primary data coming from one EPAGMA member and one supplier.

Bark can be used as a growing media constituent both fresh and composted. The bark considered in this study is fresh bark.

The average bulk density of fresh bark has been assumed to be 280 kg/m^3 at a moisture content of 30%(m/m).

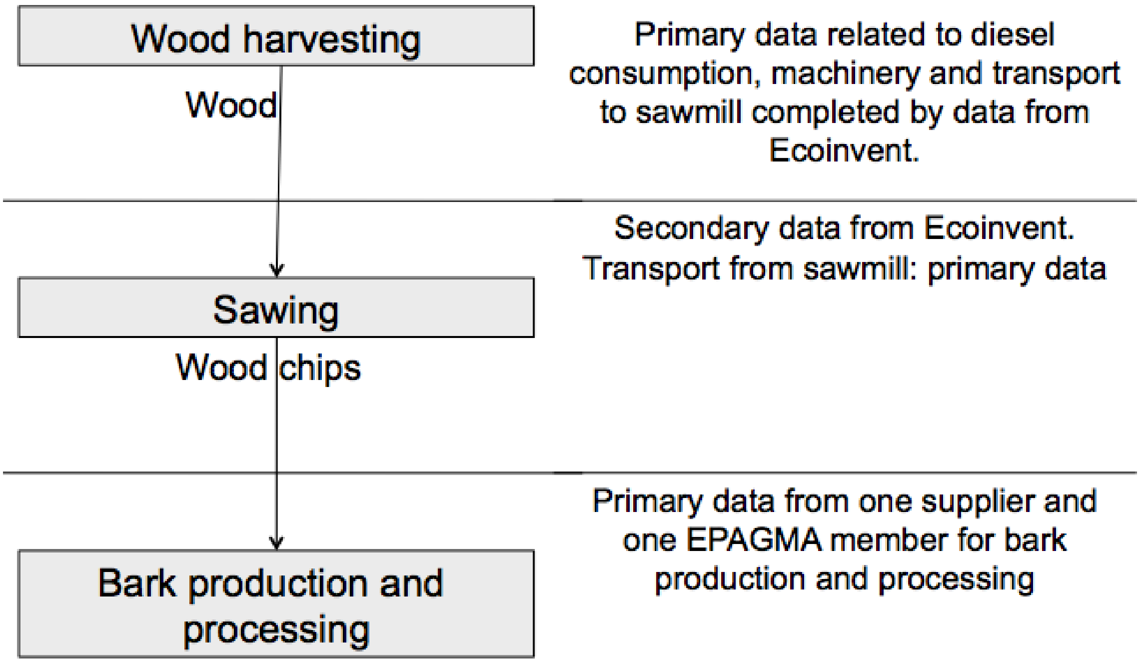

Figure 19: Bark production and processing system boundaries and source of data per each stage

2.8.2 Coir pith production and processing

The coir pith used in horticulture is normally a by-product of coir fibre production from India and Sri Lanka although dedicated operations to supply horticultural coir are becoming more common. In this study we assumed that coconut cultivation, harvesting and coir pith processing occur in Sri Lanka. Data concerning coconut production (cultivation and harvesting) come from national statistics of the Coconut Development Authority (internet), the Sri Lanka Ministry of Plantation Industries (internet) and the Coconut Research Institute of Sri Lanka (internet). Consequently, these are primary data, but they are representative at a national level instead of a local level. Following the Coconut Research Institute of Sri

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Lanka, we assumed that the weight of a coconut is on average 1.6 kg while the nut without husk has a weight of 0.73 kg (wet weight, during cultivation). After harvesting, coconuts are sun-dried. Following Perera et al. (2005)[13] we considered that 60% of the husk is fibre and 40% is coir pith (in terms of mass).

In general, as found in the literature, water consumption for coconut cultivation in Sri Lanka is not based on irrigation. The coconut producers are in fact located in the centre-west of the island (the coconut triangle) where precipitation is elevated. Excluding exceptional cases of long dry periods, coconut cultivation has no significant pressure on water resources. It is important to note that coconut cultivation is not an agriculture that causes deforestation as, for instance, palm oil cultivation does. While in Malaysia and Indonesia palm oil cultivation causes deforestation because of the high global demand of palm oil for the agro-food, cosmetics and biocarburants industry, the coconut cultivation in Sri Lanka is directed principally toward a local demand (more than 80% of the national production is dedicated to the domestic consumption according to the Sri Lanka Ministry of Plantation Industry (2008)). Consequently, the coconut cultivation does not destroy the Sri Lankan forestry. The surface areas dedicated to coconut cultivation have been stable for many decades (about 420’000 ha), and new cultivations are marginal (about 1’000 ha/year on average since 1990).

The pith is extracted from the layer of fibrous pulp that protects the coconut. Coconuts are split, either manually or mechanically, to remove the edible part and then husks are processed for coir. There are three different approaches to pith extraction: sprinkling and shredding, retting or mechanical decortication. In this study we considered the coir pith retting, and we received primary data for energy consumption of this process from a supplier. Retting can take between two weeks and six months depending on the ripeness of the fruit and the type of retting system used. Retting is an anaerobic process in which the binding material in the coconut husk is decomposed to allow easy removal of the fibre. Data used for coir pith retting are secondary data coming from Williams et al., (2007) and Blonk Milieu Advies BV (2011).

After extraction, coir pith is transported from coir fibres mills to a processing plant, in which it is subjected to storage for physical stability, buffering and washing processes. Buffering processes involve calcium nitrate and water consumption, and these were included in this study. Coir pith is then sun-dried and compressed into slabs or bales and transported by ship to Europe. All data from storage to compression are primary data coming from one EPAGMA company.

[13] Following Perera et al. (2005), weight of the dry husk of a coconut has been considered equal to 350 g. The dry fibre is about 140 g and the balance 210 g is coir pith.

In area of application 1, coir pith is compressed and decompressed directly by the grower. This is different from the other areas of application in which coir pith is decompressed immediately when it arrives in Europe and then transported to the mixing plant. Electricity for decompression has been estimated following Blonk Milieu Advies BV, 2011. Compressed coir pith density has been considered equal to 400 kg/m^3 for a moisture content of 20% while non-compressed coir pith as final product has a bulk density of 350 kg/m^3 for a moisture content of 80%. Decompressed coir pith dry bulk density is equal to 70 kg/m^3.

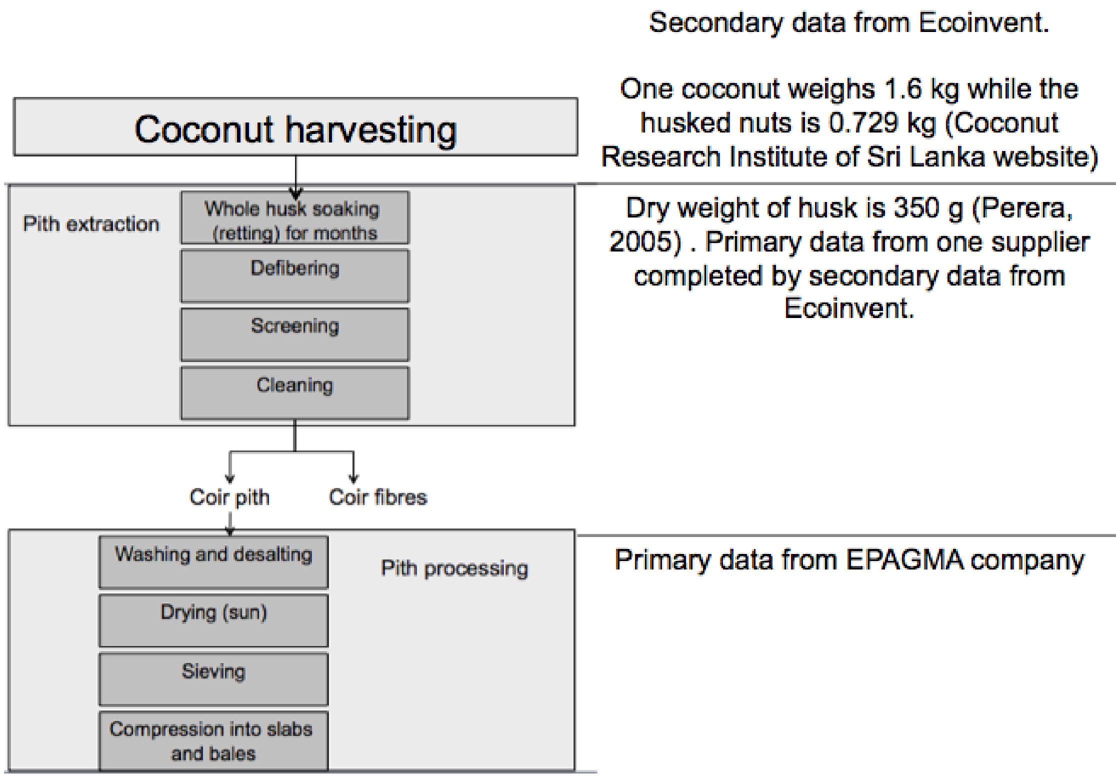

Figure 20: Coir pith system boundaries and source of data per each stage

2.8.3 Green compost production and processing

Green wastes are taken to civic collecting points by the public and then transported to the composting site by the companies or are delivered to composting sites by landscaping businesses. As food wastes can provide excess nutrients and salt content in end materials, these materials are not usually included in composts destined for inclusion in growing media. Green compost is made of woody materials, leaves, branches, grass clippings, plant residues and to some extent spent growing media.

Primary data were collected directly from two EPAGMA members through a questionnaire, and they are related to the input ingredients, the electricity and diesel consumption, and the machinery involved.

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The average density considered was 600 kg/m^3 for 45% moisture content. The production rate used was 0.72 t_{output}/t_{input} (primary data). Compost characteristics are summarized in Appendix H. Data on wastes degradation come from literature data (see References). There are uncertainties on the input element composition (calculated and estimated on the basis of the input ingredients – quantity of leaves, branches, etc.). Figure 21 shows the green compost production and processing system boundaries and the source of data for each stage.

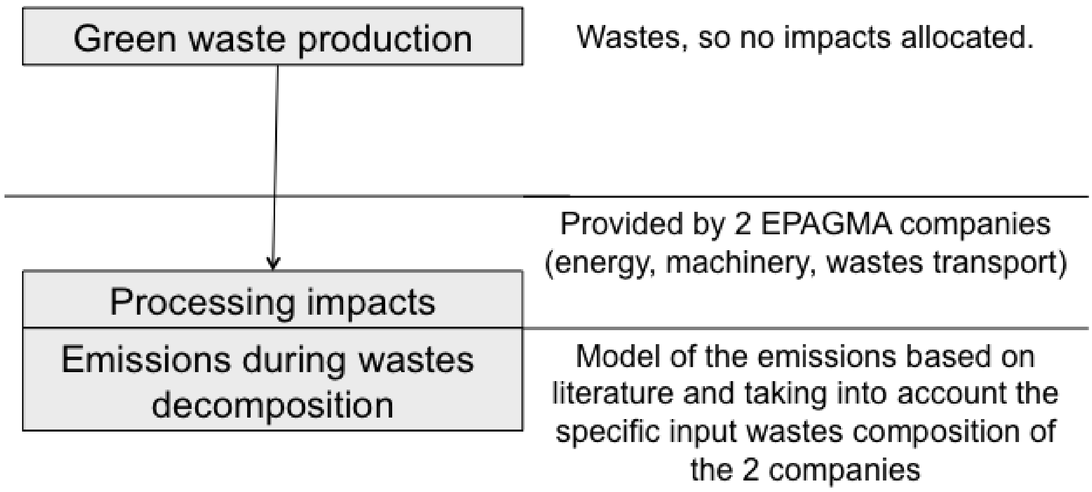

Figure 21: Green compost system boundaries and sources of data for each stage

2.8.4 Mineral wool production and processing

Results were based on primary data provided by a supplier in co-operation with the Dutch company Blonk Milieu Advies as well as the ecoinvent database.

Mineral wool is a furnace product of molten rock at a temperature of about 1600 °C through which a stream of air or steam is blown. In this study, mineral wool is produced beginning from basalt. Impacts related to basalt extraction are derived by ecoinvent, while the mineral wool processing impacts come from the supplier. Fuels used for the processing phase are cokes, natural gas and diesel. Figure 22 shows the mineral wool production and processing system boundaries and the source of data for each stage.

Mineral wool has a variable density: an average density of 70 kg/m^3 was used in this study (dry material).

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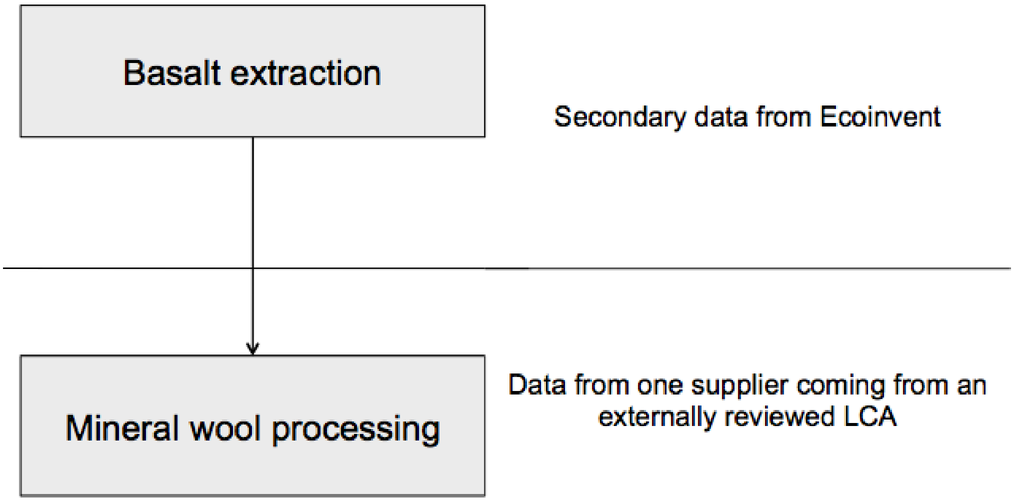

Figure 22: Mineral wool system boundaries and source of data for each stage

2.8.5 Perlite production and processing

Data concerning perlite extraction were provided by one supplier and concern 2 different sites in Greece. Primary data include extracted area, fuel consumption and machines used. Density of the crude perlite (not expanded) has been assumed equal to 1160 kg/m^3. Data related to perlite expansion and processing were provided by 2 suppliers and are related to 5 different sites in Europe. Primary data for this stage include electricity and natural gas consumption, machinery used, and transportation from the extraction site to the expansion plant and the processing plant. Expanded perlite density has been assumed equal to 105 kg/m^3.

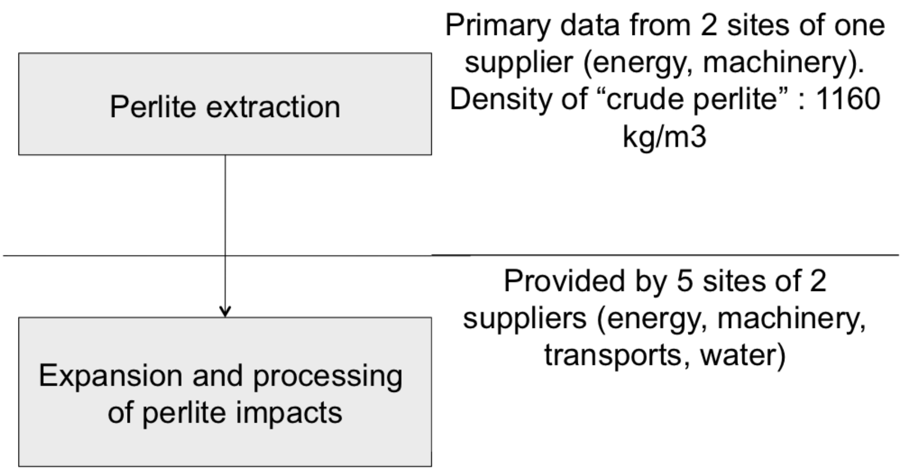

Figure 23: Perlite system boundaries and source of data for each stage

2.8.6 Rice hulls production and processing

Dried paddy has a non-edible husk or hull surrounding the kernel. During milling, all the stalks and other unwanted materials are removed from the rough rice by a sequence of processes which make use of electricity: cleaning, hulling, milling or whitening, polishing, grading and sorting. Data regarding rice cultivation and harvesting, rice drying, and rice refining come from Blengini et al. (2009). The model describes a typical farm in the Vercelli district in Italy that makes use of an average amount of products (fertilizers, pesticides, etc.) and which harvests an average yield of 7.03 t/ha of paddy rice, roughly corresponding to 6.12 t/ha of dried paddy rice (1995 to 2005 average value according to FAOSTAT). The input data were obtained from different sources: on site records, interviews with farmers, agronomists and rice processing technicians, as well as specific literature on the Vercelli district and international literature.

Economical allocations reported in Table 15 were used for the different by-products.

Density of rice hulls has been defined as equal to 110 kg/m^3 (fresh material).

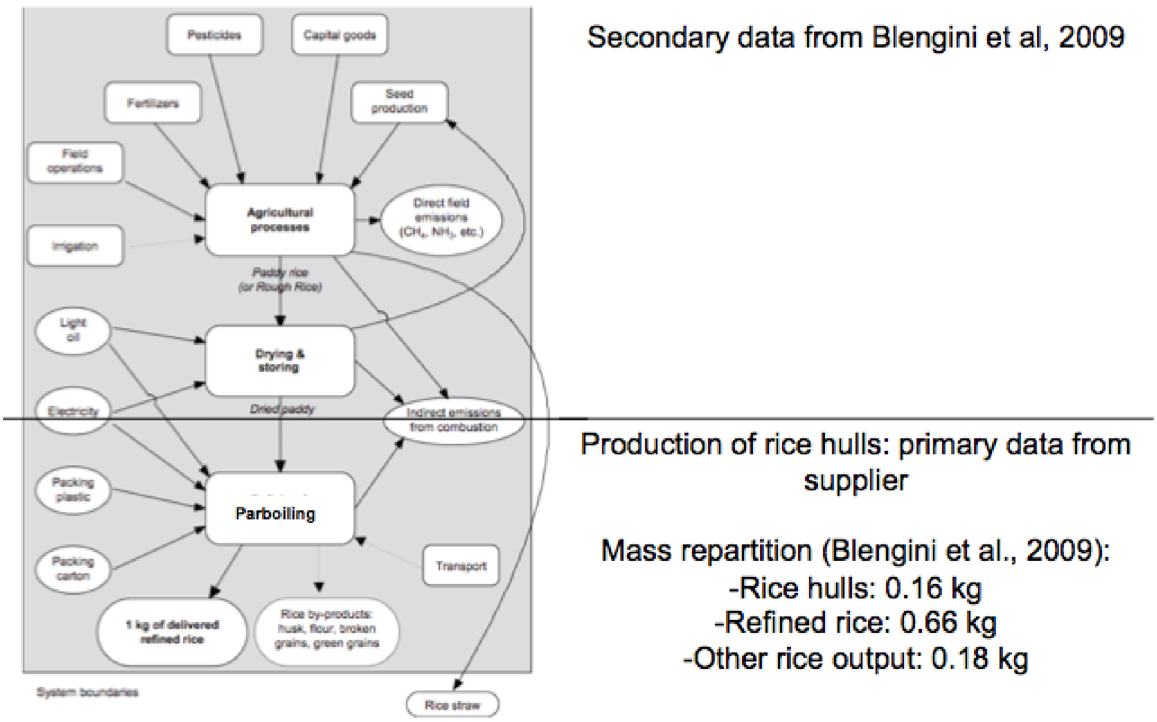

Figure 24: Rice hulls system boundaries (Blengini et al., (2009)) and source of data for each stage

2.8.7 Wood fibres production and processing

The defibration process breaks up the wood chips as carefully as possible into individual fibres and bundles of fibres. This is done thermo-physically.

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Two EPAGMA members provided us with primary data for wood fibre production and processing. Primary data are related to electricity consumption, diesel consumption, machinery, water and wood chips quantities. Primary data were completed with data from ecoinvent. i.e. wood chips production. The ecoinvent process used is “wood chips, softwood, from industry, u=40%,” and it includes the chopping of residual softwood with a stationary chopper in a sawmill.

To calculate the final impact of wood fibres production and processing, we made a weight average of the impacts of the two companies based on their yearly production.

Average bulk density of wood fibres has been considered equal to 120 kg/m^3 at a moisture content of 45% (m/m).

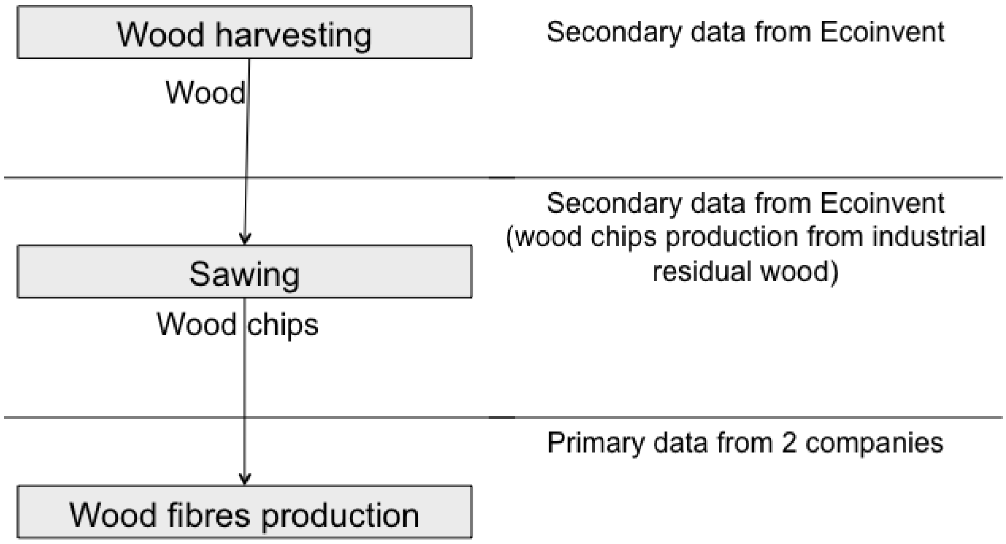

Figure 25: Wood fibres production and processing system boundaries and source of data for each stage

2.8.8 Transportation to the mixing plant

Distances assumed for transportation are summarized in Table 10. For volume-limited transport we assume that a 40 t truck transports 25 t for 102 m^3[14]. Therefore, 245 kg/m^3 has been assumed to be the density threshold below which transport is volume-limited.

[14] http://www.free-logistics.com/index2.php?option=com_docman&task=doc_view&gid=190&Itemid=82

Table 10: Distances for transportation of constituents to mixing plants with corresponding sources

Constituent	Distance (km)	Transportation mode	Source
Bark	500	truck	Primary data from supplier
Coir pith from Sri Lanka to Rotterdam	12500	ship	Assumption - based on data received from suppliers from the other constituents
Coir pith to Colombo harbour+from Rotterdam to the decompressor plant	200	truck	Assumption - based on data received from suppliers from the other constituents
Coir pith from decompressor to mixing plant	100	truck	Assumption - based on data received from suppliers from the other constituents
Coir pith from retting plant to processing plant	15	truck	Primary data
Green compost	100	truck	Assumption - compost is produced almost everywhere in Europe
Mineral wool to mixing plant	200	truck	Primary data from supplier
Basalt (raw mineral) to processing plant	20	truck	Assumption
Black peat	9	train	Primary data. Weighted average on data collected by 13 EPAGMA companies.
	200	truck	
	600	ship	
White peat	2	train	Primary data. Weighted average on data collected by 13 EPAGMA companies.
	1400	truck	
	3200	ship	
Perlite (raw mineral) to expanding plant	14	truck	Primary data from supplier
	4190	ship	Primary data from supplier
Perlite to mixing plant	191	truck	Primary data from supplier
Rice hulls	500	truck	Primary data from supplier
Wood fibres	200	truck	Assumption - they can be produced only in some countries

2.8.9 End-of-life for the growing media constituents (other than peat)

The only scenario for end-of-life considered in this study is the abandon scenario. Therefore, we assumed that growing media are not re-used by another life cycle of plants growing in them, and they are not transported to another place. They are left on the field.

For N_2O emissions during degradation, we assumed that 1.5% of nitrogen content is emitted as N_2O (Schmid et al. (2000)).

The nitrogen content for bark and wood fibres comes from the ecoinvent database, and it is equal to 987 mg/kg. For coir pith, we assumed nitrogen content of coconut fibres is 0.45%, while for rice hulls it was assumed to be equal to 0.51%[15].

For green compost, we assumed that nitrogen content is equal to 7.7 g/kg input (EPAGMA primary data completed by Sonesson (1996)).

2.9 Data and assumptions for all the growing media

2.9.1 Mixing processes

Mixing activities (e.g., energy, buildings, and packaging) were considered equivalent for all the growing media. Consequently, they were not taken into account since they are same. During mixing processes, lime and fertilizers are added to growing media.

PG Mix fertilizer products are commonly used in growing media production. In this study PG Mix 15+10+20+3.8 ($N+P_2O_5+K_2O+MgO$) + trace elements (B, Cu, Mn, Mo, Fe, Zn) is the reference fertiliser used. Its specifications can be found on the producer's website[16].

[15] www.ecn.nl

[16] http://www.yarabrasil.com.br/fertilizer/products/specialties/others/pg_mix.aspx

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Table 11: Lime and PG Mix quantities for different mixes

Area of application 1: Fruity vegetables	**Mix 1.1**	**Mix 1.2**	**Mix 1.3**	**Mix 1.4**
Lime [kg/m³]	5.5	-	-	
PG Mix [kg/m³]	-	-	-	
Area of application 2: Pot plants	**Mix 2.1**	**Mix 2.2**	**Mix 2.3**	**Mix 2.4**
Lime [kg/m³]	5.7	4.4	0.25	1.5
PG Mix [kg/m³]	1.5	1.5	1.2	1.2
Area of application 3: Young plant production	**Mix 3.1**	**Mix 3.2**	**Mix 3.3**	**Mix 3.4**
Lime [kg/m³]	5.8	1.7	2.8	4.4
PG Mix [kg/m³]	0.5	0.5	0.5	0.5
Area of application 4: Tree nursery stock	**Mix 4.1**	**Mix 4.2**	**Mix 4.3**	**Mix 4.4**
Lime [kg/m³]	0.25	3.7	1.5	5.2
PG Mix [kg/m³]	1.5	1.5	1.5	1.5
Area of application 5: Hobby market	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**
Lime [kg/m³]	-	5,3	5,7	-
PG Mix [kg/m³]	1.0	1.3	1.3	1.0

2.9.1 Growing media distribution

We assumed the same distribution distances for all the growing media. We calculated the average distances on the basis of primary data collected from EPAGMA members. Each member provided an average distance per freight mode for all the growing media produced during one year. A weighted average based on yearly company production has been used to calculate final distances. Distances used for distribution of growing media are reported in Table 12.

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Table 12: Distances for distribution of growing media to final customer

Freight mode	Distance (km)
Transport by truck	650
Transport by ship (bulk)	960
Transport by ship (container)	11100
Transport by train	1070

2.9.2 Use stage for the growing media

Since we have assumed that growing media within the same area of application are functionally equivalent, we consider the processes for the use stage to be equivalent. Consequently, heating energy in greenhouses, water use and fertilizer consumption were not taken into account since they are very much the same for all the growing media in each area of application. Possible differences in terms of water use and fertilizer consumption among growing media during the use stage were thoroughly discussed and analysed with the EPAGMA experts before arriving at the above-mentioned conclusion.

2.9.3 Electricity mix

Several approaches exist to determine which electricity mix should be used in this study. The electricity mix used for all activities occurring in Europe is that of the UCTE, representing the average electricity mix consumed in Western Europe through the highly interconnected electric grid. For coconut cultivation and coir pith retting, the electricity mix used is the one for Sri Lanka[17].

2.10 Allocation rules

In life cycle assessment, when a process has multiple outputs (that is when processes yield more than one product or they include recycled intermediate or discarded products as raw materials), it is necessary to partition the input or output flows of the process between the product systems benefitting from these multiple outputs, i.e. between the product system under study and one or more other product systems.

We explain here the allocation rules used for different products in this study.

[17] International Energy Agency (IEA) website

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2.10.1 Bark allocation

Bark mass allocation has been mainly based on data coming from West Virginia University[18] and Canadian statistics[19].

To calculate mass allocation factors, we considered that with 1 m^3 of wood we can produce:

- Wood for sawn timbers: 0.48 m^3
- Chips: 0.94 m^3 (i.e. 0.20 t)
- Sawdust: 0.14 m^3 (i.e. 0.06 t)
- Bark: 0.28 m^3 (i.e. 0.08 t)

Concerning economic allocation factors, we used the prices reported in Table 13.

Table 13: Prices for wood by-products used to calculate economic allocations factors.

	Wood for saw timbers	Chips	Sawdust	Bark
Unit	**€/m^3**	**€/t**	**€/t**	**€/t**
Value (2008/2010)	200	53	39	39
Unit	**€/m^3 of wood**	**€/m^3 of wood**	**€/m^3 of wood**	**€/m^3 of wood**
Value (2008/2010)	97	11	2	3
Unit	**%**	**%**	**%**	**%**
Allocation factors	85	10	2	3

2.10.2 Coir pith allocation

Coconuts are mainly cultivated to extract by-products as oil and copra production or fibres, rather than for the fruit itself.

Figure 26 represents some by-products of a coconut. We understand from this figure that all the impacts related to the coconut cultivation (all the agricultural processes from the cultivation to the coconut harvesting) have to be allocated among the different by-products. From a coconut, there are two parts that can be used: the husk and the nut. Coir pith is extracted from the husk together with fibres.

[18] West Virginia University website Division of Forestry and Natural Resources.

[19] Minister of Natural Resources and Wildlife of Quebec

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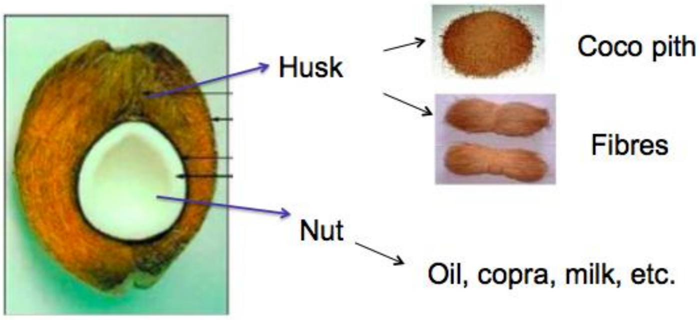

Figure 26: Some by-products from a coconut (Source: Sri Lanka Coconut Development Authority website[20])

The allocation of the impacts is calculated by economic allocation based on the prices of the different by-products. Table 15 reports the different allocation factors used. They have been calculated on the basis of the exports from Sri Lanka (information reported on the Sri Lanka Coconut Development Authority website). An average has been calculated on the basis of the exports in 2006 and 2007.

2.10.3 Rice hulls

To calculate allocation factors for the rice hulls we used data coming from Blengini et al. (2009). Table 14 reports prices used to calculate the allocation factors for rice hulls.

[20] http://www.cda.lk/stats.php

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Table 14: Prices for rice products and by-products used to calculate economic allocation factors (Source: Primary data and Blengini et al., (2009))

Product	Percentage by weight (Source: primary data)	Market value (€/t) (Source: Blengini et al., (2009))	Market value for 1 t of dried rice (€/t)
Refined rice	66	500	330
Rice hulls	16	20	3.2
Other (Rice flour, broken rice, green grains)	18	153[21]	27.6
Total	100	-	360.8

Table 15 summarizes the economic allocation factors used in the study for coir pith, bark and rice hulls.

Table 15: Economic allocations factors used in this study.
The whole coconut has 2 by-products, nuts and husk, with 58% and 42% as economical allocation factors, respectively. The husk has 2 other by-products: fibres and coir pith, with 73% and 27% as economical allocation factors, respectively. Please refer to Appendix A for more details.

	By-products	Economical allocation factor (%)	By-products of second level	Economical allocation factor (%)	Source
Whole coconut	Nut	58			Average 2006/2007 of the exports (Sri Lanka Coconut Development Authority (2009))
	Husk	42	Fibres	73	
			Coir pith	27	
Wood tree	Wood products, sawn timber	85			West Virginia University website Division of Forestry and Natural Resources (http://ahc.caf.wvu.edu/joomla/), Minister of Natural Resources and Wildlife of Quebec
	Chips	10			
	Bark	3			
	Sawdust	2			
Rice hulls	Refined rice	91.5			Blengini et al. (2009)
	Rice hulls	0.9			
	Other rice outputs (rice flour, broken rice, green grains)	7.6			

[21] Average value for rice flour, broken rice, green grains (Source: Blengini et al. (2009))

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2.11 Life cycle impact assessment method

Life cycle impact assessment (LCIA) provides the basis for analysing the potential contributions of the resource extractions and emissions in a life cycle inventory (LCI) to a number of potential impacts. To accomplish this, impact assessment allows an analyst to classify the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment, quantify and then combine these impacts into indicator results – one for each impact category.

According to ISO 14044, LCI results are classified into impact categories, each with a category indicator. The category indicator can be located at any intermediate position between the LCI results and the resulting damage (also called an endpoint, where the environmental effect occurs) in the cause-effect chain. The damage represents changes in environmental quality, human health or resource availability, and a damage indicator is a quantifiable representation of this change.

The method used here to assess the environmental impact is the peer-reviewed and internationally-recognized LCIA method IMPACT 2002+ (Jolliet et al. (2003), as updated in Humbert et al., (2009)). In addition, to provide results for 18 impact categories, IMPACT 2002+ allows their aggregation into 5 classes of damage (in which all classes, or categories, have the same relative importance).

The 18 considered midpoint categories and the 5 damage categories are summarized in Table 16.

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Table 16: Midpoint and damage categories considered in the IMPACT 2002+ method

Midpoint category	Unit	Damage category	Unit
Global warming	[kg $CO_{2\text{-eq}}$]	Climate change	[kg $CO_{2\text{-eq}}$]
Water withdrawal	[L water]	Water stress indicator[22]	[L water-eq]
Water turbined[23]	[L water]	Ecosystem quality	[PDF.m^2.y]
Aquatic eco-toxicity	[PDF.m^2.y]		
Terrestrial eco-toxicity	[PDF.m^2.y]		
Aquatic acidification	[PDF.m^2.y]		
Aquatic eutrophication	[PDF.m^2.y]		
Terrestrial acidification/nitrification	[PDF.m^2.y]		
Land use	[PDF.m^2.y]		
Primary non-renewable energy	[MJ]	Resources	[MJ]
Mineral extraction	[MJ]		
Human toxicity (carcinogen, non-carcinogen)	[DALY]	Human health	[DALY]
Respiratory organics	[DALY]		
Respiratory inorganics	[DALY]		
Ozone layer depletion	[DALY]		
Ionizing radiation	[DALY]		

[22] The water stress indicator is assessed based on water withdrawal characterized by country-based Water Stress Index (WSI) from Pfister et al. (2009).

[23] The characterization factor to quantify the Ecosystem quality impacts related to water turbined are taken in Maendly and Humbert (submitted paper).

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Based on these impact categories, the IMPACT 2002+ method is considered to encompass a broad range of potential impacts. Consideration of noise and social impacts would be desirable as well, but there are currently no sufficiently robust models to evaluate these two impact areas.

A restricted set of impact categories are presented and discussed in more detail for all of the growing media:

1. Climate change
2. Ecosystem quality
3. Human health
4. Resources

We chose to show these damage categories because they are the most pertinent for the studied products. In particular, Climate change and Ecosystem quality are sensitive issues for peat. Additional information regarding IMPACT2002+ is to be found in Humbert et al., (2009), Jolliet et al (2003), www.impactmodeling.org for IMPACT 2002+ and in Goedkoop et al, (2008) for ReCiPe.

For the life cycle inventory, the SimaPro 7.1 software was used to calculate the potential impacts related to the inventoried emissions. This software package classifies all of the elementary flows between the midpoint categories and generates the damage categories results.

2.12 Data Quality Analysis

Table 17 shows an evaluation of the data quality for each constituent. The quality is assessed on the three following criteria:

- Completeness: represents the exhaustiveness of the data collected. Data are complete when all of the elements necessary for carrying out the activity are quantified.
- Reliability: pertains to the data sources, acquisition methods and verification methods. Reliable data have been verified and measured in the field. This criterion chiefly refers to flow quantification.
- Representativeness: (also called validity) assesses the geographic and technological correlations and is essentially a sensibility check. This criterion chiefly refers to the choice of processes used when modelling the system.

The evaluation is expressed as follows:

- 1 = very good precision, complete. Good representativeness. Reproducible and low uncertainty.

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- 2 = good precision. Medium representativeness. Reproducible and medium uncertainty.
- 3 = medium precision, not very complete. Medium/low representativeness. Not very reproducible and medium uncertainty.
- 4 = not good precision, need to be improved: low precision, not complete. Low representativeness. Not reproducible and high uncertainty.

If we analyse the data reported in Table 17, we can see that there are no constituents that have an average rate between 3 and 4. The highest values are reached by green compost and coir pith (average values of 2.7), due in particular to high uncertainties in literature on emissions for waste degradation (for compost) and secondary data on coconut cultivation from national statistics (for coir pith).

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Table 17: Data quality analysis

Constituents	*Completeness*	*Comment*	*Reliability*	*Comment*	*Representativeness*	*Comment*	*Average*
Bark	1	Data concerning all the stages, very complete.	2	Wood chips production: secondary data from ecoinvent	3	Wood chips production: secondary data from ecoinvent. The choice of the round wood production process from the ecoinvent database can affect the results (land occupation factors for different kind of wood are very variable in ecoinvent).	2.0
Coir pith	2	All stages included but data on pesticides excluded because no official statistical data available.	3	For coconut cultivation, secondary data from the Coconut Development Authority, the Sri Lanka Ministry of Plantation Industries and the Coconut Research Institute of Sri Lanka.	3	For coconut cultivation, secondary data come from the Coconut Development Authority, the Sri Lanka Ministry of Plantation Industries and the Coconut Research Institute of Sri Lanka. Representative for Sri Lanka but they may not be representative for other countries as India	**2.7**
Green compost	1	Data concerning all the stages, very complete and detailed for all the emissions during all the degradation steps .	3	Emissions coming from literature, high uncertainty in literature on different GHG emissions	3	It is very difficult to model a natural degradation process, emissions can vary a lot, they depend on a lot of parameters (physical and chemical). High uncertainty.	**2.3**
Mineral wool	1	LCA from a supplier, critically reviewed externally. Very complete.	1	LCA from a supplier, critically reviewed externally. Precise and reliable.	2	Data coming from one supplier, medium representativeness of the European context.	1.3
Black peat	1	Primary data from 13 companies. Each company provided data for 1-5 sites. Very complete.	2	The analysis should be improved for EQ, high uncertainty on GHG emissions (large variety in literature).	1	Data collection all over Europe. Very representative for European context	1.3

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Constituents	*Completeness*	*Comment*	*Reliability*	*Comment*	*Representa tiveness*	*Comment*	*Average*
White peat	1	Primary data from 13 companies. Each company provided data for 1-5 sites. Very complete.	2	The analysis should be improved for EQ, high uncertainty on GHG emissions (large variety in literature).	1	Data collection all over Europe. Very representative for European context	1.3
Perlite	1	Primary data from 5 sites all over Europe from 2 suppliers. Very complete.	2	Data provided by 5 companies, collected internally. No possibility of verification by Quantis on them.	1	Data collection from 5 sites all over Europe. Very representative for European context	1.3
Rice hulls	1	Secondary data from a scientific paper. Very complete.	1	Secondary data from a scientific paper. Very reliable.	3	Data are referred to rice cultivation and production in Italy. Representative for European context but it may not be representative for other countries as China and USA.	1.7
Wood fibres	1	Primary data from 2 European companies on wood fibres production. Secondary data from ecoinvent for wood chips production. Very complete.	2	For wood chips production, secondary data from an ecoinvent process.	3	For wood chips production, secondary data from ecoinvent. The choice of the round wood production process from the ecoinvent database can affect the results (land occupation factors for different kind of wood are very variable in ecoinvent).	2.0

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2.13 Critical review process

This study compares different mixes within the same area of application and is intended to be communicated to the public. It is therefore considered to be a comparative assertion in the proper ISO sense, and this entails requirements for a third-party report as determined by ISO 14044 norms.

Therefore, a critical review has been performed on this study.

The critical review panel includes four experts, each one representing a different area addressed in this report: the LCA method and the growing media. These areas are represented by:

1. Michael Zwicky Hauschild, Dr, Head of Section for Quantitative Sustainability Assessment (QSA) and professor at the Technical University of Denmark (DTU), chairman of the panel and LCA expert;
2. Elke Meinken, Dr, Professor at the Weihenstephan-Triesdorf University of Applied Science, growing media expert;
3. Arina Schrier, Dr, NGO Wetlands International, peatland expert;
4. Kari Minkkinen, Dr, University of Helsinki, peatland expert.

The review process consisted of a critical review of the entire report in several steps: first the goal and scope, then the intermediary results, and finally the final results. Final comments and suggestions were summarized by the panel chair and delivered to the authors of the study in a critical review report. The authors addressed each of the comments and delivered an updated version of the critical review report which was accepted by the panel.

The first 3 experts took part to all the above-mentioned critical steps, while the four expert took part in the last round only.

The critical review report is presented in Appendix E.

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3 Results & Discussion

3.1 Inventory

The life cycle inventory is significantly based on ecoinvent and is presented in Appendix A.

3.2 Comparison among growing media

In this section, we present results for the Climate change, Human health, Resources, and Ecosystem quality damage categories.

3.2.1 Application 1: Growing media for fruity vegetables

Figure 27 presents the main results for growing media in area of application 1 for the entire life cycle of all mixes.

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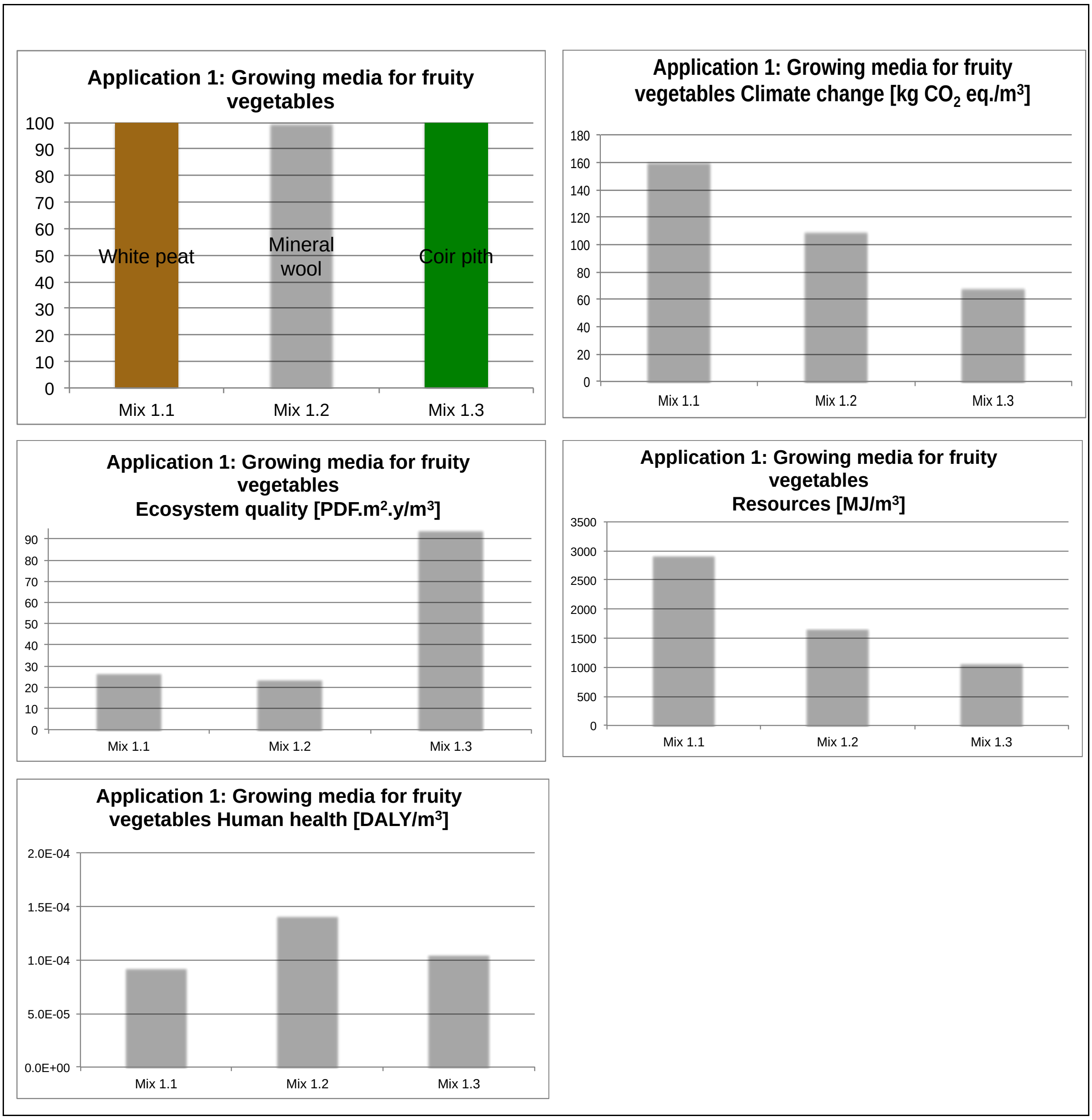

Figure 27: Results for growing media within area of application 1

For Climate change and Resources, the most impacting mix is the Mix 1.1 (100% white peat). This is due to the land use changes during peat harvesting and after-use, and the GHG emissions during peat decomposition in the use and end-of-life stages. For Human health, the most impacting growing medium is the Mix 1.2 (100% mineral wool). In terms of Human health, the most impacting stages of the mineral wool life cycle are distribution to customers and basalt extraction.

Considering Ecosystem quality, the Mix 1.3 (100% coir pith) is the most impacting because of land occupation during the coconut harvesting stage. It is worth noting that for all the constituents other than peat, and also for coconut, land use impacts have been calculated

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assuming a natural state due to a lack of more detailed information (land occupation values come from the Coconut Development Authority (CDA) of Sri Lanka). Peat land use impacts, however, have been calculated considering 4 different categories of prior use (as explained in paragraph 2.7). A comparison with peat Ecosystem quality impacts calculated assuming pristine bog as the reference scenario is computed as sensitivity analysis.

It is important to note that in LCA, Human health and Ecosystem quality have important uncertainties. Furthermore, the underlying inventory data have higher uncertainties for Human health and Ecosystem quality than for climate change for example (please refer to section 2.11 for more details). Differences in climate change results may be statistically significant, contrary to differences in Human health and Ecosystem quality that, for the same relative value, might probably be statistically insignificant due to large assessment uncertainties.

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3.2.2 Application 2: Growing media for pot plants

Figure 28 presents the main results for growing media with application 2 for the entire life cycle of all mixes.

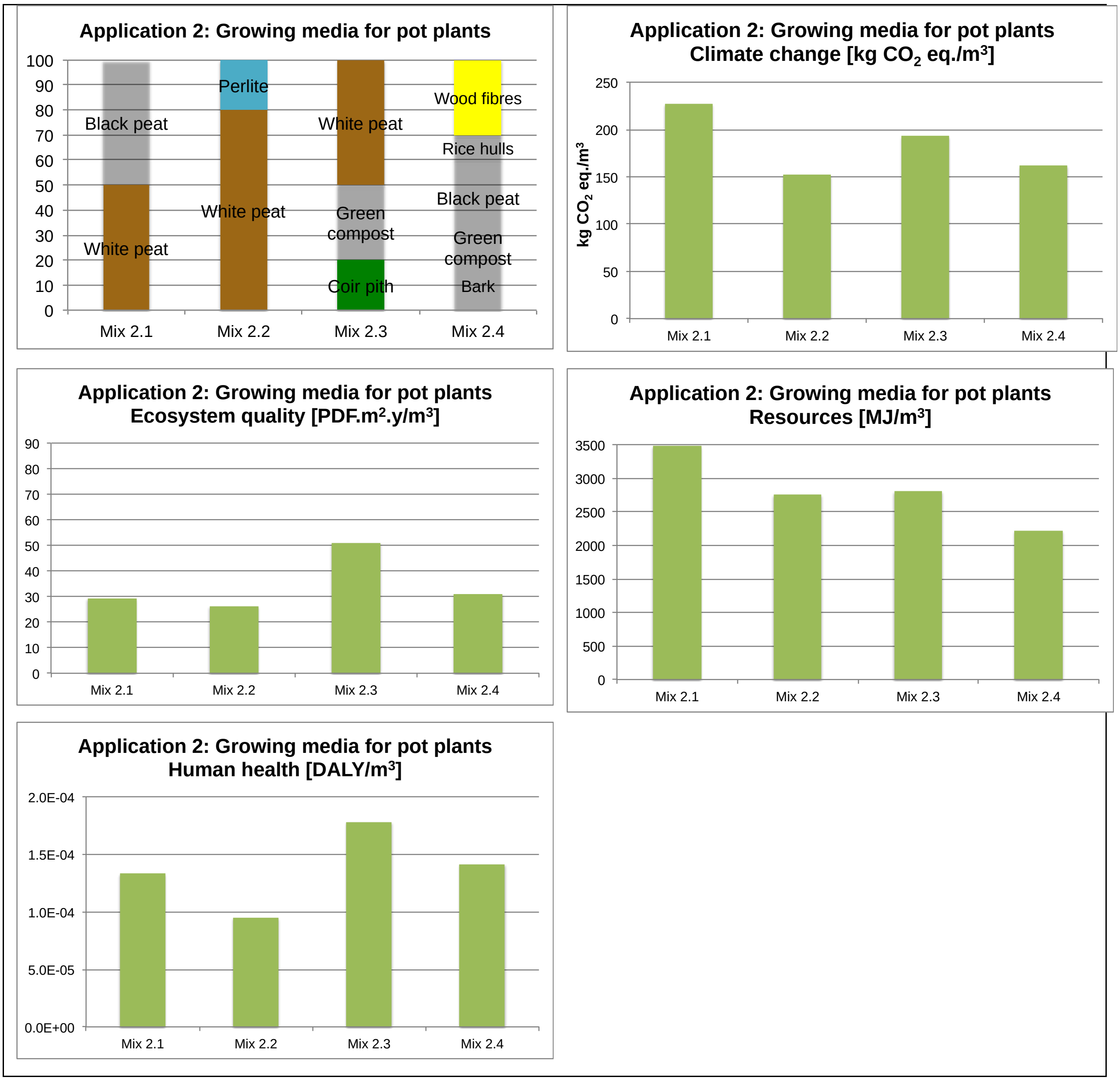

Figure 28: Results for growing media within area of application 2

Analysing the results reported in Figure 28 we can see that for Climate change and Resources, the most impacting mix is Mix 2.1, with 100% peat (50% black peat and 50% white peat). For Human health and Ecosystem quality, the most impacting mix is Mix 2.3 (20% coir pith, 30% green compost, 50% white peat). For this mix, transportation of coir pith (transportation from Sri Lanka to Europe and distribution to customers) and processing emissions for the green compost contribute to increased impacts on Human health, while land occupation of coconut harvesting contributes mostly to Ecosystem quality impacts.

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The considerations regarding uncertainty that were described in section 3.2.1 are valid here as well.

3.2.3 Application 3: Growing media for young plant using loose-filled trays

Figure 29 presents the main results for growing media of area of application 3 for the entire life cycle of all mixes.

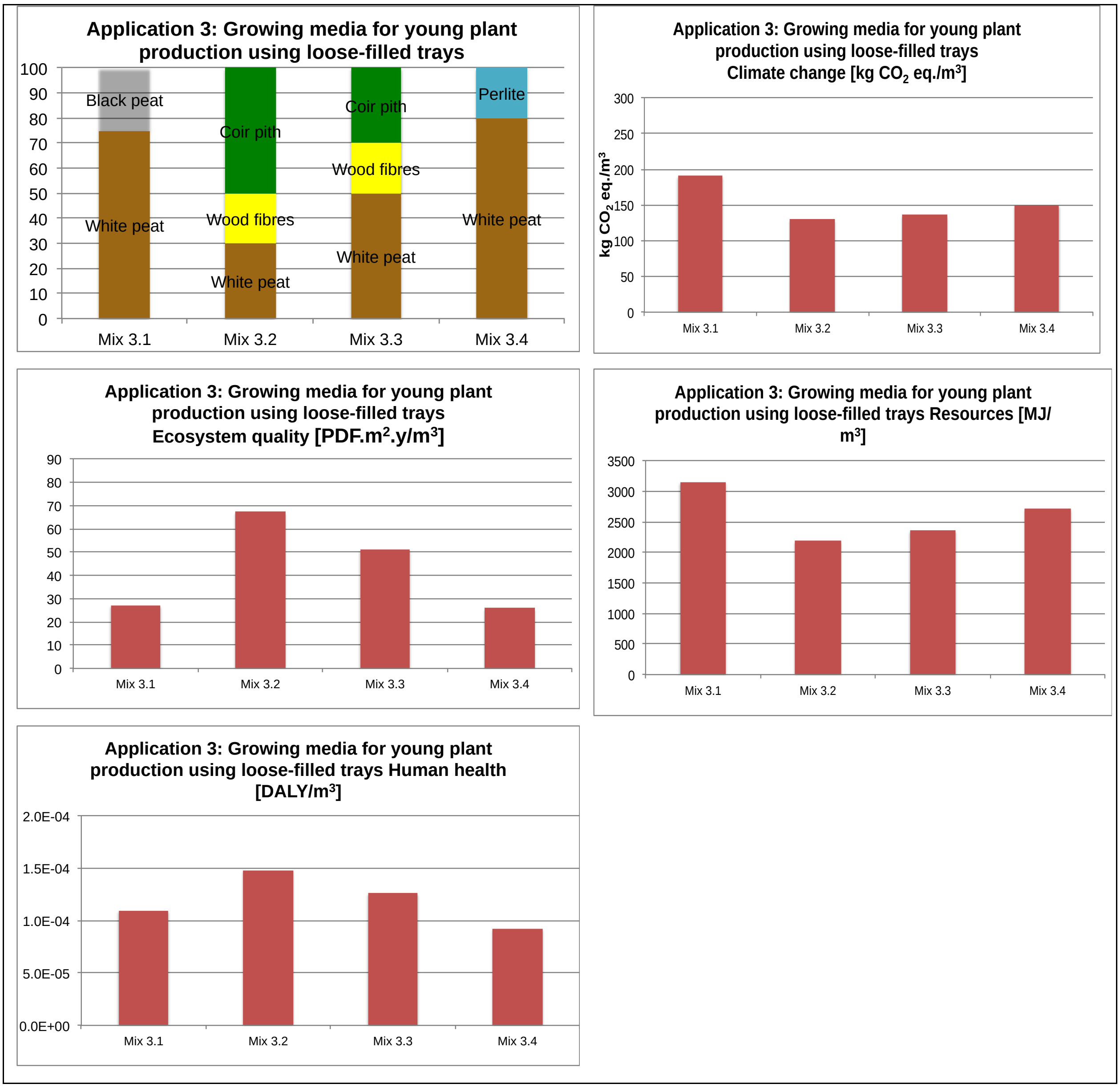

Figure 29: Results for growing media within area of application 3

For the Climate change and Resources indicators, the growing media with high percentages of peat are the most impacting ones. In particular, Mix 3.1 made with 100% peat (20% white peat and 80% black peat) is the highest in term of impacts.

For Ecosystem quality, Mixes 3.1 and 3.4 (with the highest content of peat) turn out to be the least impacting while Mix 3.2 (50% of coir pith, 30% white peat, 20% wood fibres) is the

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most impacting for Ecosystem quality. Land occupation of coconut harvesting contributes mostly to the Ecosystem quality impact of Mix 3.2.

For Human health, Mix 3.2 appears to have the highest impacts because of the transportation of coir pith to the mixing plant.

The considerations regarding uncertainty that were described in section 3.2.1 are valid here as well.

3.2.4 Application 4: Growing media for tree nursery stock

Figure 30 reports the main results for growing media of area of application 4 for the entire life cycle of all mixes.

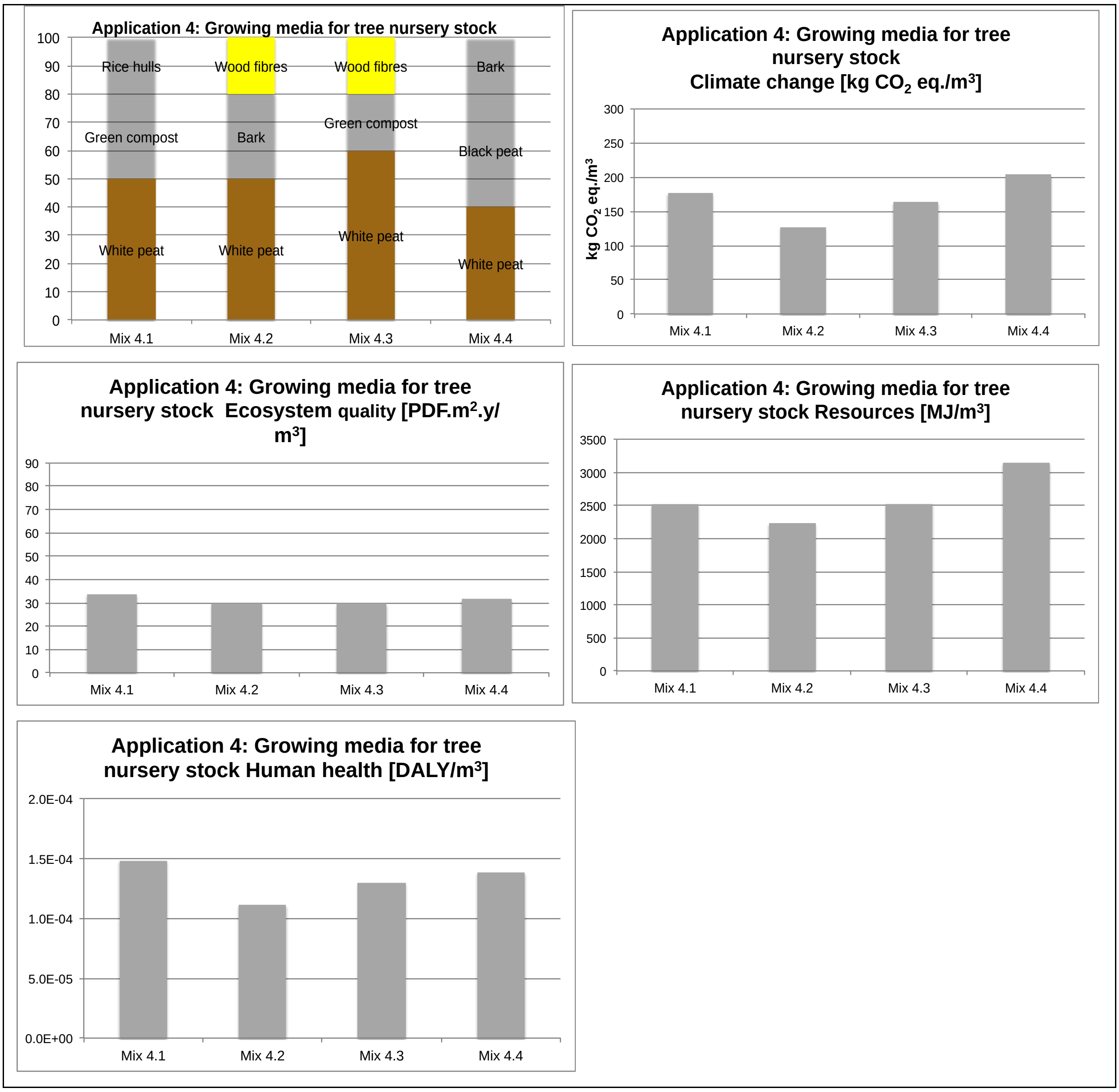

Figure 30: Results for growing media within area of application 4

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For Climate change and Resources, Mix 4.4 (20% bark, 40% black peat, 40% white peat) is the most impacting. For Ecosystem quality and Human health, the mix that stands out from the others is Mix 4.1 (50% white peat, 30% green compost, 20% rice hulls), whose high quantity of green compost significantly contributes to those two indicators through the emissions of N-compounds during the processing. It is worth noting that Mix 4.2 (50% white peat, 30% bark, 20% wood fibres) is the only mix with lower impacts than the other alternatives for all of the indicators presented here.

The considerations regarding uncertainty that were described in section 3.2.1 are valid here as well.

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3.2.5 Application 5: Growing media for hobby market

Figure 31 shows the main results for growing media within area of application 5 for the entire life cycle of all mixes.

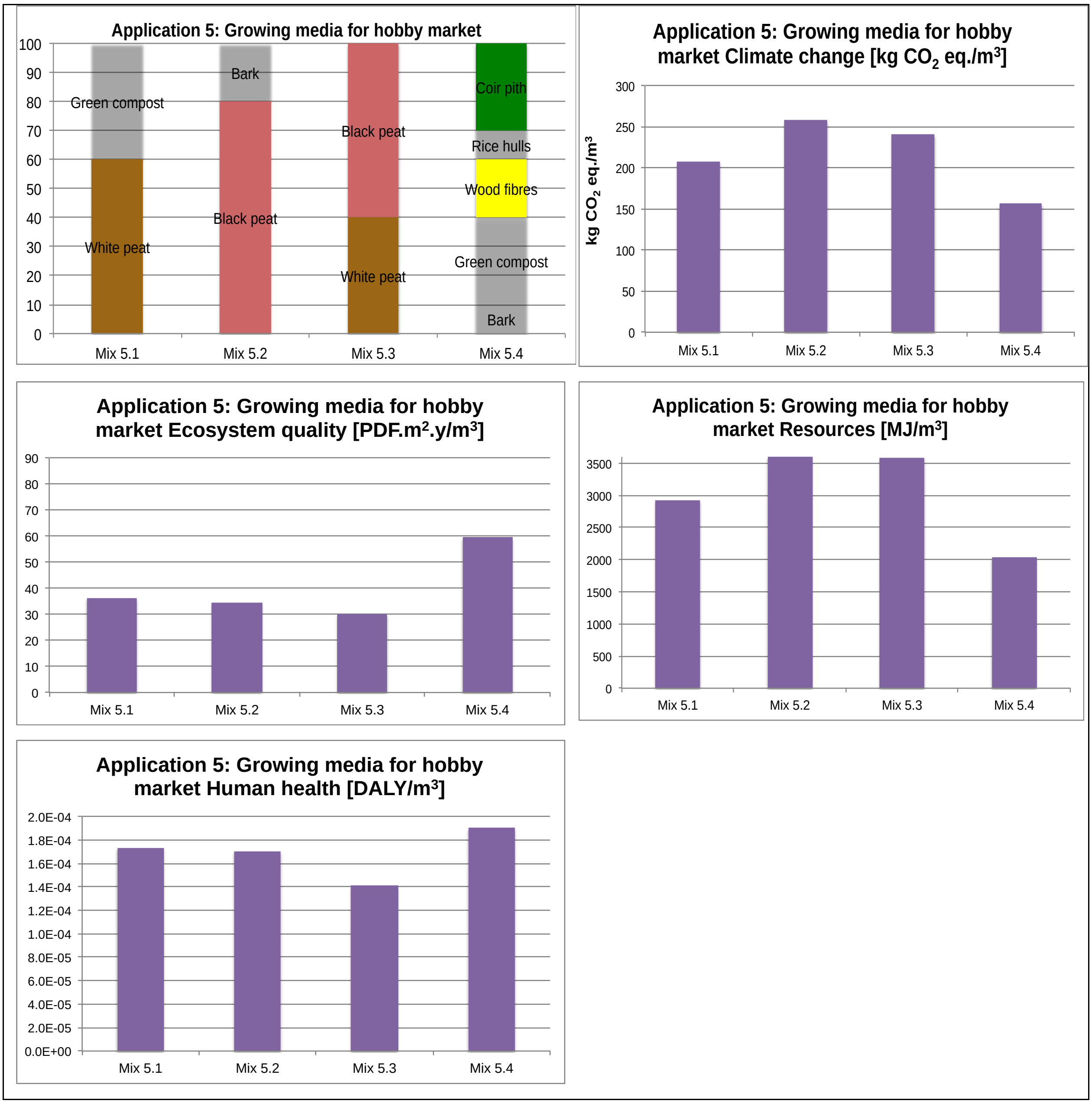

Figure 31: Results for growing media within area of application 5

For Climate change and Resources, the most impacting growing media are the Mixes 5.3 (60% black peat, 40% white peat) and 5.2 (20% bark, 80% black peat).

For Ecosystem quality and Human health, the most impacting growing medium is Mix 5.4 (10% bark, 30% green compost, 20% wood fibres, 10% rice hulls, 30% coir pith) because it has the highest content of coir pith. Land occupation of coconut harvesting and transport of coir pith contribute significantly to the Ecosystem quality and Human health indicators, respectively.

In conclusion, the peat-free growing medium (Mix 5.4) is less impacting than the other mixes for Climate change and Resources but more impacting for Ecosystem quality (mainly from land occupation in coir pith harvesting) and Human health (mainly from the coir pith transports and green compost emissions).

The considerations regarding uncertainty that were described in section 3.2.1 are valid here as well.

3.3 Detailed results for black and white peat

Figure 32 and Figure 33 report the contribution of each life cycle stage to the global impacts for black and white peat. We present results for the following indicators: Human health, Ecosystem quality, Resources, and Climate change.

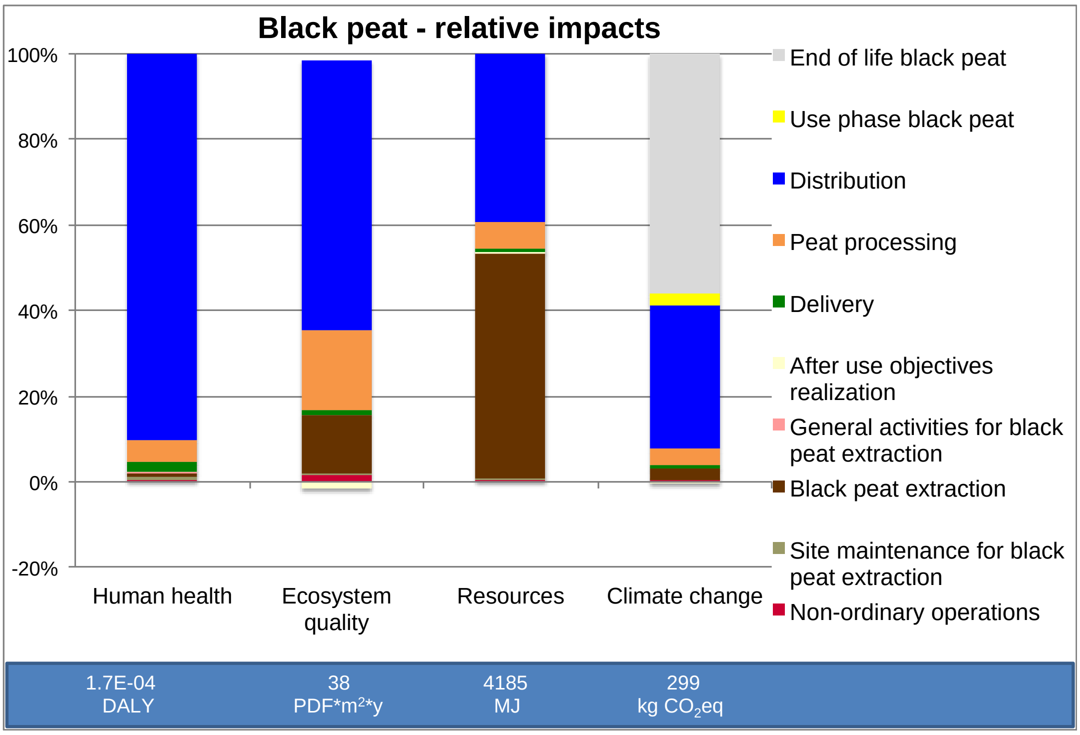

Figure 32: Results for 1 m^3 of black peat. The figure shows the relative contribution - expressed in percentages - of each stage to the global impact. Below the chart, absolute values of total impacts are shown for each indicator.

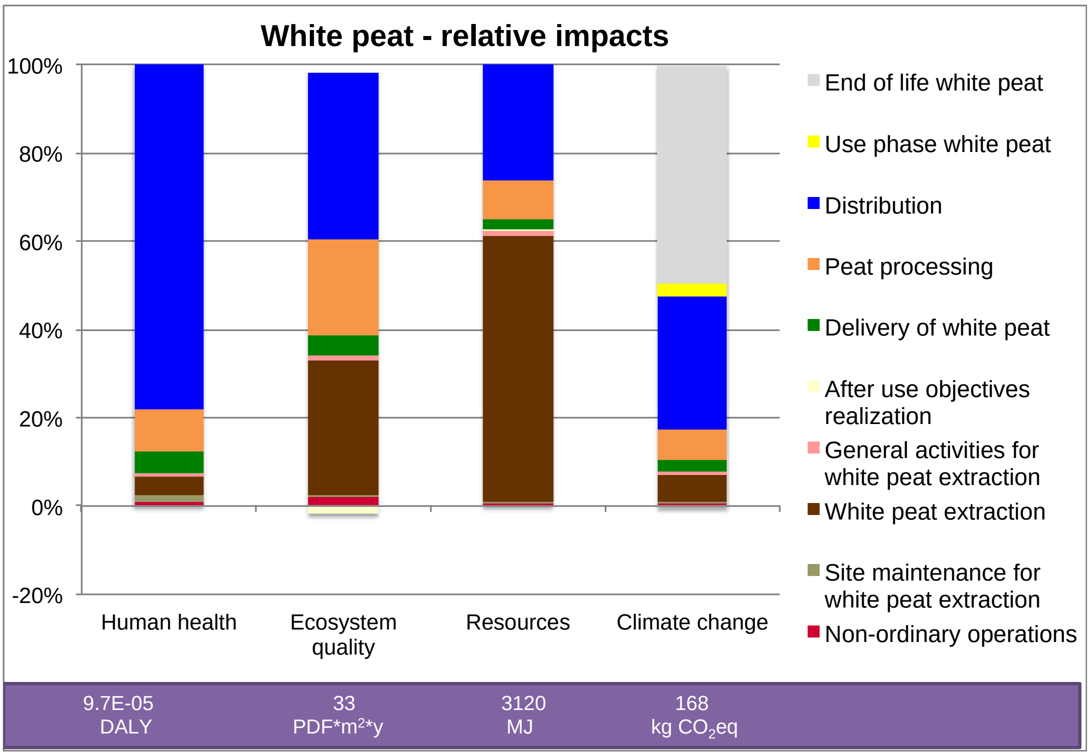

Figure 33: Results for 1 m^3 of white peat. The figure shows the relative contribution - expressed in percentages - of each stage to the global impact. Below the chart, absolute values of total impacts are shown for each indicator.

Concerning both **black and white peat** results we can observe that:

- **Human health**: the most impacting stage is distribution (related to the particulate matter and NOx emissions from the transport of peat from the processing plant to the consumer). Note that we considered the same average distances for all the growing media (for details, see section 2.7).
- **Ecosystem quality**: the most impacting stages are distribution, processing and extraction.

  Distribution contributes to Ecosystem quality because of heavy metals and NOx emissions during transportation. Distribution impacts depend on the distances and quantities transported. Transportation work is expressed in kg.km, so the higher the density of the constituent transported, the higher the impacts will be. This effect of density explains why the distribution impact for black peat is higher than for white peat.

  The processing stage includes packaging (LDPE films) and mixing activities, and they contribute to Ecosystem quality because of the electrical energy involved.

  The extraction stage contributes to this indicator because of the land occupation impact. As explained in section 2.7, land use impact was calculated by considering the previous state of the peatland as reference scenario. This leads to negative Ecosystem quality impacts for the after-use stage due to the avoided impacts for the

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realisation of the after-use objectives. In fact, for a 100 year time horizon, avoided impacts are dominant for the forestry, restoration and rehabilitation scenarios.

- **Resources**: the extraction stage is the most impacting stage. Peat oxidation in situ causes a loss of the peat resource. Additionally, for black peat, distribution has a high contribution because black peat distribution is more impacting than white peat distribution, as explained above.
- **Climate change**: the most impacting stage is the end-of-life. Peat decomposition takes about 200 years (Cleary et al. (2005)), and most of the emissions take place during first 100 years (as explained in 2.7). A 100-year time horizon was chosen in this study and GHG emissions over time were assessed with the dynamic LCA approach. The distribution stage highly contributes to Climate change because of the emissions during transportation. Black peat end-of-life impacts are higher than the impacts for white peat because black peat has a higher carbon content and density than white peat.

3.4 Sensitivity analysis results

The sensitivity analyses are intended to assess the robustness of conclusions, i.e. the comparison between the systems. Sensitivity analysis is a procedure to determine how changes in data and methodological choices affect the results of the LCIA.

According to ISO14044, an analysis of results for sensitivity shall be conducted for studies intended to be used in comparative assertions to be disclosed to the public.

In this study the following sensitivity analyses were conducted:

- Use a 500-year time horizon instead of 100 years
- Use the ReCiPe LCIA method instead of IMPACT 2002+
- Vary the allocation factors for bark, coir pith and rice hulls
- Evaluate Ecosystem quality when considering the peatland natural state (pristine bog) as the prior use (reference scenario) rather than an average of the before use categories presented in section 2.7.2.1.

3.4.1 Sensitivity analysis 1: use of 500-year time horizon instead of 100 years

Figure 34 reports Climate change results for a 500-year time horizon compared to the reference scenario (100-year time horizon), for all the applications. In general it is possible to see that adopting a 500-year time horizon leads to a reduction of the Climate change impacts for all the growing media, but without changing the ranking within the same application. So this sensitivity scenario will not change the conclusions concerning the internal ranking of the mixes according to their climate change impacts.

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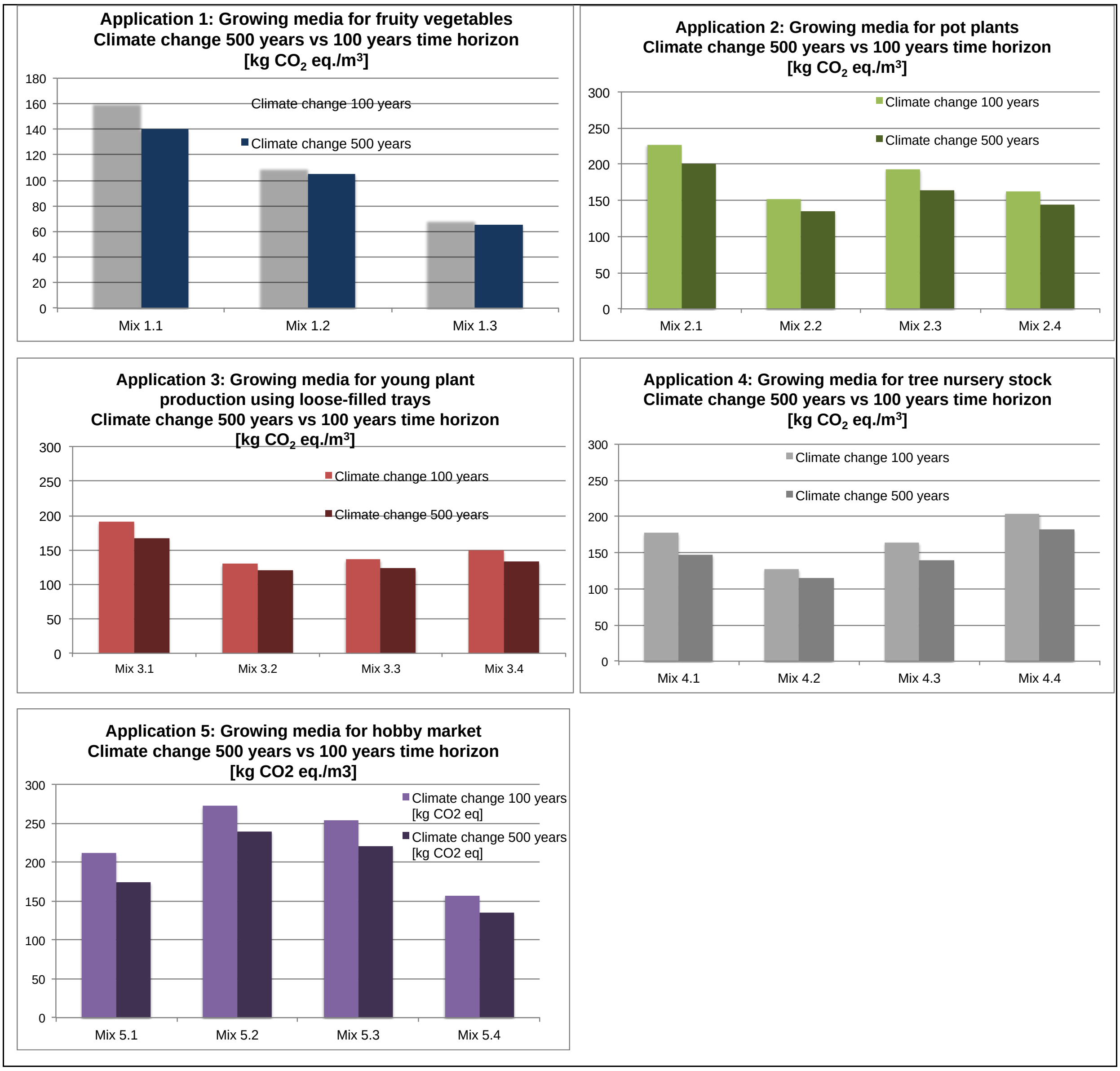

Figure 34: Sensitivity analysis: 500-year time horizon vs 100-year time horizon results for Climate change.

Figure 35 reports Ecosystem quality results for 500-year time horizon compared to the reference scenario (100-year time horizon) for all the applications. In general it is possible to see that using a 500-year time horizon causes a diminution of the Ecosystem quality impacts for all the growing media, and sometimes the impact becomes negative (because the longer the time horizon that is considered, the higher the avoided impacts for all after-use scenarios will be). It is worth noting that the variation of the time horizon for the Ecosystem quality indicator is meaningful only for peat. In fact, the life cycles of the other constituents are very short if compared to peat, where extraction stages and after-uses last many years. Consequently, Ecosystem quality is equal to the reference scenario for the constituents other than peat. Consider also that peat results for Ecosystem quality take into account the previous state of the peatland (reference scenario) while this is not the case for the other constituents because of their lack of specific data.

We can conclude that the choice of the time horizon affects the results of Ecosystem quality for peat and consequently the total ranking. In this study we used 100 years as time horizon for Ecosystem quality in conformity with Climate change, but a change of this assumption may change the conclusions of the analysis. In fact:

- Area of application 1: Mix 1.1 (100% peat) decreases its impacts and the relative differences with other mixes increase. The ranking continues to be the same.
- Area of application 2: Mixes 2.1 (50% black peat and 50% white peat) and 2.2 (80% white peat and 20% perlite) decrease their impacts, but the ranking remains the same.
- Area of application 3: Mixes 3.1 (20% white peat and 80% black peat) and 3.4 (80% white peat and 20% perlite) decrease their impacts and the difference between them increases, making Mix 3.1 less impacting than Mix 3.4 (because Mix 3.1 contains more peat).
- Area of application 4: impacts for all Mixes decrease, and the ranking changes. Mix 4.4 (20% bark, 40% black peat, 40% white peat) becomes the least impacting because it contains more peat than the other Mixes within same application.
- Area of application 5: impacts decrease for all Mixes but the ranking remains the same.

This underlines the importance of interpreting the results/conclusion based on the subjective choice of a time horizon: if we focus on a relatively short term time horizon, one would set different priorities than for a longer term time horizon.

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Figure 35: Sensitivity analysis: 500-year time horizon vs 100-year time horizon results for Ecosystem quality.

3.4.2 Sensitivity analysis 2: use of ReCiPe method instead of IMPACT2002+

Figure 36, Figure 37 and Figure 38 report results calculated using the ReCiPe impact assessment method (ReCiPe World H/H[24]).

For Human health (Figure 36) we observe that:

- Area of application 1: Mix 1.2 (100% mineral wool) is the mix with the highest impact. This is in line with the IMPACT 2002+ results.

[24] ReCiPe World H/H refers to the normalization values of the world with the weighting set belonging to the hierarchic perspective. More information on http://www.lcia-recipe.net/.

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- Area of application 2: the least impacting mix is Mix 2.2 (80% white peat, 20% perlite), in line with the IMPACT 2002+ results. According to ReCiPe, the most impacting mix in term of Human health is the Mix 2.1 (50% black peat and 50% white peat), even if there are no large and relevant differences with Mixes 2.3 and 2.4. According to IMPACT 2002+, Mix 2.3 was the most impacting (50% white peat, 30% green compost, 20% coir pith), even though there were no large differences with Mixes 2.4 and 2.1.
- Area of application 3: Mix 3.1 is the most impacting (75% white peat, 25% black peat), in accordance with IMPACT 2002+ results. The ranking of the other Mixes (3.2, 3.3 and 3.4) is in line with IMPACT 2002+ results, even though differences in terms of results among these mixes are very low and not relevant either for ReCiPe or IMPACT 2002+.
- Area of application 4: According to ReCiPe, the most impacting Mix is Mix 4.4 (40% white peat, 40% black peat, 20% bark) followed by 4.1 and 4.3 (the same impacts) and 4.2 (50% white peat, 30% bark, 20% wood fibres). According to IMPACT 2002+ the most impacting is 4.1 (50% white peat, 30% green compost, 20% rice hulls), the least impacting is 4.2 (the same as ReCiPe), and Mixes 4.3 and 4.4 have comparable results.
- Area of application 5: Mix 5.4 (10% bark, 30% coir pith, 30% green compost, 20% wood fibres, 10% rice hulls) is the least impacting followed by 5.1, 5.3 and 5.2 (20% bark and 80% black peat). According to IMPACT 2002+, the least impacting is 5.3 (40% white peat, 60% black peat), followed by 5.2 and 5.1.

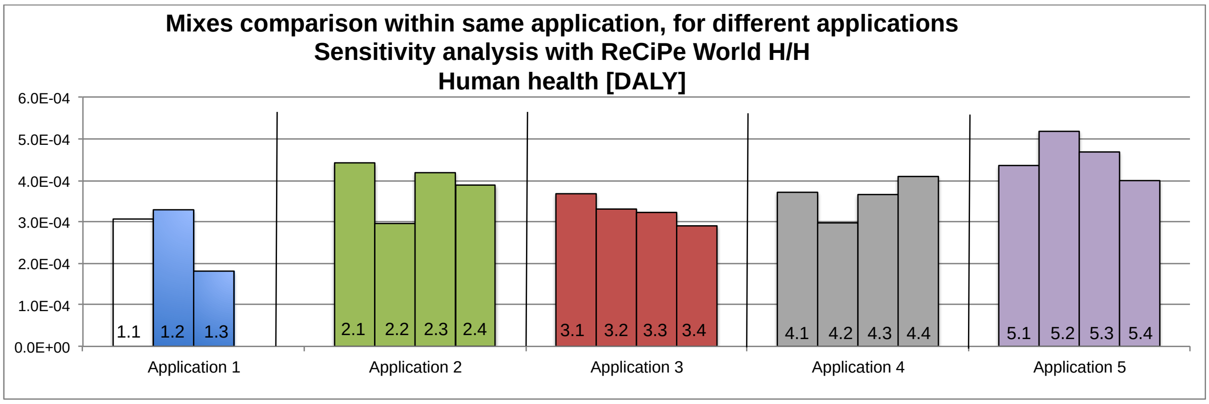

Figure 36: Sensitivity analysis: use of the ReCiPe impact assessment method. Results for the different growing media, within the same application for Human health (DALY per 1 m^3 of growing media). Please compare only growing media within the same application. Growing media from different applications are not comparable.

Concerning Ecosystem quality (Figure 37) we can observe that:

- Area of application 1: the Mix 1.3 (100% coir pith) is the most impacting one and this is in line with IMPACT 2002+.

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- Area of application 2: the only difference is related to Mix 2.4 (20% bark, 10% green compost, 30% black peat, 30% wood fibres, 10% rice hulls) that, by using IMPACT 2002+, turns out to be more impacting than 2.1 and 2.2.
- Area of application 3: conclusions are in line with IMPACT 2002+.
- Area of application 4: according to ReCiPe, Mix 4.4 (40% white peat, 40% black peat, 20% bark) is the most impacting, whereas with IMPACT 2002+ the mixes have comparable impacts.
- Area of application 5: according to ReCiPe the most impacting Mixes are 5.2 (20% bark and 80% black peat) and 5.4 (10% bark, 30% coir pith, 30% green compost, 20% wood fibres, 10% rice hulls) (these two mixes have comparable impacts). While according to IMPACT 2002+, Mix 5.4 has the highest impacts, while Mix 5.3 (40% white peat, 60% black peat) has the lowest impacts.

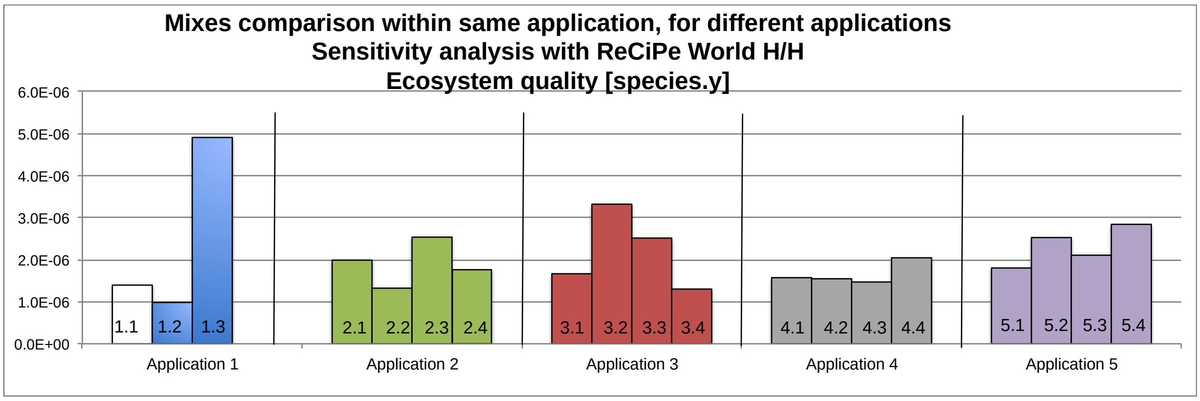

Figure 37: Sensitivity analysis: use of ReCiPe impact assessment method. Results for the different growing media, within the same application for Ecosystem quality (species.y per 1 m^3 of growing media). Please compare only growing media within the same application. Growing media from different applications are not comparable.

Concerning Resources (Figure 38) we can observe that:

- Area of application 1: Mix 1.2 (100% mineral wool) is the most impacting while Mix 1.2 and 1.1 have similar impacts. The ranking is different from the IMPACT 2002+ results.
- Area of application 2: the ranking obtained by ReCiPe is different from the IMPACT 2002+ results. According to ReCiPe, Mix 2.3 (20% coir pith, 30% green compost, 50% white peat) is the most impacting one, followed by 2.4, 2.1 and 2.2. According to IMPACT 2002+, Mix 2.1 is the most impacting one, followed by Mixes 2.3, 2.2 and 2.4.
- Area of application 3: the ranking is again completely different from IMPACT 2002+. According to IMPACT 2002+, the most impacting mix is Mix 3.1 (75% white peat, 25% black peat), followed by 3.4, 3.3 and 3.2 in order of magnitude.

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- Area of application 4: according to ReCiPe, the most impacting mix is Mix 4.1 while for IMPACT 2002+ Mix 4.1 is at the second position, at the same level of 4.3. According to IMPACT 2002+, Mix 4.4 (40% white peat, 40% black peat, 20% bark) is the most impacting one.
- Area of application 5: according to ReCiPe, Mix 5.4 (10% bark, 30% coir pith, 30% green compost, 20% wood fibres, 10% rice hulls) is the most impacting. According to IMPACT 2002+, the most impacting mixes are 5.2 and 5.3, while 5.4 is the least impacting one.

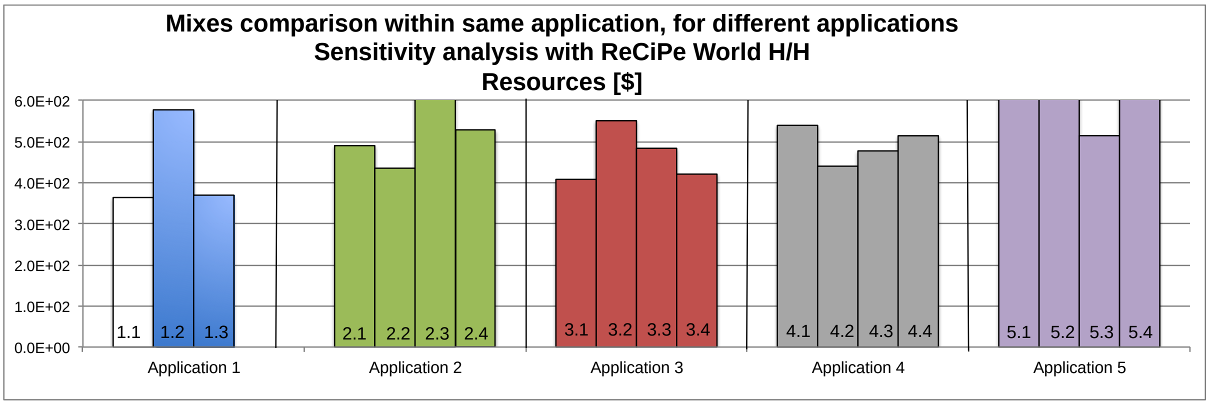

Figure 38: Sensitivity analysis: use of ReCiPe impact assessment method. Results are for the different growing media, within the same application for Resources ($ per 1 m^3 of growing media). Please compare only growing media within the same application. Growing media from different applications are not comparable.

We can conclude that results are influenced by the choice of impact assessment method and the ranking may change on the basis of the chosen method. When using the ReCiPe method we can conclude that:

- Concerning the Resources indicator: black and white peat decrease their impacts, while expanded perlite impacts increase. These modifications change the ranking of the results: for example Mix 2.2 with 80% of white peat decreases its impact, becoming the least impacting mix in Application 2 for Resources.
- Coir pith continues to have the highest impact in term of Ecosystem quality, while for the Resources indicator the Mix 1.2 (100% mineral wool) becomes more impacting than Mix 1.1 (100% white peat).
- Concerning the Ecosystem quality indicator, rice hulls decrease their impacts, while black peat increases. That is why in Application 5, Mix 5.2 (with 80% of black peat) increases its impacts.
- Concerning the Human health indicator, green compost decreases its impacts: that is why Mix 4.1 with 30% of green compost and Mix 5.4 with 30% green compost decrease their impacts.

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3.4.3 Sensitivity analysis 3: variation of the allocation factors

3.4.3.1. Bark allocation factors

Bark prices may vary over the years. We considered two sensitivity scenarios by increasing the bark market price:

- Reference scenario: bark has a market price equal to 39 €/t
- Sensitivity scenario 1: market price is 56 €/t
- Sensitivity scenario 2: market price is 85 €/t

Details of the sensitivity scenarios are reported in Table 18.

Table 18: Sensitivity analysis scenarios for bark allocation factors

	Reference scenario	**Sensitivity analysis 1**	**Sensitivity analysis 2**
Wood products	85.9%	84.9%	83.3%
Sawdust	1.9%	1.9%	1.9%
Bark	**2.7%**	**3.8%**	**5.7%**
Wood chips	9.5%	9.4%	9.2%

Figure 39 shows the effect of the changes of the bark allocation factors on the impacts, for all the mixes containing bark. Impacts are reported in percentages of to the most impacting mix within the same indicator (indicated by a red border). For example, in application 2, for Ecosystem quality, the most impacting Mix is 2.3 (100% of the impacts). Mix 2.4 has about the 70% of the Mix 2.3 impacts, and it contains bark. If we vary the allocation factor, we increase the impacts of the Mix 2.4 and we reach for the two scenarios respectively 70% and 78% of the impacts of Mix 2.3.

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Figure 39: Effect of bark allocation factors changes. Results are expressed in percentage calculated based on the most impacting mix for each indicator (indicated by a red border).

It is possible to observe that changes in the bark allocation factors do not change global results for application 2 and 5. In these cases, ranking among the mixes within same application is always respected, for all the indicators analysed.

For application 4, ranking for Ecosystem quality results could be changed. In fact, Mix 4.2 (30% of bark) could reach 110% of Mix 4.1 impacts for the first scenario (3.8% allocation factor) and more than 120% of the mix 4.1 impacts for the second scenario (5.7% allocation factor). Mix 4.4 (20% of bark) could reach the 110% of the Mix 4.1 impacts for the first scenario (3.8% allocation factor) and more than 120% of the Mix 4.1 impacts for the second scenario (5.7% allocation factor), thus becoming the most impacting mix.

3.4.3.2. Coir pith allocation factor

Sensitivity analysis on coir pith considers its allocation factor equal to 0% (coir pith as a waste). As a reference scenario we considered in this study an economic allocation factor equal to 27%. To consider the coir pith as a waste allows us to analyse an economic situation typical of about 10 years ago or more, when high quantities of coir pith were produced as a waste of the coconut fibres production chain in Sri Lanka. Thanks to the increase of the demand in the growing media field and the development of compression technologies, a re-use of this waste, considered as problematic, was organized. Today coir pith is an important economical resource for Sri Lanka, and it is sold internationally.

In general, it is possible to say that considering coir pith as a waste causes an important decrease of the growing media coir pith-based impacts. For simplicity, we show here only the results for Ecosystem quality, the most sensitive indicator for coir pith. Figure 40 shows how the ranking can sensitively change by considering the coir pith allocation factor equal to 0. New mixes impacts are indicated by arrows and cross-hatched.

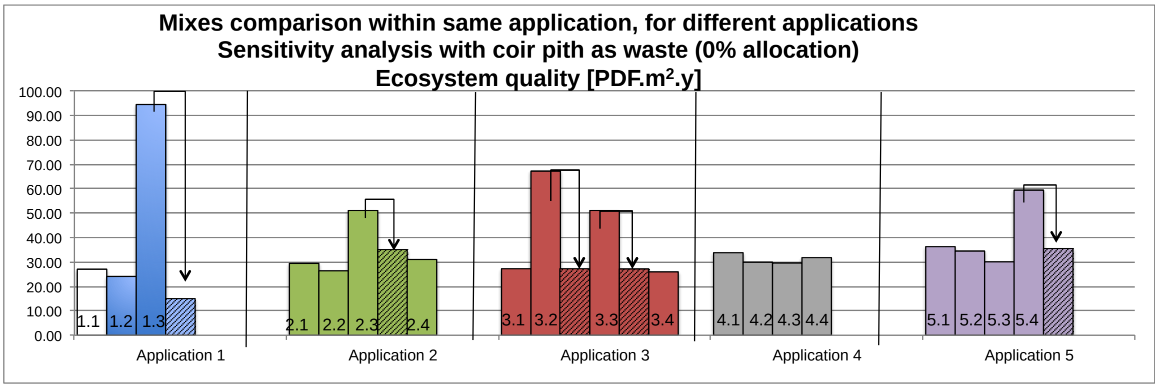

Figure 40: Effect of coir pith allocation factors changes on Ecosystem quality (PDF.m^2 .y/m^3). Please compare only growing media within the same application. Growing media from different applications are not comparable.

3.4.3.3. Rice hulls allocation factor

Sensitivity analysis on rice hulls considers its allocation factor equal to 0% (rice hulls as a waste). As reference scenario we considered in this study an economic allocation factor equal to 0.9%. To consider rice hulls as a waste allows us to analyse an economic situation typical of some years ago, when high quantities of rice hulls were produced as a waste of the refined rice production chain. Thanks to the use of rice hulls in many fields (growing media, insulating material, etc.), a re-use of this waste was organized.

For simplicity we report here only the results for Ecosystem quality. Figure 41 shows how the ranking will almost not change by considering a rice hulls allocation factor equal to 0 or

2.1%. New mixes impacts are indicated by arrows and cross-hatched. Rice hulls do not have high impacts, and they are present in the studied mixes with low percentages (between 10% and 20%). The same trend could be seen for the other indicators.

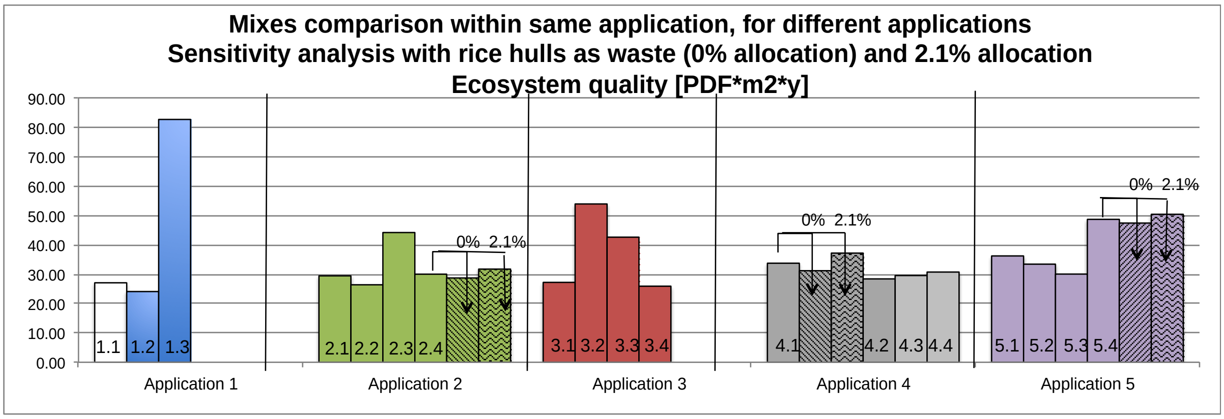

Figure 41: Effect of rice hulls allocation factors changes on Ecosystem quality (PDF.m^2 .y/m^3). Please compare only growing media within the same application. Growing media from different applications are not comparable.

3.4.4 Sensitivity analysis 4: Ecosystem quality indicator with pristine bog as reference scenario

Results reported in section 3.2 show Ecosystem quality impacts for black and white peat with reference to the previous state of a peatland, based on a classification of 4 hemeroby categories: pristine bog, drained cultivated peatland, drained forested peatland and degraded peatland. For all of the constituents other than peat, impacts on Ecosystem quality do not taken into account the previous use of the ecosystem. For example, for coir pith, land use occupation impacts have been calculated by taking into account a natural previous state as reference scenario. In this sensitivity analysis, we calculated the impacts on Ecosystem quality of the different mixes considering the pristine bog as reference scenario. Results are reported in Figure 42.

Generally we can see an increase of the Ecosystem quality impacts for all the mixes containing peat, but in a comparative context, the ranking is kept the same for all the applications.

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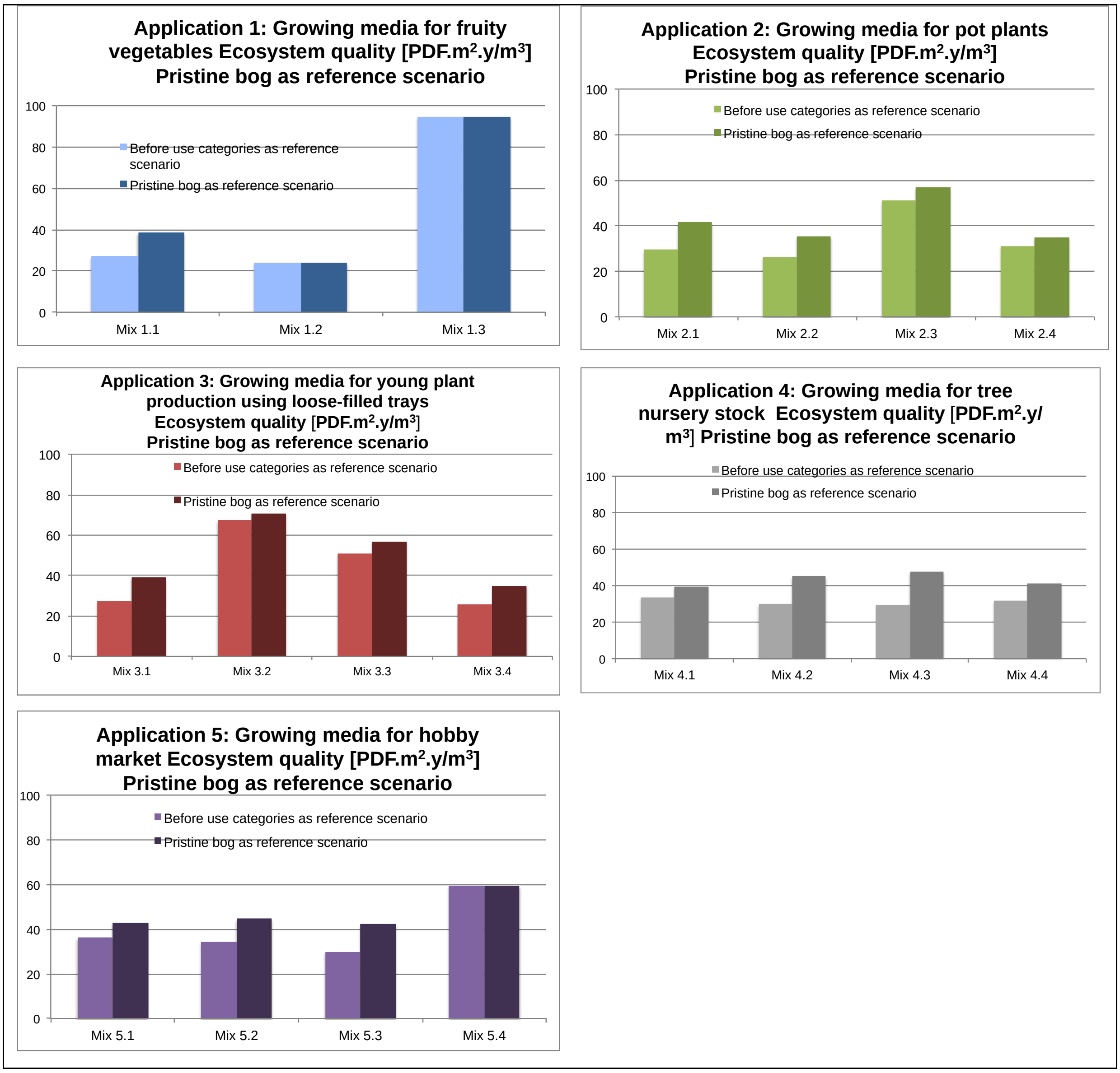

Figure 42: Results for Ecosystem quality indicator for different mixes, considering the pristine bog as reference scenario. Please compare only growing media within the same application. Growing media from different applications are not comparable.

3.5 Uncertainty analyses

Uncertainty analyses have been performed for applications 1 and 4:

- Mix 1.1 (100% white peat) vs Mix 1.2 (100% mineral wool);
- Mix 1.1 (100% white peat) vs Mix 1.3 (100% compressed coir pith);
- Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.2 (30% bark, 50% white peat, 20% wood fibres);
- Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.3 (20% green compost, 60% white peat, 20% wood fibres).

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- Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.4 (20% bark, 40% white peat, 40% black peat).

Monte-Carlo calculations (1000 runs) were carried out for the comparisons described above. For this study the uncertainty range of each input parameter was defined for most of them through a lognormal distribution described by a coefficient of variation (squared geometric standard deviation) as per Table 19. The data quality information has been used for this purpose and then combined with the uncertainty of ecoinvent background processes.

Table 19: Level of data quality and uncertainty coefficients. For uncertainty coefficient, a given value X for a parameter has its uncertainty that varies the value between X/SD^2 and $X*SD^2$. This table shows the general reflection that lead to the coefficient of variation used for the processes that were created for this study. The exact coefficients used are available with the reference flows in Appendix C. For ecoinvent processes applied in the product models, the distribution and uncertainty coefficients are taken as they are given in the ecoinvent database, and they do not follow these ranges.

	Importance of data		
Data quality criteria	High	Medium	Low
Time-related coverage	2000-2007	1995-2007	1990-2007
Geographical coverage	Country	EU	World
Technology coverage	Actual tech used	Similar tech	Similar tech
Precision	Accurate	Fairly accurate	Fairly accurate
Completeness	95%	90%	80%
Representativeness	Good	Fair	Fair
Consistency	High uniformity	Fair uniformity	Fair uniformity
Reproducibility	High	Medium	Medium
Sources of the data	Preferably primary from interested party	Primary or generic	Primary or generic
Uncertainty range (coefficient of variation: squared geometric standard deviation, SD^2)	1 – 1.2	1.3 – 1.5	2 – 5

3.5.1 Mix 1.1 vs Mix 1.2

Figure 43 reports the uncertainty analysis results of Mix 1.1 (100% white peat) vs Mix 1.2 (100% mineral wool).

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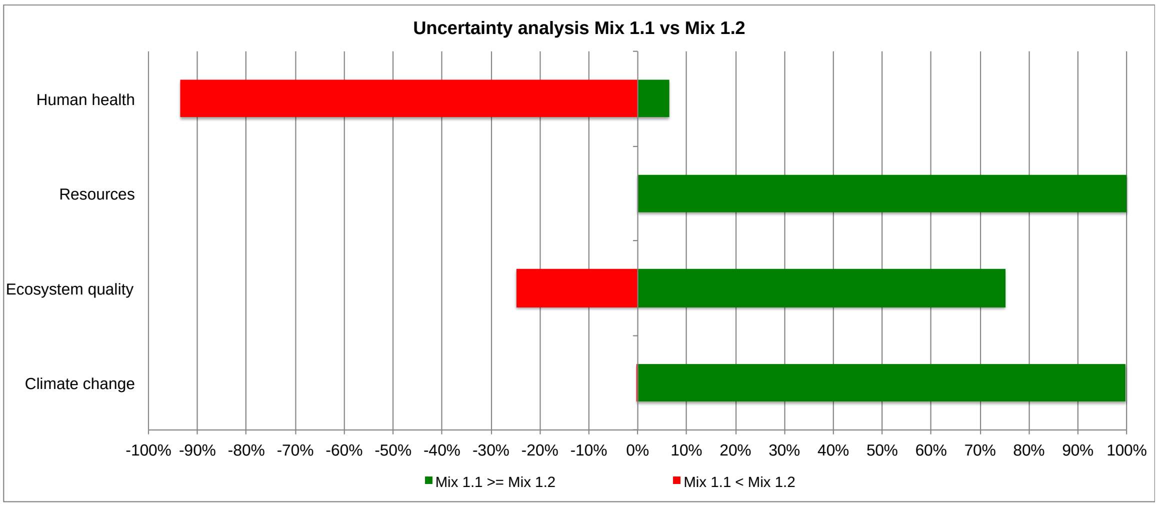

Figure 43: Uncertainty analysis results of Mix 1.1 (100% white peat) vs Mix 1.2 (100% mineral wool). Red means that Mix 1.1 has lower impacts than Mix 1.2, and green means that Mix 1.1 has higher impacts than Mix 1.2. These results correspond to a Monte-Carlo analysis with 1000 runs.

The results of this uncertainty analysis show that Mix 1.1 has significantly higher impacts than Mix 1.2 for 3 indicators over 4, but lower impacts for 1 indicator over 4. However, for Ecosystem quality it is possible to say that, with the current data and uncertainties, it is not possible to state with confidence whether Mix 1.1 has overall higher environmental impacts than Mix 1.2. It is also worth to note that these results do not consider uncertainties on allocation factors and LCIA characterization factors.

Therefore it is not possible to discriminate between the two mixes without making a value choice on a preferred environmental indicator(s).

3.5.2 Mix 1.1 vs Mix 1.3

Figure 44 reports the uncertainty analysis results of Mix 1.1 (100% white peat) vs Mix 1.3 (100% compressed coir pith).

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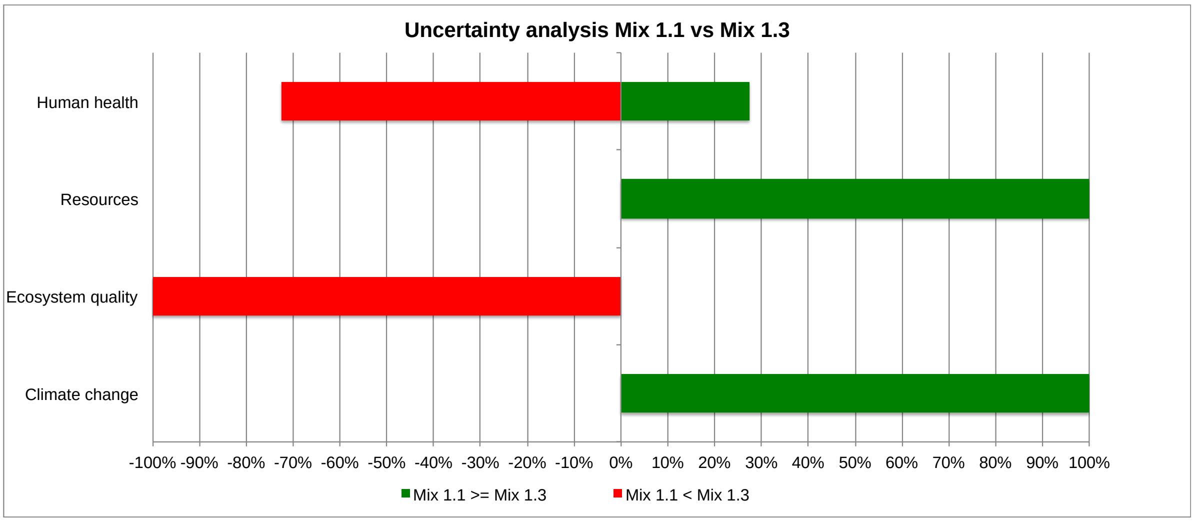

Figure 44: Uncertainty analysis results of Mix 1.1 (100% white peat) vs Mix 1.3 (100% compressed coir pith). Red means that Mix 1.1 has lower impacts than Mix 1.3, and green means that Mix 1.1 has higher impacts than Mix 1.3. These results correspond to a Monte-Carlo analysis with 1000 runs.

The results of this uncertainty analysis show that for 3 out of 4 indicators the discrimination between the two mixes is 100% certain. For Human Health, although the difference shown in Figure 27 is small, the likelihood that Mix 1.3 is higher than Mix 1.1 is still about 75%. It is important to note that these results do not consider uncertainties on allocation factors and LCIA characterization factors.

Therefore it is not possible to discriminate between the two mixes, considering that at this stage not all uncertainties have been accounted for as well as without making a value choice on a preferred environmental indicator(s).

3.5.3 Mix 4.1 vs Mix 4.2

Figure 45 reports the uncertainty analysis results of Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.2 (30% bark, 50% white peat, 20% wood fibres).

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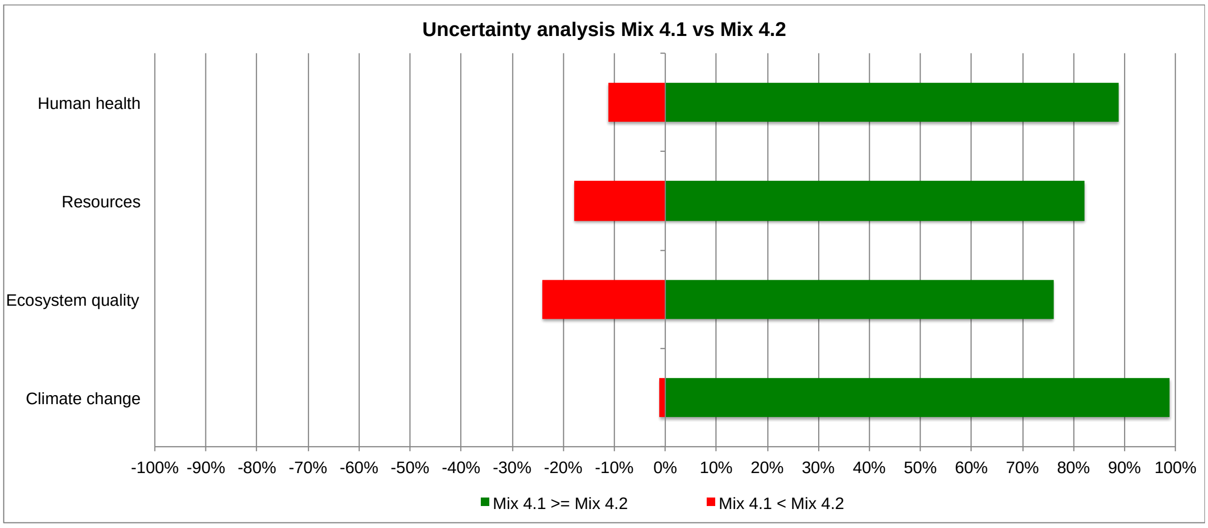

Figure 45: Uncertainty analysis results of Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.2 (30% bark, 50% white peat, 20% wood fibres). Red means that Mix 4.1 has lower impacts than Mix 4.2, and green means that Mix 4.1 has higher impacts than Mix 4.2. These results correspond to a Monte-Carlo analysis with 1000 runs.

The results of this uncertainty analysis show that Mix 4.1 has higher impacts than Mix 4.2 for all the indicators with a confidence ranging from 98% (Climate Change) to about 75% (Ecosystem Quality), despite the relative differences shown in section 3.2.4 are not so elevated for this latter indicator.

It is important to note that these results do not consider uncertainties on allocation factors and LCIA characterization factors.

Therefore at this stage, keeping in mind that not all uncertainties have been accounted for, it is possible to say that Mix 4.2 seems to have lower environmental impacts than Mix 4.1.

3.5.4 Mix 4.1 vs Mix 4.3

Figure 46 reports the uncertainty analysis results of Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.3 (20% green compost, 60% white peat, 20% wood fibres).

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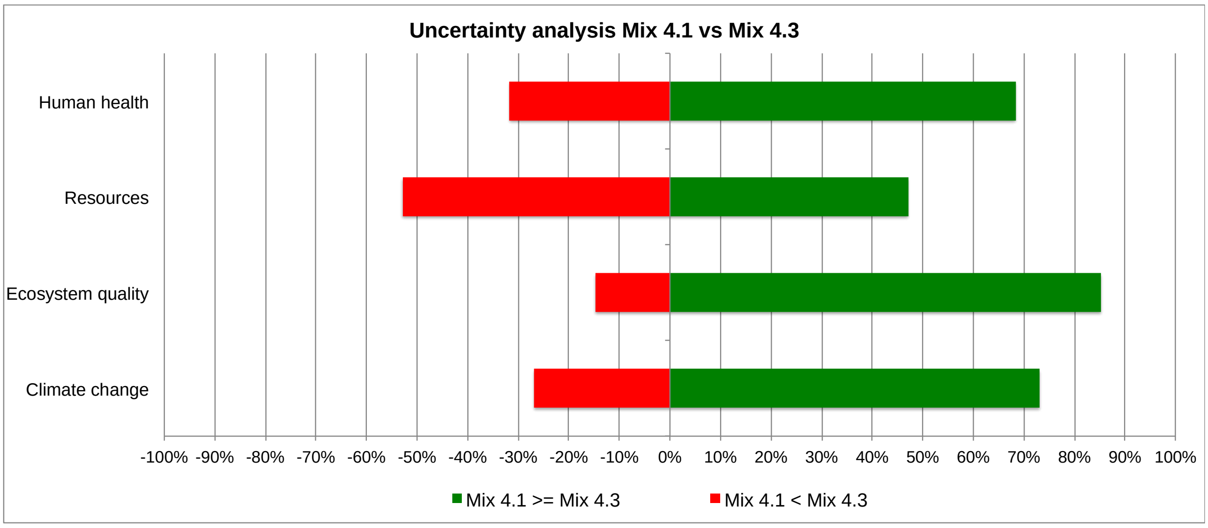

Figure 46: Uncertainty analysis results of Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.3 (20% green compost, 60% white peat, 20% wood fibres). Red means that Mix 4.1 has lower impacts than Mix 4.3, and green means that Mix 4.1 has higher impacts than Mix 4.3. These results correspond to a Monte-Carlo analysis with 1000 runs.

The results of this uncertainty analysis show that Mix 4.1 has higher impacts than Mix 4.3 for 3 indicators with a probability ranging from around 69% to 85%. For the resources indicator no discrimination can be made between the two Mixes. In addition, it is important to note that these results do not consider uncertainties on allocation factors and LCIA characterization factors.

Therefore, considering that at this stage not all uncertainties have been accounted for, it is not possible to discriminate between the two mixes.

3.5.5 Mix 4.1 vs Mix 4.4

Figure 47 reports the uncertainty analysis results of Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.4 (20% bark, 40% black peat, 40% white peat).

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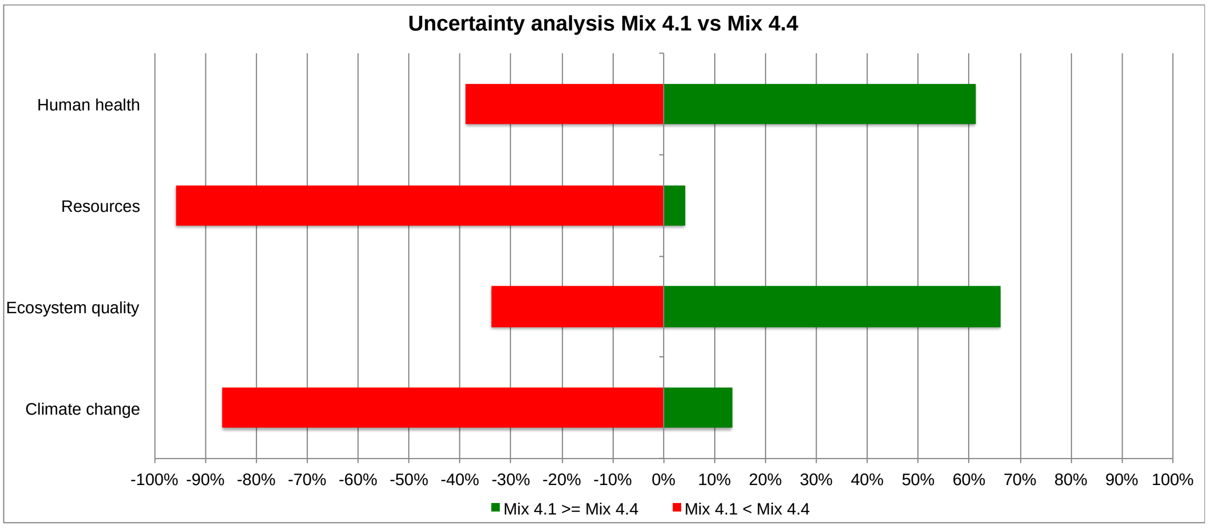

Figure 47: Uncertainty analysis results of Mix 4.1 (30% green compost, 50% white peat, 20% rice hulls) vs Mix 4.4 (20% bark, 40% black peat, 40% white peat). Red means that Mix 4.1 has lower impacts than Mix 4.4, and green means that Mix 4.1 has higher impacts than Mix 4.4. These results correspond to a Monte-Carlo analysis with 1000 runs.

The results of this uncertainty analysis show that Mix 4.1 has lower impacts than Mix 4.4 with a probability higher than 85% for Climate Change and Resources indicators. As shown in Figure 30 Mix 4.1 seems to have, however, higher impacts than Mix 4.4 for the two other indicators (Human Health and Ecosystem Quality), but both with a probability of less than 65%. In addition, it is important to note that these results do not consider uncertainties on allocation factors and LCIA characterization factors.

These results confirm the results of Figure 30, where it is not possible to discriminate between the two mixes, considering that at this stage not all uncertainties have been accounted for as well as without making a value choice on a preferred environmental indicator(s).

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3.6 Study Limitations

The present limitations are detailed below:

- The Ecosystem quality results for peat are based on working assumptions as presented in section 2.7. A more thorough analysis should be conducted on the Ecosystem quality of a peatland based on a close collaboration between LCA experts and ecologists that are experts in peatlands. This would be part of another project and is out of the scope of this study.
- Economic allocation, in particular for bark, is based on factors that may vary with time. Results presented here are valid only if we consider that bark is a by-product of sawmills whose main products are sawn timbers and chips. Another approach for bark production (e.g. direct processing of round wood in bark, without production of chips or sawn timbers) may cause impacts very different from those calculated here. Also, the choice of the round wood production process from the ecoinvent database can affect the Ecosystem quality (land occupation factors for different kind of wood are very variable in ecoinvent).
- Coir pith is based on coconut harvesting in Sri Lanka. Cultivation activities have been modelled considering the main input and emissions. Chemical products different from fertilizers, such as pesticides and herbicides, have not been considered due to lack of information. There are no national statistics about the use of these products for coconuts cultivation, their use is extremely variable and depends on specific and local parameters. Not all the coconut palms are treated in the same manner and to make this assumption may change sensitively the results. Therefore, we chose not to include these chemical products into the model.

These limitations of the LCIA results do not challenge the main conclusions relative to the defined goal and scope of the study as the results still allow the identification of the key environmental parameters and key differences among scenarios.

When this study is communicated to stakeholders, the magnitude and nature of the limitations should be communicated at the same time.

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4 Conclusions of the study

The analysis of the results shows that in general it is not possible to clearly identify any among the growing media as the least or the most impacting across all the indicators. This is true for all the areas of application 1 (fruity vegetables), 2 (pot plants), 3 (young plant production using loose-filled trays) and 5 (hobby market), but not for area of application 4 (tree nursery stock). For this latter, it is worth noting that Mix 4.2 (50% white peat, 30% bark, 20% wood fibres) has lower impacts than all other alternatives for all the indicators presented in this study.

For all the **growing media**, the following general tendencies can be observed:

- Growing media containing a relatively large share of peat have a higher impact on Climate change;
- Growing media containing a large share of green compost have a higher impact on Human health;
- Growing media containing a large share of coir pith have the highest impact on Ecosystem quality.

For **growing media constituents** that are functionally equivalent, we observe that:

- Coir pith has the highest impacts on Ecosystem quality;
- Mineral wool has the highest impacts on Human health;
- Peat has relatively the highest impacts on Climate change and Resources.

For the different constituents, the key parameters playing an important role in the cradle-to-gate environmental assessment (excluding mixing processes and distribution to the customers) are described as follows:

- For **bark** and **wood fibres**, the dominant processes for Climate change, Resources and Human health are electricity consumption for sawing and processing (about half of the impacts) and transportation. Land occupation during wood harvesting contributes to Ecosystem quality impacts. The same conclusions also apply for wood fibres.
- For **coir pith**, more than half of the impacts on Climate change and Resources are due to transportation to the mixing plant due to CO_2 and CH_4 emissions and diesel consumption. The rest of the impacts are due to electricity consumption for processing and calcium nitrate for buffering. Land occupation during coconut harvesting contributes to Ecosystem quality impacts (70% of the total impact) while transportation contributes mostly to Human health (80% of the impact is due to transportation to the mixing plant) because of particulate matters and NOx emissions.

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- For **green compost**, processing emissions (ammonia and N_2O) and transportation contribute to Ecosystem quality impacts, Human health and Climate change impacts (respectively, about 80% and 20%).
- For **mineral wool**, processing energy for expansion contributes to 70% of the Ecosystem quality impacts and to more than half Climate change and Resources. Half of the impacts on Human health are related to basalt extraction (because of particulate matter emissions during extraction), while 30% are due to transports.
- For **perlite**, the energy consumption for expansion contributes to 70% of the Climate change impacts, while for Ecosystem quality blasting contributes more than half of the impacts and for Human health the transports and processing stages are the most impacting.
- For **rice hulls**, rice cultivation contributes to Climate change, Resources and Ecosystem quality impacts (70% of total impacts) through CH_4 emissions from land and fertilizers, while transportation contributes to Human health impacts.

The environmental profile of **peat** is characterized by three dominant processes, depending on the considered impact categories: distribution to the final customer, end-of-life, and peat extraction. Black peat is in general more impacting than white peat above all because its higher density. More precisely:

- The distribution of peat is a contributor to almost all the indicators (between 80% and 30%), in particular for Human health, Aquatic acidification and Aquatic eutrophication, because of particulate matters and NOx emissions during transports.
- The end-of-life, i.e. the peat decomposition, represents about 50% of the Climate change potential;
- Peat extraction, because of peat oxidation in situ, represents up to 60% of the impact for the Resources indicator. The extraction stage also contributes more than 30% of the Ecosystem quality impact (similar to distribution), because of the land use change over 50 years due to the extraction activities.
- Less important than the three above-mentioned processes is the processing stage, which contributes between 10% and 25% of the overall impacts. The highest relative contribution is for Ecosystem quality because of the electricity consumption of the machinery.

4.1 Outlook

To reduce impacts of a growing medium one could imagine changing the growing media composition, substituting one constituent for another. It is, however, important to consider that this may influence the function of the mix, and growing media are comparable only if they fulfil the same function.

For the professional grower in the horticultural industry, the most important factor is that the growing medium functions well under the given growing conditions (Altmann, (2008)), and the choice of a growing media composition is limited by technical considerations (e.g. growing medium characteristics, crop requirements, safety, reliability, availability of constituents, price). In substituting a peat-based mix for a peat-free mix, it is essential for the grower to consider whether the crop quality and yield will remain the same. If this is not the case, the growing media will not be comparable because they will not be functionally equivalent.

Growing media quality evaluation is out of scope of this study though this aspect must be taken into account during the analysis and interpretation of the results of this study.

Another way to reduce the impacts of growing media is to optimise the impacts of individual constituents over their respective life cycles, particularly the distribution of growing media to the final customer. In this study we assumed the same transportation distances for all the growing media. The higher the density of the growing media, the higher the transportation impact will be, and therefore the shorter the distribution distance should be if possible.

The peat industry has developed different strategies to lower the environmental impact of peat harvesting. According to the “EPAGMA Code of Practice”, some examples are:

- Setting criteria for choosing bogs to harvest (for instance, focus peat production on drained peatlands with high greenhouse gas emissions). There is a need for a simplified methodology to determine/estimate emissions from individual sites.
- Developing new production technology allowing harvesters to:
  - Reduce the amount of residual peat to reduce emissions from the aftertreated area (in the case of afforestation);
  - Reduce the moisture content of the extracted peat: the drier the peat, the lower the fresh peat density, and consequently the lower the emissions from transport;
  - Shorten the harvesting time as much as possible.
- Starting the after-use as soon as possible after harvesting. The choice of after-use will depend on many factors. Restoration, rehabilitation or afforestation should be the preferred peatland after-uses.

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7 Appendices

Appendix A: Reference flows, unit processes, impact scores, and sources (see Excel table: EPAGMA_Growing-media-LCA_AppedixA_Reference-flows_2011-08-26_Quantis)

Reference flows are detailed in an excel file and correspond to the exports of the SimaPro modelisation (Name of the file: EPAGMA_Growing-media-LCA_AppedixA_Reference-flows_2011-09-26_Quantis)

Appendix B: IMPACT 2002+

Information available on www.impactmodeling.org and in Jolliet et al. (2003) and Humbert et al. 2010.

Appendix C: ReCiPe

Information available on www.lcia-recipe.net and in Goedkoop et al. (2008)

Appendix D: Results per constituent

We present here results for Climate change (also known as carbon footprint), Human health, Resources, Ecosystem quality separated for each constituent. Compare only constituents that are functionally equivalent (i.e. constituents in area of application 1: peat, coir pith and mineral wool).

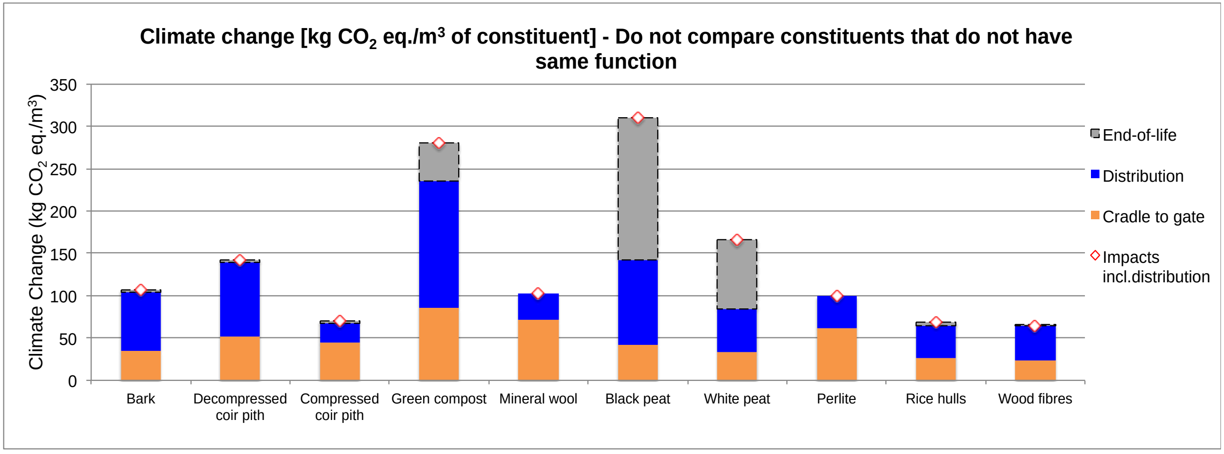

Figure 48: Results for Climate change indicator for 1 m^3 of the different constituents. Compare only constituents that are functionally equivalent (i.e. constituents in area of application 1: peat, coir pith and mineral wool).

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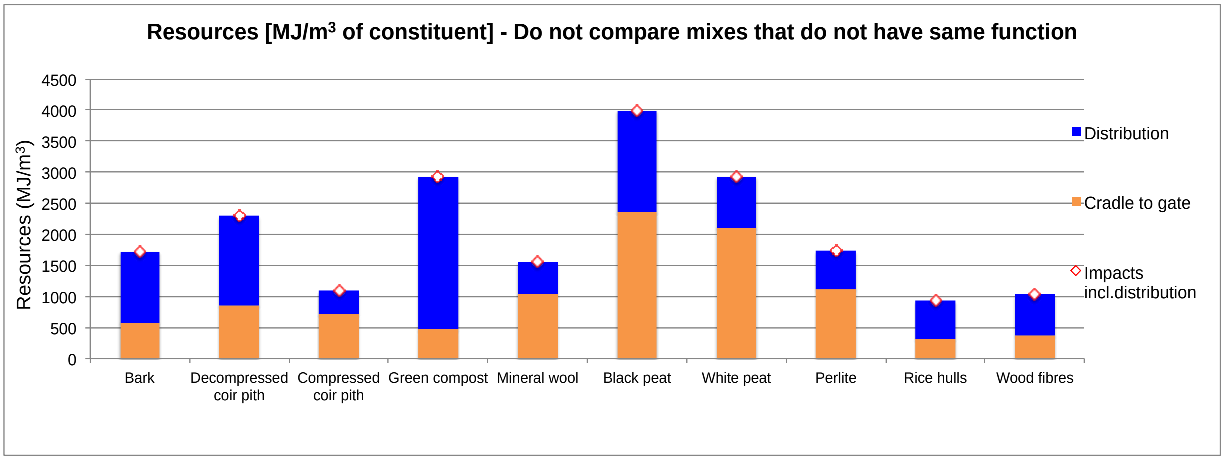

Figure 49: Results for Resources indicator for 1 m^3 of the different constituents. Compare only constituents that are functionally equivalent (i.e. constituents in area of application 1: peat, coir pith and mineral wool).

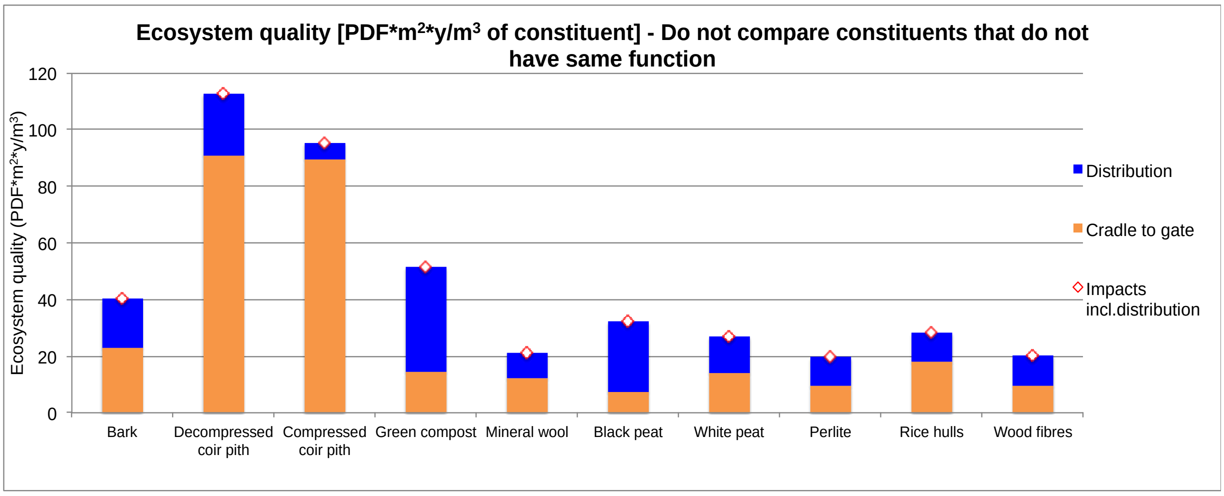

Figure 50: Results for Ecosystem quality indicator for 1 m^3 of the different constituents. Compare only constituents that are functionally equivalent (i.e. constituents in area of application 1: peat, coir pith and mineral wool).

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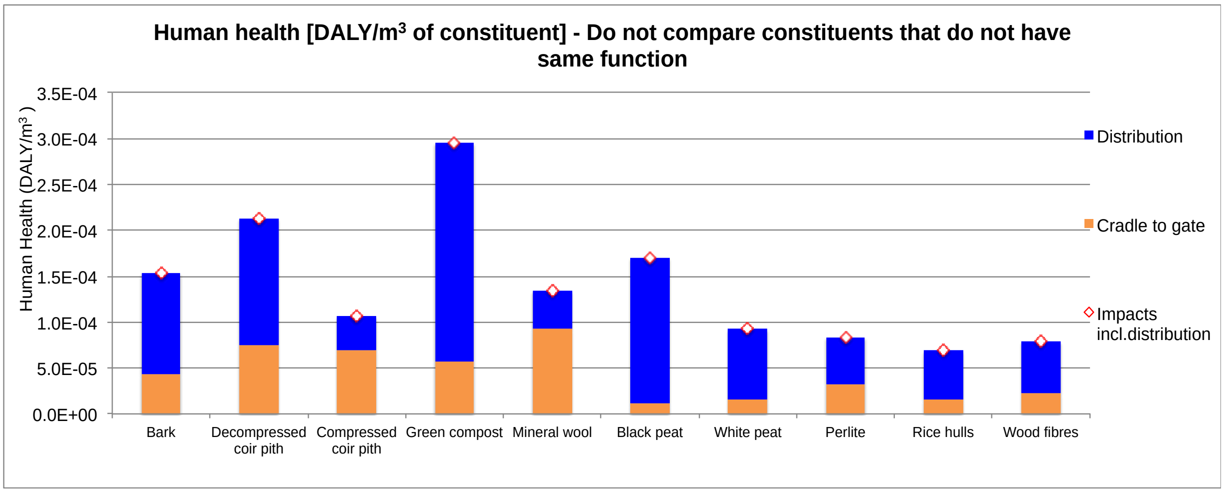

Figure 51: Results for Human health indicator for 1 m^3 of the different constituents. Compare only constituents that are functionally equivalent (i.e. constituents in area of application 1: peat, coir pith and mineral wool).

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Appendix E: Preliminary critical review report

This part corresponds to the **preliminary** critical review report. It is given for information and feedbacks.

a) Part 1: Goal and scope critical review

For this part of the review, we received comments directly in the report from Michael Hauschild, Arina Schrier and Elke Meinken.

The name of the file sent to the reviewers for this part was: EPAGMA_Growing media LCA report _2010-12-09_Quantis

Comments made directly in report		
Report section (and sentence)	**Comments from reviewers**	**Quantis answers**
Index	Arina Schrier: Why only talking about Climate change and warming potential? In my opinion carbon loss other than through GHG emission (e.g. biomass removal needed for peat removal, leaching through drainage ditches, losses through wastes etc) is of great importance when assessing environmental impact of growing media	All carbon losses that can be quantified are included in GHG emissions and therefore will be included in the Climate change/GWP impact score.
1.2 Context and background	Arina Schrier: I did not receive the appendices yet.	In the intermediary report we have added the explanation of appendixes A,B,C.
2. Goal and scope definition		
2.1 Objectives of the study	Arina Schrier: Is it just comparing? Or is the goal also to make climate and environmentally friendly choices in the future, so in this case, to make stakeholder able to select the optimum growing media.	The aim of the study is just to compare the LCA results.
Table 1: Growing media analysed	Arina Schrier: Would prefer adding Bd's in this table because you're basing the LCA on 1 m^3 of growing media	Please specify: what do you mean with Bd's?
2.3 System function and functional unit		
To provide 1 m^3 (EN 12580) of growing media for the following applications: fruity vegetables, pot plants, young plant production using loose-filled trays, tree nursery stock, hobby market.	Michael Hauschild: This definition requires that the different growing media are functionally equivalent on a volume basis, i.e. adding 1 m^3 has the same effect in the named applications regardless which medium is added. Is this the case? The definition disregards content and release of nutrients, differences in texture and resulting porosity and in water retention capacity when added to the soil. Please consider whether this is OK in the current study	Yes, within each application the different mixes are functionally equivalent. However no comparison is done among applications.
	Elke Meinken: Remark to the comment	OK

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	of Michael Hauschild: growing media are not added to the soil, they are used instead of soil	
2.5 System boundaries		
The setting of system boundaries […] should include: 2) all the processes and flows that significantly contribute to the potential environmental impacts.	Arina Schrier: What environmental impacts: carbon losses and gains? GHG emissions? Biodiversity implications?	All indicators described in section 2.8. For example, carbon losses and gains as well as other GHG emissions are included in the GWP/Climate change impact category, biodiversity implications are included into Ecosystem quality , etc.
This study assesses the life cycles of the different terrains/growing media made of peat and other complementary constituents and/or competitors of the peat (Bark, Green compost , Perlite, Wood fibres, Rice hulls, Mineral wool, Coir pith)	Michael Hauschild: Terrains? Not clear from the functional unit that this is an issue to include	We meant growing media, we deleted terrains.
	Arina Schrier: Figure 2.1 is not representative for all mentioned growing media (e.g. not for perlite and rice halls). It would be helpful to design figures separate for all assessed growing media, especially for the production and transformation part of the life cycle.	The system boundaries specific to each growing media constituents are presented in Appendix.
The system is divided into five principal life cycle stages: (1) Production (including transports from cultivation place to production center), (2) Transformation (including packaging supply and production), (3) Distribution, (5) Use stage, and (6) End of Life.	Arina Schrier: What about the life-cycle duration of the different growing media? Quite long due to slow renewal of peat? Or based on the 100 years global warming potentials of the GHG-s? define not only system boundaries spatially, but also temporally.	Life cycle inventory considers all the inputs related to extraction during the overall lifetime of a peatland, the inputs related to the opening and after-use of a peatland, all the emissions related to peat degradation during end-of-life. Michael Hauschild: This should be made clear in the scoping of the system (in section 2.4?) OK, we explained it better in section 2.7.
This figure shows a simplified process flow diagram including the main unit processes (boxes), each of them covering a whole cradle-to-gate sub-system.	Arina Schrier: Based on literature, the distribution/use stage/end-of-life stage will contribute only little to the total budgets. So, focus of quantification will be on the first two stages. In the production stage of peat quite some sources are missing: carbon/GHG fluxes related to land use change (digging of drainage canals -> CH_4 fluxes from open water, biomass removal, fluxes related to fertilizer application, emissions from stockpiles,	All these fluxes will be taken into account.
	Arina Schrier: What happens to wastes? Real wastes just decomposing? I would include a diagram representing life cycle comparison between the different growing media.	Emissions and impacts related to wastes are considered. The process description specific to each growing media constituents is presented in Appendix.
	Arina Schrier: What about use of pesticides for production of the	Pesticides are not taken into account for coconuts cultivation

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	different growing media.	only. Please see the limitations section for more details.
Figure 2 1: Product system description for the LCA of the systems studied	Arina Schrier: What is peat conditioning, explain. Is it how peat is compressed, bricks/briquettes etc. ?	It includes mixing and sieving of peat.
The « Use phase » includes all the materials used for the greenhouse plants cultivation or in flowerpots (fertilizer production, water consumption, air humidification).	Michael Hauschild: ISO uses the term "stage" for this while "phase" is reserved for the main elements of the LCA methodology (e.g. the "inventory phase"). I suggest that you follow this use of the word	OK, we changed.
Plants cultivation are taken into account into the study but as their growing is considered equivalent for all the scenarios, it can be neglected in this comparative LCA. Consequently, we did not consider the plants growing and decomposition.	Arina Schrier: Plants cultivation can be neglected? Not in terms of pesticide use and differences in media wastes between crops.	We assume plant growing to be the same therefore not to consider it in the study. When we say it can be neglected it is not because we consider it negligible but because it is the same everywhere and therefore will not change the ranking.
Here we consider the abandonment of the growing media after the use (anaerobic degradation) next to the use place.	Arina Schrier: Will also biodiversity impacts, other ecological impacts such as erosion be included?	Biodiversity will be included in the Ecosystem quality , however erosion as such will not be included as no impact assessment methods are currently able to quantify it.
2.6 Life cycle inventory data, sources and hypothesis		
Information regarding production, transformation and distribution of the different growing media constituents, including manufacturing processes, distances of immediate suppliers, distribution distances and transportation modes is collected directly from EPAGMA members	Arina Schrier: Make sure that not everything is based on EPAGMA data and communication. More information sources, preferably scientific literature (surely when quantifying the production stage) will improve robustness of the LCA.	We use a range of data included in literature review.
2.7 Scenarios and main data and assumptions		
All mixes related to a specific scenario were required to be similar in terms of physico-chemical properties.	Arina Schrier: How is that possible with materials that are chemically and physically very different…	All growing media within an application are comparable. We discussed with Elke Meinken (growing media expert) and she agrees with the choices.
Following these considerations, we decided to compare the growing media constituents on the basis of their use in horticulture, so on the basis of their application.	Michael Hauschild: This is wise, please make it clear in the definition of the functional unit	The functional unit has been rephrased as such: To provide 1 m^3 (EN 12580) of growing media for each of the following five applications: fruity vegetables, pot plants, young plant production using loose-filled trays, tree nursery stock, hobby market.
Application 5: Growing media (universal potting soil) for end consumer (potting soil is a general term for Growing media for the hobby	Elke Meinken: I suggest to avoid the word 'soil' because it might cause confusion. 'Soil' should only be used when you mean mineral soil in situ	OK

market)		
Table 2: Mixes (scenarios) for the 5 applications, for 1 m^3 of each one (Figures in % of the total volume)	Arina Schrier: Are these mixtures realistic? Why have these mixtures been chosen, more explanation needed. Not enough to say that it is based on year of experience in the sector. Why for fruits just one growing medium and for the others real mixtures? Not clear now. Perlite is currently mainly used for tomato growing, why not included in application 1?	All growing media within an application are comparable and realistic. We discussed with Elke Meinken (growing media expert) and she agrees with the choices.
For each application, different scenarios (mixes) were defined in collaboration with EPAGMA experts. All mixes related to a specific scenario were required to be similar in terms of physico-chemical properties	Michael Hauschild: I would consider moving this to the section where you define the functional unit, or at least explain that this is the approach that you will take in the comparisons – it is essential for the definition, cfr. My comment in that section	Ok, we added an explanation of the approach.
2.8 Life cycle impact assessment method		
Impact assessment classifies the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment	Arina Schrier: Emissions of what?	Emissions defined in the ecoinvent database (more than 700 to air, water and soil) that have a characterization factor defined in IMPACT 2002+ (www.impactmodeling.org).
2.8 Life cycle impact assessment method→ Climate change indicator	Arina Schrier: Is the carbon balance included here? Or only GHG's	All carbon losses that can be quantified are included in GHG emissions and therefore will be included in the Climate change/GWP impact score.
The goal is to evaluate the sensitivity of the results in respect to the assumptions for several key input parameters and evaluate the probability that the conclusion is maintained, based on the uncertainty of all the input parameters.	Arina Schrier: Not clear	This part is developed and analysed in the final report.
The 18 midpoint categories considered are:	Elke Meinken: only 17 categories are listed	The categories are 18 because terrestrial acid/nitrification includes the 2 midpoints: terrestrial acidification and terrestrial nitrification.

b) Part 2: Intermediary critical review

For this part of the review, we received comments directly in the report from Michael Hauschild, Arina Schrier and Elke Meinken.

The name of the file sent to the reviewers for this part was: EPAGMA_Growing media LCA_Intermediary-report _2011-04-15_Quantis

We sent a first version of the report to Michael Hauschild. After, we sent his reviewed report to Arina Schrier. Elke Minken received a report with comments from both reviewers, Michael Hauschild and Arina Schrier.

Comments made directly in report		
Report section (and sentence)	**Comments from reviewers**	**Quantis answers**
1.2 Context and background	Elke Meinken: Appendices D and F are not mentioned	Ok, added a sentence on Appendices D and F.
Goal and scope definition		
General comments	Arina Schrier: in the explanation of what an LCA is in paragraph 1.1, also Human health is included, why not considered in this LCA?).	Yes, we considered Human health among the results.
	Arina Schrier: peat in itself does not have impact	OK
More specifically, the objectives of the study are: *I. To characterize the environmental impacts of the extraction, processing and use of black and white peat;*	Michael Hauschild: I don't see a specific focus on this in the current outline of the report?	Added the impacts relative to the excluded phases in the comparative assessment (mixing, packaging) and distribution of peat to the customer.
II. To compare the environmental impacts over the life cycle of the different growing media within the same application;	Michael Hauschild: How is this possible without characterizing the impacts of the other growing media as well, not just those of black and white peat?	With growing media we consider the mixes compared within the same application, not the constituents. We calculated the impacts of the different mixes in this study.
III. To identify the key parameters of the study and provide an assessment of their influence on the overall environmental impact through a sensitivity and scenario analysis.	Arina Schrier: Not clear what ' key parameters' of the study are. The parameters that have the highest negative impact on….?	The parameters that have the highest impact on all the IMPACT 2002+ end points.
Table 1: Growing media constituents analysed. *Green compost :* *Composting is an aerobic process where microorganisms break down organic matter. The process is highly dependent on a wide range of different parameters such as temperature, pH, and moisture content. In addition, the nutrient content and structural properties of the material to be composted influence the end product. It is used in gardens, landscaping,*	Michael Hauschild: I would avoid appraisals and keep the description in the same neutral wording as for the other components	Ok, we deleted the sentence

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horticulture, and agriculture. The compost itself is beneficial for the land in many ways, including as a soil conditioner, a fertilizer, addition of vital humus or humic acids, and as a natural pesticide for soil.		
2.3 System function and functional unit		
For each application, different scenarios (mixes or growing media) were defined in collaboration with EPAGMA experts. All mixes related to a specific scenario were required to be similar in terms of the physical and chemical properties of relevance to the application. Consequently the scenarios are distinguished on the basis of these properties and they are comparable from a functional point of view (same function for all the mixes) as they have the same properties necessary to their desired use (the cultivation). For more details related to scenarios please refer to section 2.6.	Arina Schrier: This sentence is very hard to read…..and what do you mean by physical properties? Also further on in the doc. You are writing about physical properties, but for me it is not clear: do you mean: bulkdensity? Pore-space? Texture? Capillairy rise? Water holding capacity? And how do you test if physical properties are similar?	By physical and chemical properties we mean: air porosity, moisture, hydraulic conductivity, tortuosity. The choice of mixes has been defined in collaboration with EPAGMA experts, based on their experience and approved by Prof. Elke Meinken, our growing media expert.
	Arina Schrier: It is confusing using these different terms: mixes, scenarios, applications. Maybe explain exactly earlier in the document.	Ok ,we tried to be more clear by using the same terms. An explication is provided in the glossary section at the beginning of the document.
	Michael Hauschild: Application? Don't you mean "created" or "designed"?	Yes, application, changed. Ok, we used "designed".
	Michael Hauschild: Your use of the terms application, scenario and mix seems inconsistent to me. You have five applications, and for each of them you analyse a number of different mixes, but what are the scenarios then – are they different from the mixes? If not, I propose that you choose one of the two terms. (I would use "mix" as "scenario" is often used in a broader sense about a situation that may occur, and that you choose to analyse).	Ok, we did not use anymore the term "scenario". Mixes=growing media, but to make more clear the sentence we decided to prefer (and repeat) the same word "mixes" instead of changing it with "growing media".
	Elke Meinken: The physical and chemical properties of the mixes of each application must not be similar. Nevertheless, the mixes might be functionally comparable if different cultivation techniques are used.	Ok, we changed the sentence.
2.4 System boundaries		

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Figure 1: Product system description for the LCA of the systems studied	Arina Schrier: Is product system description the same as the word life-cycle-stage on page 19?	Yes
	Arina Schrier: I would prefer also some text on what is excluded from the analyses, outside the system boundaries. E.g. leakages.	What do you intend with leakages?
General comment	Arina Schrier: Here the order (production..processing….delivery..) is different from page 13.	Ok, changed.
We assume in this study that mixing activities (related energy and packaging) are the same for all growing media, consequently they can be excluded in this comparative LCA.	Michael Hauschild: But here you get a conflict with the first goal of your study: to characterize the environmental impacts of the production of white and black peat	In the section related to peat comparison, we considered these excluded activities (based on primary data). Anyway, mixing and packaging activities are not so important in term of impacts if compared to the other stages.
In order to reach the same physical and chemical characteristics, lime and fertilizers need to be added.	Michael Hauschild: More chemical than physical for these two additives? (lime and fertilizers)	Sentence changed as following (thanks to modifications made by Elke Meinken): "In order to reach functionally comparable mixes within each application different quantities of lime and fertilizers need to be added.. They were therefore taken into account."
Product system description for the LCA of the systems studied	Michael Hauschild: Where do you include the production of the packaging materials? Transport to transformation center mentioned under Production – isn't it now addressed under Delivery? Where do you include the production of the packaging materials – under the Processing stage or under the Distribution stage? Why do you call it Use stage when none of the other stages have "stage" in their name?	We assume in this study that mixing activities (related energy and packaging) are the same for all growing media, consequently they can be excluded in this comparative LCA. Packaging and mixing energy are added only to present peat results (in conformity with the 1st goal of the study) and they are included in the "Processing" stage. Ref. Delivery stage: yes, we changed the figure.

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The « Use stage » includes all the materials used for the cultivation of plants in greenhouses or in flowerpots	Elke Meinken: outside?	Flowerpots outside or inside for the hobby market (application 5).
General comment	Arina Schrier: Accordingly the comments of the other reviewer: this study is mainly a comparison between the different scenarios., not a total LCA. Per growing media, even not for black peat and white peat because you are excluding ' things' that are similar e.g. ' growing of the plant, mixing activities, etc. So, perhaps rewrite the goals of the study.	What do you intend with total LCA? This is a full comparative LCA. We added the excluded stages for peat only and only in the section related to peat results presentation, in order to be able to comply with the first goal.
2.5.1 Data collection		
For the constituents other than peat, we contacted directly the suppliers. In total we contacted about 20 suppliers	Michael Hauschild: In addition to the 18 EPAGMA companies?	Yes, in addition to them.
	Michael Hauschild: It would be relevant with an appendix providing information on which materials were supplied by members of EPAGMA (i.e. the commissioner of the study) and which materials were supplied by non-members (i.e. in principle competitors of the commissioner)	Ok, we added a table.
For each application, different scenarios (mixes) were defined in collaboration with EPAGMA experts. All mixes related to a specific scenario were required to be similar in terms of physical and chemical properties. Consequently the scenarios are distinguished on the basis of these properties and the mixes of each application are identical from a functional point of view (same function for all the mixes) as they have the same properties necessary to their desired use (the cultivation).	Arina Schrier: Confusing again. So, each scenario has 5 applications, each three mixes? So 15 different scenarios?	We defined 5 applications: Growing media for fruity vegetables, Growing media for pot plants, Growing media for young plant production using loose-filled trays, Growing media for tree nursery stock, Growing media for hobby market. Each application has different mixes. In total we studied 19 mixes.
	Elke Meinken: to solve Arina's confusion: each of the 5 applications has 3 or 4 mixes (scenarios), this means in total 19 mixes	Ok.
2.6.1 Description of the scenarios		

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General comment	Arina Schrier: I miss information on which ' environmental impacts' are assessed. I think it is good to have a paragraph on this in chapter 2. The goal is to assess environmental impacts of…I miss terms as water footprint, carbon footprint, GHG/climate, biodiversity etc.	Impacts categories are presented in section 2.8: Life cycle impact assessment method. You will find the 18 midpoint categories, the six damage categories considered.
In this study we analysed only the peat milling extraction (excluding the sod peat extraction less common in Europe).	Elke Meinken: Is this true? In my opinion more sod peat than milled peat is used in professional horticulture	Following EPAGMA experts, sod extraction is no longer the main method to extract white peat. The reasons are of economical nature. In addition, we wanted to make our study easier to compare with the Canadian LCA.
We created a model specific for each company and per each stage of black and white peat life cycle.	Arina Schrier: Quite ' broad' : a model for assessing environmental impacts?	A model for assessing environmental impacts was created on SimaPro software.
2.6.2 Data and assumptions		
Using different technologies of peat milling (peat harvesting or Haku-Peco system).	Elke Meinken: What does it mean?	In the Peco system the ridge on the fifth field from the stockpile is picked up by a harvesting machine, passed along a conveyor and dropped on top of the ridge on the fourth field from the stockpile. This process is repeated "leap frog" fashion until all the peat is harvested onto the stockpile which is located in the middle field of the 11 field unit. In the Haku system each ridge is picked up by the same type of harvester and loaded into a trailer on an adjoining field. This trailer of peat is then taken to the central stockpile while another trailer moves in under the harvester. The operations of milling, harrowing, ridging and harvesting are repeated for each crop and are collectively described as a cycle. Generally at least 12mm of evaporation is required to dry a crop to the target moisture content. This normally takes a period of 3 to 4 days. In an

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		average year 12 crops or production cycles are achieved. However, due to the undependable nature of our summer weather, the number of crops produced varies considerably from year to year. Please see glossary.
Figure 2: Details of the peat production stage	Arina Schrier: Where in this figure is site preparation (e.g. drainage, clearing of forest etc) included?	It is included in “Non-ordinary operations”.
Table 3: Characteristics of black and white peat	Michael Hauschild: My calculation says 55 kg/m^3	Yes, we introduced 55 kg/m^3 into the model correctly.
GHG emissions related to land use change: Literature data were used for the GHG emissions related to land use change during the steps of peatland opening, peat extraction and after-use objectives realization. For this intermediary report, we used data reported in Table 5. These data are average data for a pristine bog converted to extraction field. Consequently they do not take yet into account the real previous use of the peatland (Hemeroby categories). GHG emissions for after-use objectives realization steps has been calculated following Cleary et al. (2005), as reported in Figure 3.	Arina Schrier: Sentence not correct.	It is not sure for us what do you mean, in any case we changed this sentence.
GHG emissions are caused by an oxidation of the peat in situ that causes a degradation of the peat resource.	Arina Schrier: Double. Exactly the same sentence on page 21	Ok, changed this part.

An average value for black and white peat of 10.55 MJ/kg CO_2 *has been considered*	Michael Hauschild: How does this value relate to the upper heating values given in Table 3 (5 and 8.8 MJ/kg)?	10.55 are MJ per kg of CO_2 emitted by peat. We calculated before the CO_2 emitted (kg/m^3) as following: [44/12 . C quantity per m^3 (kg/m^3)] After we made: Upper heating value [MJ/m^3] / CO_2 emitted [kg CO_2 /m^3] = MJ/kg CO_2 . We made this calculation for both black and white peat and made an average of those values.
Table 4: Emissions due to land use change	Arina Schrier: I suggest to add information on this table in the text. For example, it is unclear to me why emissions in the peat restoration stage is higher per year than the emissions in the years of peat extraction.	Ok, we modified this part.
	Michael Hauschild: But not including N_2O emissions, and not including stockpiling operations, so complimentary to Alm et al. and Lapveteläinen et al??	Yes, exactly. Anyway, we changed Cleary's source.
	Arina Schrier: Is the clearance of vegetation included here and site preparation? Probably not, because it is during extraction. In this table I miss the emissions from going from a ' native' site to a peat extraction site (which causes a considerable part of emissions due to LUC).	These land emissions are included and considered equal as for extraction. This is in line with the latest studies on this matter (as Hagberg and Holmgren (2008)).
	Michael Hauschild: You must explain better how you arrive at these durations and emission quantities based on Figure 3 and other assumptions.	We modified these assumptions.
Figure 3: CO_2 *emissions evolution for the after-use objectives (Cleary et al. 2005)*	Arina Schrier: The Y-axe is in gC m-2 yr-1. The tables are in kg CO_2 -eq ha-1 yr-1. Be consistent.	We changed assumptions so we deleted this figure.
	Arina Schrier: CO_2 ? I would say carbon.	We changed assumptions so we deleted this figure.

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Coir pith production and processing	Arina Schrier: For the reader it would help to get a table in which for each growing medium the sources/sinks/environmental impacts are listed, like you did for the rice hulls and maybe also were you ‘ draw’ your system boundaries.	Ok, we added a table with bulk densities and moisture contents of each GM constituent. We added also some additional explanatory charts.
In this study we considered the coir pith retting.	Michael Hauschild: Why? Because it is the approach that is relevant for the study? Because it is representative of the other approaches?	Because this is the approach used by an EPAGMA company and for which it was possible to collect primary data.
It is important to note that coconut cultivation is not an agriculture that causes deforestation as for instance palm oil cultivation.	Michael Hauschild: Why – doesn’t it use the same types of land?	There is a difference between plantations and production of Coconut-oil (Cocos nucifera) and palm-oil (Elaeis guineensis). There are both members of the palm-family, with quite some difference in application and cultivation in various parts of the world. While in Malaysia and Indonesia the palm oil cultivation causes deforestation because of the high global demand of palm oil for the agro-food, cosmetics and biocarburants industry, the coconut cultivation in Sri Lanka is addressed principally to a local demand (more than 80% of the national production is dedicated to the domestic consumption according to the Sri Lanka Ministry of Plantation Industry, 2008). Consequently, the coconut cultivation does not destroy the Sri Lankan forestry. The surfaces of coconuts cultivation have been stable since many decades (about 420’000 ha) and new cultivations are marginal (about 1’000 ha/years on average since 1990).
Coir pith production and processing: Compressed coir pith has been considered equal to 600 kg/m^3 while not-compressed coir pith has a bulk density of 60 kg/m^3.	Elke Meinken: dry material?	Yes, dry material.

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Mineral wool production and processing. *Average density used for mineral wool was 50 kg/m^3.*	Elke Meinken: dry material?	Yes, dry material.
Rice hulls production and processing. *Density of rice hulls has been defined equal to 122 kg/m^3 (dry material).*	Elke Meinken: dry material?	No, moisture content of 9%.
Table 5: Compost characteristics and main assumptions for waste degradation	Elke Meinken: 0.11 is too low; I assume it is 11.0, although it seems relatively high 0.07 is too low, I assume it is 7.0	We changed and we calculated 3.35 g/kg (Total P) and 12.15 g/kg (Total K) (calculated on basis of the input composition).
Bark can be used as growing media constituent both fresh and composted. Bark considered in this study is fresh bark.	Elke Meinken: The bark used in growing media is mostly composted. Only maritime pine bark can be used without composting	We discussed about this a lot with EPAGMA and we decided to consider bark instead of composted bark. They states that maybe in Germany composted bark is more important but not in some other countries.
Average density of fresh bark has been considered equal to 482 kg/m^3	Elke Meinken: moisture content?	It is of 30%. Added.
Table 6: Distances for transport of constituents to mixing plant (assumptions). Coir pith from Sri Lanka to Rotterdam (ship) 12477 km	Michael Hauschild: Considering the rounding of the other distances I would make this 12500 km	Ok, changed
Use stage and end-of-life for peat: The main difference related to this stage between peat and the other constituents is that the carbon emitted by peat is fossil carbon , while CO_2 emitted from the other biologic constituents (compost, coir pith, rice hulls, bark, wood fibres) during their degradation is biogenic CO_2	Arina Schrier: Don't know exactly what you mean here.	Following ILCD Handbook, "land use change-related CO_2 emissions from soil, peat etc. in all cases and from biomass and litter of virgin forests shall be inventoried as "Carbon dioxide (fossil)". Emissions from biomass and litter of secondary forests shall be inventoried as "Carbon dioxide (biogenic)"." Following IPCC glossary, "biogenic carbon is carbon derived from biogenic (plant

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		or animal) sources excluding fossil carbon. Note that peat is treated as a fossil carbon in these guidelines as it takes so long to replace harvested peat. "
Use stage and end-of-life for peat: correcting biogenic emissions of other gases accordingly by subtracting the equivalent value for CO_2 based on the carbon content of the gas	Michael Hauschild: It is not clear for me what you do here, but methane should be counted as a greenhouse gas regardless whether it comes from biogenic or petrochemical sources	Here, we have followed the recommendation of the PAS 2050 product carbon footprinting guidance in not considering either the uptake or emission of CO_2 from biological systems. By consequence, the biogenic and fossil methane GWPs are calculated the following way: biogenic methane has the GWP given by IPCC 2007. Fossil methane has the same GWP as biogenic methane plus the GWP of the fossil CO_2 that is formed by its degradation, which is 2.75 kg CO_2 /kg CH4. (BSI, 2008).
Use stage and end-of-life for the other growing media Stated that growing media within the same application are functionally equivalent, we decided to consider the same all the processes related to the use stage. Consequently, greenhouses heating energy, water and fertilizers consumption were not taken into account since it is equal for all the growing media. Possible differences in terms of water and fertilizers consumption among growing media during use stage were deeply discussed and analysed with the EPAGMA experts that arrived to the above-mentioned conclusion.	Michael Hauschild: This is also the case for the peat-based growing media	Yes, it is.
2.7.1 Coir pith allocation	Arina Schrier: So, for coconut you included the footprints of all different by-products in the assessment? Unclear. For me it sounds very ambitious to include also the life cycles of the by-products. The table as I mentioned earlier would help to make things more clear. Try also to keep figures and tables per growing media as consistent as possible. The information is quite ' messy' now.	We did not include the impacts of all the by-products. We allocated the impacts related to coconut harvesting as a coconut can be harvested for several purposes. Same approach has been used for bark and rice hulls.

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	Michael Hauschild: Table 7 is about wood by-products and Table 8 presents the resulting allocation factors, not the economical ficures on which they are based.	Ok, corrected.
2.7.2 Bark allocation	Michael Hauschild: Also allocation for production of wood fibres?	For wood fibres, the wood chips used are scraps from industrial processes and of very low quality. So, differently from bark, we did not make any allocation and used the ecoinvent process:" Wood chips, softwood, from industry, u=40%, at plant"
	Michael Hauschild: Please present the by-products between allocation has to be performed	By-products are presented in Table "Prices for wood by-products used to calculate economical allocations factors"
2.7.3 Rice hulls	Michael Hauschild: No table with the economical data for rice hulls	Please see table "Economical allocations factors used in this study"
Table 8: Economical allocations factors used in this study	Michael Hauschild: How do you foresee these factors applied to arrive at the share of the coir pith? Do you see the fibres and the coir pith as parts of the nut?	Added the explication
	Michael Hauschild: Not clear how these derive from the figures in Table 7	Added the explication
Intermediary results: 3.2 Comparison among growing media at damage level		
General comments	Michael Hauschild: This seems to be a trend for many of the comparisons. In the final report it is therefore important that you discuss the uncertainties of the Climate change and the Human health impact scores, both in terms of the underlying inventory data and the impact assessment data (characterization at midpoint (CC) versus endpoint (HH)), to avoid that differences in CC, that may be statistically significant, are neutralized	Added the explication

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	by differences in HH that are statistically insignificant due to large assessment uncertainties.	
Figure 8: Results for growing media within application 2. Results for Human health.	Michael Hauschild: Please mirror and turn upside down	Not clear. Could you please specify? 2011/10/16 Michael Hauschild: Figure turned correctly now
Figure 9: Results for growing media within application 3	Elke Meinken: At first sight this is in contradiction to application 1, where the impacts of peat and coir pith on Human health seem to be comparable. But this is a false conclusion because of the different scales at the Y-axis. I suggest to use the same scale for each application.	OK, we tried to change scale where possible. At the same time, we would like to choose a scale that allows seeing well the chart and the differences between mixes. Please consider that only the mixes within same application must be comparable. And each mix is different from the other.
3.5 Study Limitations		
The present limitations (for intermediary results) are detailed below: • *The analysis has been conducted on a comparative basis: therefore it is not possible to separate the environmental impacts for different growing media as we excluded some common processes in their life cycles (as equivalent).*	Michael Hauschild: Conflict with the first of your three goals	To comply with the first goal, we added the excluded stages in the analysis of the impacts for black and white peat.
• *The model related to wood fibres has been extrapolated from a process for fibreboard production in the ecoinvent database because of lack of more accurate information;*	Michael Hauschild: To the production of wood fibres from wood mass?	We changed the model.
• *Coir pith is based on coconut harvesting in Sri Lanka. Cultivation activities have been modelled considering the main input and emissions. Chemical products different from fertilizers, as pesticides and herbicides, have not been considered because of lack of information. There are no national statistics about the use of these*	Michael Hauschild: But if they are used to a considerable extent in the life cycle of the coir pith it means that the results for this material are misleading.	There are no statistics about the use of these products for coconuts cultivation and no official data available. Use of chemical products is extremely variable, it depends on specific and local parameters like the farmer's sensitivity and it cannot be quantified.

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products for coconuts cultivation, their use is extremely variable and depends on specific and local parameters. Not all the coconuts palms are treated at the same manner and to make this assumption may change sensitively the results. Therefore, we considered not to include these chemical products into the model.		

a) *Part 2: Final critical review*

For this part of the review, we received comments directly in the report from Michael Hauschild, Arina Schrier, Elke Meinken, Kari Minkkinen.

The name of the file sent to the reviewers for this part was: EPAGMA_Growing media LCA_Intermediary-report _2011-09-26_Quantis

Comments made directly in the report		
Report section (and sentence)	**Comments from reviewers**	**Quantis answers**
General	Arina Schrier: Overall Suggestion: do not use sub-paragraphs with more than 3 numbers in the text e.g. 2.7.2.2.1. Very confusing. improve fig., add meaningful graph titles and titles + units on the Y-axes. A lot of words are lumped together without spaces. I did not check on English or on the structure of sentences. Try to avoid repetition of subjects throughout the doc.	OK, we avoided the use of sub-paragraphs too long and for styles “Heading 5” and “Heading 6” we used letters and roman numerals. We changed captions of figures to better explain them. We cannot find words lumped together. It may be due to a passage from Mac to pc. English of the report has been reviewed by an English native speaker.
Summary		
Summary	Arina Schrier: Overall: The results have to reflect the objectives of the study. The first two objectives (page 16) are in the results, however, the third objective an assessment of the overall environmental impact through a sensitivity analysis is not. Would add the main results of this.	We assessed impacts through different sensitivity analysis that you can find in the section 3.4.
Summary: *The system is divided into six principal life cycle stages: (1) Production, (2) Delivery, (3) Processing, (4) Distribution, (5) Use, and (6) End of Life.*	Kari Minkkinen: see figure: post -consumption should be during consumption?	Yes, we changed the Figure I.
Climate change results for	Arina Schrier: Climate change	“Climate change” is not synonym of

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growing media within area of application 1	results?? Suggestion: call it ' Emissions of CO_2 for the growing media within application 1. Also use Y-axes titles. It is strange to shift the Y-axes titel and units to the top of the graphs. Where are error bars?	"Emissions of CO_2". Climate change is the name of one of the damage categories of IMPACT 2002+ as explained in section 2.11. We will change it by writing "Results for…". Concerning error bars, we performed an uncertainty analysis. Please refer to section 3.5.
Ecosystem quality results for growing media within area of application 5	See earlier comment. Would use a different tekst. E.g. The impacts on ecosystem quality, expresses as (…), for different compositions of growing media as used in the hobby market.	Ok, we changed it by writing "Results for Ecosystem quality indicator, expressed as…".
In general, for all the areas of application, the growing media that have relatively speaking the highest contribution to Climate change and Resources, are the mixes containing peat	Arina Schrier: Choose either for 1) highest contribution to climate change and decrease in resource function or 2) ' highest impact on climate and resources.	Climate change and Resources are the names for the respective indicators in IMPACT2002+. The higher are the values of these indicators, the higher are the impacts.
Conclusions	Arina Schrier: You mean that production, delivery, processing, distribution, use and degradation of the media have impact on the environment; not the growing media in itself.	Yes, this is correct. Here we meant growing media life cycle.
Conclusions	Arina Schrier: When looking at the objectives on page 16, the conclusion has to be in the opposite direction. For a chosen growing medium, the following indicators are the most important (obj 1). Or: within an application (e.g. fruity vegetables) the following indicators are the most important (obj 2).	Objectives on page 16 say that: 1) calculate impacts for each constituent: this step was necessary to assess the further step… 2) calculate and compare impacts of the different growing media 3) define which are the most impacting stages for each growing media (you can find it in the conclusions and results discussion) and do sensitivity analysis (section 3.4).
For the professional grower in the horticultural industry, the most important factor is that the growing medium functions well under the growing conditions (Altmann, 2008).	Arina Schrier: Is this a conclusion of this study?	This is not a conclusion of the study but it is a key point to well understand and interpret results, that is why we wrote it in the report. However, we reformulated the conclusions.
Growing media choice is mainly influenced by the type of soil	Elke Meinken: I don't understand, because growing media are used instead of soil	Ok, we deleted by the type of soil.
Growing media constituents, other than peat, play and will continue to play a subordinate role as compared with peat.	Kari Minkkinen: Why was this study ever done, if it would have no effect on the subject? It is not very wise to say that "no matter what the results are, nothing will change".	Ok, we deleted the sentence for the summary. We reformulated the conclusions.

	Michael Hauschild: I agree, this is not a statement that belongs in a summary. Arina Schrier: idem	
Conclusions	Michael Hauschild: There is a lot of repetition about the importance of functional equivalence here which gives the reader the impression that you try to step away from your results of the study because they are inconvenient. This is not credible. You should consider to delete and stress the importance of functional equivalence only once (preferably in relation to the definition of the functional unit where you already mention it)	Ok, we reformulated the conclusions in the summary trying to stress less on the functionally equivalence aspect. Anyway we consider it a key point to well understand results. Reader must be aware of these considerations in analysing results. If not, the risk is that results could lead to false and not realistic conclusions.
Developing new production technology allowing to: *- Reduce the amount of residual peat: this would result in lower emissions from the aftertreated area (in the case of afforestation).* *- Reduce the moisture content of the extracted peat: the drier the peat the lower the combustion emission factor and consequently emissions from transport and combustion.* *- Shorten as much as possible the harvesting time*	Kari Minkkinen: Is this relevant: How good is the bottom most peat for horticulture? It is usually very humified and ash content is high (because of the proximity of mineral soil on the bottom).	The higher is the bottom layer, the higher are the emissions during after-treatment. This is also one of the conclusions raised by some published reports as Hagberg and Holmgren (2008). In term of quality, it is true that it could not be of good quality for horticulture use.
N_2O Dinitrogen Monoxide	Arina Schrier: In climate research called nitrous oxide.	Dinitrogen monoxide is the IUPAC name and both assertions are used. Anyway we changed the name here in nitrous oxide as requested.
GWP Global Warming Potential	Arina Schrier: Early in the document it has to be explained that the GPS's for CO2, CH4 and N2O are 1, 24 and 298 resp.	Weights factors of each substance are not written directly in the report , they are part of the IMPACT 2002+ method. For more information on it please refer to Jolliet et al. (2003) and Humbert et al. 2010, as reported in appendix B.
Glossary		
	Arina Schrier: It would be very helpful if in this glossary, or furtheron in the tekst (e.g. paragraph 2.11, page 68) per indicator (climate, resources,	We added a table explaining for each damage category, which are the midpoint associated. For more information and to know exactly which are the weights, please refer

	etc) the input parameters for the model were given very briefly. The most simple way is probably to do this in a table.	to Jolliet et al. (2003) and Humbert et al. 2010.
IMPACT 2002+	Kari Minkkinen: what's this? Include in glossary.	Ok, we included it.
	Kari Minkkinen: SI-unit abbreviation for year is a (annum)	Yes. However, year is widely used in scientific reports.
The damage can directly be determined as a Potentially Disappeared Fraction of species (PDF) over a certain area (m2) and during a certain time (y).	Michael Hauschild: Consider to mention the midpoint impact categories that contribute to this damage category just as you do for the human health indicator below.	Ok, we specified it in the glossary and we added a table (table 13).
Goal and scope definition		
General	Arina Schrier: Suggestion: Order this chapter in a different way, do not use paragraph numbers with more than three to four numbers: e.g. 2.7.2.1.2.1.	Ok, we avoided the use of sub-paragraphs too long and for styles "Heading 5" and "Heading 6" we used letters and roman numerals.
General	Arina Schrier: Suggestion to restructure the paragraph 2.7 en 2.8 and add tables to show overviews of the findings per category or scenario. Specific comments are given in the texst. I would suggest to make 2.7 and 2.8 separate chapters and then following the ' impacts' or indicators to be studied: Chapter black and white peat 1. Introduction (methods used to come to estimates, explanation of ' ratings': shortly wat inputs are used in the models) 2. Emissions (carbon and greenhouse gases) 3. Resources 4. Ecosystem Quality 5. Human health Chapter other growing media constituents Same paragraphs. Now it is confusing and hard to read.	Chapters 2.7 and 2.8 present data and assumptions made to calculate impacts. Therefore it is difficult to refer these chapters to the different studied damage categories. To make it more clear, we added tables summarizing the emissions and for forestry we separated emissions and carbon sequestration.
General	Arina Schrier: • explanation on why choosing these init. conditions, which scenario is	These reference scenario have been suggested by EPAGMA and they have been often used in literature too.

	more common than others etc.	
General	Arina Schrier: • clear subdivision in carbon and GHG losses (figs?): 1) direct losses through clearance of e.g. above ground biomass , depending on the forest type (estimates?? Scientific information available). Is harvested wood sold? Is it pulvarized and used for restoration? Is it burned and totally lost? Needs more explanation in this paragraph. 2) indirect losses through ' missed' sequestration of carbon through photosyntesis) and 'missed' uptake of carbon because trees are harvested(sequestration is given: 416-820 g CO2 m2 (Hagberg and Holmgren)) and 3) losses through peat oxidation/decomposition (assumed 818 g CO2 M2 Yr-1, Hagberg and Holmgren).	Ok, we clearly separate emissions from sequestration for forestry scenario.
General	Arina Schrier: • Afteruse: explanation on the different scenarios. Forestry is replanting of trees/reforestation? Agriculture is any crop? To me restoration includes two main components 1) rewetting (reduced oxidation of peat and thus decreased CO2 emissions, increased CH4 emissions and similare N2O emissons) and 2) reforestation. (sequesration of carbon (photosynthesis, growth of forest). What is the exact difference between rehabilitation and restoration? Not clear now from the definitions used, except that during rehabilitation the intitial situation in terms of biodiversity is not reached and with restoration it can be reached. • Maybe add table with the four scenario's and the carbon and GHG gains and losses. • Fig 16?? See	Definitions of restoration and rehabilitation come from Clarke et al, 2010 and are reported at the section "After-uses of extracted peatlands": - Peatland rehabilitation: The reparation of ecosystem processes, productivity and services of the former peatland, but does not imply the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure (Clarke et al., 2010) - Peatland restoration: The process of assisting the recovery of peatland that has been degraded or damaged to as near as possible its original natural condition (Clarke et al, 2010). We added tables summarizing emissions and carbon sequestration for all scenarios considered. We changed figure about N_2O cumulated emissions for black and white peat end-of-life. The formula in Figure 17 (source: http://www.ciraig.org/dynCO2__en/) is the same than the formula proposed by you, but it is more

	calculations added in the tekst. • Fig. 17?? Is not really helpful for understanding. Better a simple formula (for the 100-years time horizon which is used in the rest of the doc: GHG total = CO2 * a + CH4 * b + N2O * c With a, b and c the GPS's for the different gases (1, 24 and 298 resp (IPCC 2007).	general and takes into account all the greenhouses gases (not only N_2O, CO_2, CH_4).
III. To identify the key parameters of the study and provide an assessment of their overall environmental impact through a sensitivity analysis.	Arina Schrier: Suggestion: explain what is meant by 'parameters'. Are that the impact factors, or mid-point categories from page 68? If yes, be consistent in wording. Just add a simple table with the indicators and the parameters per indicator that have been considered.	Key parameters are the data that affect most the results for all the indicators analysed (e.g. allocation, land occupation, etc.). In the discussion of the results for growing media and the different constituents these key parameters are presented.
Black peat: Highly esteemed for the production of blocking media for vegetable growing.	Michael Hauschild: I would use more neutral wording as for the other constituents focusing on how widespread the use is.	Ok, we deleted the sentence.
Perlit	Elke Meinken: The raw material is often written without 'e' at the end	OK, we added it.
The comparability of the mixes has been approved by the growing media expert in this panel, Prof. Elke Meinken.	Michael Hauschild: I assume that you mean "the review panel"?	Yes, we specified it.
The product systems to be studied are summarized in Figure 1. This figure shows a simplified process flow diagram including the main unit processes (boxes), each of them covering a whole cradle-to-gate sub-system.	Michael Hauschild: If you want to call it a flow diagram, you should indicate the flows using arrows from one stage to the next	Ok, we called it a process diagram.
	Michael Hauschild: The boxes are not main unit processes but the six stages into which you divide the life cycle in the previous paragraph	Ok, modified with six life cycle stages.
Figure 1: Product system description for the LCA of the systems studied. Common processes (excluded in the growing media comparison) are not included in this figure.	Michael Hauschild: Use stage has the same content as end-of-life stage. Used to be: "Plants cultivation (fertilizer production, water consumption, air humidification)"	Ok, we corrected the use stage specifying that it includes degradation of growing media during use stage (1 year). Plants cultivation was considered equal for all the growing media within same application and so excluded.
The following 5 areas of applications were identified:	Arina Schrier: Repetition, 5 areas of applications were already summarized on page 7 and page 18.	The page 7 is the summary. At page 18 there is the definition of the functional unit: 5 areas of application were enunciated but not defined and described.

Every effort has been made by the EPAGMA experts and Quantis to create comparable areas of application to follow ISO requirements and the expert panel (internal and external) accepted them as equivalent.	Michael Hauschild: I don't think the areas of application are comparable – that is exactly the reason why you distinguish them separately. I guess you mean that you have tried to create comparable mixes within each area of application?	Correct, the areas of application re not comparable. We corrected the sentence as follow: "Every effort has been made by the EPAGMA experts and Quantis to create comparable growing media within each area of application…"
	Michael Hauschild: You need to be more explicit about which panels you are talking about. At least the review panel should be named as such when you refer to it	Ok, we corrected it using "review panel".
2.7 Data and assumptions for black and white peat		
General	Arina Schrier: Why not ordering paragraph 2.7 following the scheme Fig 1: ?	The structure of the report reflects the model structures on SimaPro and follow in part the structure of Figure 1: - Section 2.7 and 2.8 refer to production and processing stages: a specific section has been dedicated to peat because of complexity of the subject; - Section 2.9 refers to common processes for all the growing media constituents: 2.9.1 Mixing processes, 2.9.2 distribution, 2.9.2 use stage.
Four possible pre-uses (pristine, agriculture, forestry, degraded)	Kari Minkkinen: Please define degraded! Do you mean cutaway peatlands with this? Or degraded by agriculture or fellings? or all?	Ok, we added definitions.
Table 4: Characteristics of black and white peat	Kari Minkkinen: Bulk density is dry mass / fresh volume, NOT fresh mass! So the correct values are 100 and 72. Elke Meinken: The bulk density seems to be on fresh weight basis. This specification is not usual. Mostly bulk density is specified on dry weight basis.	Ok, we corrected it.
Use and end-of-life stage	Michael Hauschild: Don't these belong to the use or end-of-life stage for the growing medium? They aren't part of the peat production stage?	Yes, we deleted it.
Reference scenarios	Arina Schrier: Would be helpful to add a table and show per reference scenario the emissions (for CO2, CH4 and N2O) as found in the literature (with references)	Ok, we did tables summarizing emissions for each stage (reference scenarios, harvesting and after-use).

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Reference scenarios have been subtracted by assuring that the agriculture as before use has not been moved elsewhere.	Michael Hauschild: Not clear what you mean, please rephrase	The transformation of a drained cultivated peatland into an extracted peatland could cause the shift of the cultivated peatland elsewhere. In that case you would only move emissions of cultivation and at the same time you would have emissions from peat extraction. We assumed that emissions from a drained cultivated peatland are not moved elsewhere after a peat bog opening. Anyway, we deleted the sentence as it was not clear and very useful for the understanding of the reader.
2.7.2.1. Reference scenarios – – before site preparation	Arina Schrier: Are there restrictions or assumptions for peat-depth for choosing peat-harvesting areas?	What do you mean? Please rephrase.
In this study, according to Hagberg and Holmgren, 2008, the values of 55 g CO2 /(m2 .y) and 7 g CH4 /(m2 .y) are used.	Kari Minkkinen: these equal 15 g C and 5.25 g C. This means that less than 10 g C is accumulated as peat, which is a rather small amount compared to present estimates (20 to 30 g C).	Ok, these are figures coming from a published report (Hagberg and Holmgren, 2008)
	Elke Meinken: sink or source?	With the word emissions we considered a source. When we speak about carbon sequestration we speak about sink of carbon.
2.7.2.1.2.1 Emissions	Arina Schrier: When going from the reference scenario to a peat-harvesting area emissions consist of 1) direct loss of carbon through clearance of forest 2) indirect losses through ' missed' sequestration through photosynthesis 3) increased losses trough ongoing peat drainage. Maybe make a small overview of all numbers found in lit in a table	We considered the net value of these losses coming from published sources. We added tables summarizing emissions for each stage (reference scenarios, harvesting and after-use) to make it more clear.
Masera et al., 2003, study accumulation in a Norway spruce forest stand in Central Europe by using the CO2FIX Model.	Kari Minkkinen: Masera gives results for Central Europe. The growth rate of spruce in Northern Europe (i.e. Fennoscandia) is about half of the presented one. This means that your estimates for C fixing are not at least underestimates!	Ok, we corrected it and wrote that Masera refers to Central Europe.
2.7.2.3. After-uses of extracted peatlands	Kari Minkkinen: I am confused with this soil C accumulation / soil CO2 emissions question. If you decide that there are net soil CO2 emissions from peatland forests, then you can not have soil C accumulation going on. Unless you are	CO_2 emissions for forested peatlands and coming from Hagberg and Holmgren are not net emissions (taking into account accumulation too). That is why we considered separately accumulation (as Habgerg and Holmgren do in their report , too).

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	talking about separate soil layers (for example litter layer and old peat layer). This needs clarfication. Is this soil C accumulation rate relevant for cutaway peatlands? The existing soil C stock of 14 kg C m-2 equals about 30 cm of residual peat, which is a good estimate. However, in this model the soil C stock increases, which is because of very high litter input from the stand. In your other modeling of after use, soil C decreases. So I am still confused.	For forestry as after-use: we considered a decrease of emissions but an accumulation coming from Masera. For forestry as reference scenario: we considered constant values for accumulation and emissions. We added tables summarizing emissions for each stage (reference scenarios, harvesting and after-use) to make it more clear and separated emissions and sequestration in two sections for both forestry as reference scenario and forestry as after-use.
Figure 6: Carbon stocked in biomass and soil in the model adopted in this study.	Kari Minkkinen: You just said you decided to use Masera-model. So what was the figure 6 data used for? And if it was used for after-use, how did you treat soil CO2 emissions/sequestration - according to the emission of 818 g, or according to the sequestration shown in the figure 6, or as their sum? Please clarify these issues.	We needed to enter Maser model in our model on SimaPro, consequently we had to linearize Masera model. Linearization of the model is reported at figure 6.
Carbon sequestration in forestry as after-use. For assumptions, see the considerations made for forestry as before use scenario	Kari Minkkinen: How is this soil C accumulation related to CO2 emissions from forest soil, shown in the last chapter? Please draw these in one figure, showing the actual C dynamics.	Ok, we tried to make more clear the explications in the report separating the carbon accumulation section into 2 parts, one for forestry as after-use the other for a drained forested peatland.
2.7.2.1.3 Drained cultivated peatland: The emissions vary with land-use, consequently soil management practices	Arina Schrier: The main factor causing emissions is peat drainage, followed by N2O emissions through fertilizer application	Ok, thank you for this clarification.
2.7.2.1.3 Drained cultivated peatland: CH_4 emissions are assumed to be negligible (Hagberg and Holmgren, 2008).	Arina Schrier: Is that true? Alm 2007 reports emissions of 7.2 g CH4 M2 yr-1 for harvesting+ditch emissions. Also Nykanen et al 1996 reports 1.3 – 5.3 mg m2 yr-1 for drained peat. Emissions from drainage ditches can add considerably to the GHG balance.	Hagberg and Holmgren (2008) show that CH_4 emissions of drained forested peatland are negligible by comparing different published sources.
Harvesting stage: In literature, the CO_2 emissions from stockpiles have been estimated to 250 ± 125 g CO_2 /(m^2 .y) (per peat harvesting	Kari Minkkinen: Actually, emissions in Alm 2007 are from Nykänen et al. 1996, (which are from Ahlholm & Silvola 1990, which are from	Ok, thank you for this clarification.

area) according to Kirkinen et al, 2007 based on Finnish measurements in Nykänen et al, 1996. This is also in accordance with measurements in Alm et al, 2007.	Silvola & Ahlholm 1989). This means that no other measurements exist, but calculations have been done with varying assumptions.	
Since the area of the stockpiles is very small compared to the harvesting area the CH4 emissions are assumed to be negligible in the study, following Hagberg and Holmgren, 2008.	Kari Minkkinen: They are 2 to 5% of total in CO2 eq. (Alm et al. 2007). Is it negligible?	Yes, we considered that 2% to 5% is negligible. Following Hagberg and Holmgren: 250 g $CO_2/m^2.y$ (per peat harvesting area) and about 20 g $CH_4/m^2.y$ (per stockpile area). They are negligible if compared to CO_2 emissions and considering that the harvesting area is much bigger than the stockpile area.
2.7.2.3. After-uses of extracted peatlands	Arina Schrier: I would add per scenario what will be practically done: rewetting? Reforestation? And what will be the consequence for emissions: increased C-sequestration? Decreased or increased CH4 emissions? Etc. Suggestion: add information on what is meant by these scenarios (like the explanation for rehabilitation and restoration)	Ok, we added definitions for the different scenarios of after-uses. The evolution of GHG emissions is presented in the section: "After-uses of extracted peatland".
In this study, we considered that, of the total carbon left in cutaway previously forested peatlands, half is stable in the soil (never degraded)	Arina Schrier: Ref?	Reported in footnote: Dr Heinrich Höper (State Authority for Mining, Energy and Geology, Soil and Groundwater Monitoring, Hannover). Personal communication, April 14, 2011.
CO_2 emissions for the forestry after-use scenario	Arina Schrier: Different from the 818 g CO_2 m^2 yr-1 in paragraph 2.7.2.1.2.1.	Yes, 818 g CO_2 m^2 yr-1 is the constant value used to evaluate emissions of forested peatland as reference scenario. We modified the description of assumptions for CO_2 emissions from a peatland, adding 2 sections (emissions and carbon sequestration) for both after-use and reference scenario, trying to make it more clear.

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In this study, we considered that, of the total carbon left in cutaway previously forested peatlands, half is stable in the soil (never degraded). Following Hagberg and Holmgren, 2008, we assumed that the CO_2 emissions in the afforested cutaway peatland decrease exponentially from 1100 g CO_2 /(m^2 .y) before the first harvest (assumed at 70 years) when 50% of the residual peat has been decomposed. Thereafter slow release during the rest of the simulation period.	Kari Minkkinen: First you say half will never degrade, then you say it will degrade slowly?	Ok, we corrected the sentence as follow: In this study, we considered that, of the total carbon left in cutaway previously forested peatlands, half is stable in the soil (never degraded). Following Hagberg and Holmgren, 2008, we assumed that the CO_2 emissions in the afforested cutaway peatland decrease exponentially from 1100 g CO_2 /(m^2 .y).
The carbon content in the soil has been calculated considering that a bottom peat layer of 25 cm remains. With a density in situ (the density of peat when it is intact in the peatland) of 100 kg/m^3 and 50 kg C/m^3, we have 12.5 kg C/m^2	Kari Minkkinen: According to your model, in 70 years 6.9 kg C have been lost. Half of the original 12.5 is 6.25, which is lost in 46 yrs. So which figures are correct?	We explained better the model. We considered that of the total carbon left in cutaway previously forested peatlands, half is stable in the soil (never degraded). We deleted the sentence that before 70 years, 50% of the residual peat has been decomposed.
Figure 7: CO_2 emissions for the forestry after-use scenario (qualitative chart)	Kari Minkkinen: Please explain the values in red: 1100/980, in this first graph at least. What would be the reason for the initial increase from 980 (use) to 1100 (after-use)? Elke Meinken: I do not understand the two values in red	The increase from 980 g CO_2 /(m^2 .y) to 1100 g CO_2 /(m^2 .y) follows Hagberg and Holmgren, 2008. We deleted the qualitative chart because not clear, and we left only the quantitative chart.
CO_2 emissions for the forestry after-use scenario quantitative chart	Arina Schrier: Difference with fig. 7 is quite large: for the ' close-to-0' emissions the qualitative chart shows 186 years after extraction and the quantitative chart shows 100 years. Explanation?	We deleted the qualitative chart and we left only the quantitative chart, because more correct and clear.
It is assumed that N_2O emissions will be 0.15 g N_2O/(m^2 .y) after afforestation; they decrease linearly to 0.06 g N_2O/(m^2 .y) after 45 years and then remain constant at that level throughout a reference 100-year time horizon	Kari Minkkinen: What is the reason for the decrease? When new litter from the new forest increases soil organic matter, should it not rather increase? Plantation forests are also usually fertilised, which should increase N_2O emissions. Kari Minkkinen: Alm 2007 does not show any such trend.	This trend comes from Hagberg and Holmgren, 2008 (page 25 of the report). Hagberg and Holmgren state this trend is based on Alm et al, 2007. (page 25 of the report).

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We assumed that the CO_2 emissions from the cultivated cutaway peatland decrease exponentially from 1780 g CO_2 /(m^2 .y) (Hagberg and Holmgren, 2008).	Arina Schrier: Why choosing drained cultivated land as a ref? Is it common that agricultural land before peat harvesting will be again agricultural land after peat harvesting? Why not choosing the same reference point as for ' forestry' as ' after-use'?	We considered different possible scenarios for before use and after-use of a peatland. Agriculture can be both a before use category and after-use.
CO_2 emissions for the agriculture after-use scenario (quantitative chart)	Elke Meinken: The descent must be faster: 0 after 20 years	The quantitative chart is correct even if the qualitative chart was not so clear, so we deleted it. To make the chart we considered: - half carbon is stable in the peat soil (never degraded - as for the afforestation scenario). - CO_2 emissions from the cultivated cutaway peatland decrease exponentially from 1780 g CO_2 /(m^2 .y) (Hagberg and Holmgren, 2008).
The average uptake of the restored peatland is assumed to be 120 g CO_2 /(m^2 .y) (mainly based on Kirkinen et al, 2007 and Hagberg and Holmgren, 2008)	Kari Minkkinen: Notice that this is over two times higher than the value used for pristine peatlands. Could be right for a short period, but hardly for a longer one	Ok, thank you for the clarification.
The first year of the peat degradation has been supposed to take place during plants growing and it was included in the use stage.	Michal Hauschild: Don't the emissions from the following years of degradation belong in the end-of-life stage?	Yes, it is correct. We added the following sentence: Emissions occurring during the following years were included in the end-of-life stage.
We considered that 1.5% of nitrogen content is emitted as N_2O (Schmid et al., 2000)	Kari Minkkinen: I am not familiar with this Swiss report, but does it show actual measurement data from peat pots? Are there any data from peat pot N2O emissions It has been said earlier that bog peat (in situ) does not emit N2O. This despite the fact that it contains about 1% of organic nitrogen. So is this possible emission from the pots caused by fertilisation? N2O emission will not occur by itself. It usually requires denitrifying conditions and high N content. Therefore this is a very rough and probably a wrong assumption. Anyway, the values in the Figure 15 must be incorrect. The whole N_2O stock of black peat is 1.57 kg m-3. If 1.5% is emitted, this makes 0,0235 kg, cumulative emissions. Elke Meinken: The values on	Following available literature, N_2O emissions have been considered negligible in some cases, but in other they have been taken into account (as in drained forested peatland as before use). Schmid et al., 2000 does not refer specifically to peat, but it refers to a generic organic material. We corrected the charts in Figure 15. Thank you for the comment.

	the y-axis can't be correct. They must be much lower.	
2.7.3 Dynamic LCA and current LCA methodology	Arina Schrier: To me this seems the wrong place for this paragraph. Suggestion: bring it either to the introduction or merge it with another paragraph on LCA methodology. Also paragraphs are very unevenly in length. E.g. paragraph 2.7.3 is 4 pages, paragraph 2.7.4 s 2 sentences and is also not 1 of the 'indicators (Climate, resource, EQ, HH). Restructuring needed.	We applied the dynamic LCA to peat GHG emissions, so it seems to us that the best place is to collocate it next to the section related to the explications of the assumptions made for peat GHG.
Global warming impact assessment with current LCA methodology for a 100-year time horizon. GHG1 to GHGx stand for each greenhouse gas identified by the IPCC. E1 to Ey stand for the different emission sources (source: http://www.ciraig.org/dynCO2_en/).	Arina Schrier: I don't think this fig. is informative and/or clear. Perhaps better to insert a formula with GHGtotal = CO2*a + CH4*B + N2O*c with a, b and c the GWP's	We think this figure is complete from a scientific point of view because it considers all the GHG.
Temporal boundaries must be defined in addition to the usual system boundaries,	Arina Schrier: Or spatial boundaries?	Yes, the usual system boundaries are spatial boundaries.
By choosing a 100-year time horizon for GWPs, one considers only the radiative forcing occurring during the 100 years following the emission. After that timeframe the radiative forcing of each gas is implicitly considered being zero.	Michael Hauschild: I know that this interpretation is widespread but I would like to challenge it. The fact that a 100 year time horizon is chosen as the basis for calculating the relative GWPs (ratio between the absolute GWP of the GHG and CO2) is nowhere explicitly reasoned in the wish to ignore any impacts occurring after 100 years (as also stated by Shine et al.), and it might just as well be interpreted as assuming that the ratio between the impact of the gases is the same after 100 years as it is up to 100 years. (This is of course not the case but it is also not the case that there will be no impacts after 100 years).	This is right. Thank you for this clarification.
In more detail, we considered that the peat extraction starts at the year 0. The peat extraction occurs during 50 years.	Kari Minkkinen: It is very long period, considering peat production in Finland, for example (20 yrs). Should there be a sensitivity analysis, for looking at the impacts of shortening this period.	The chosen period has been calculated through a weighted average of all the data collected from the different countries.

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CO_2 emissions for peat extraction and after-use scenario with a time horizon of 100 years. Example of forestry as after-use.	Michael Hauschild: Please explain the meaning of the red and blue lines and the different types of dotting	The blue line represents the CO_2 emissions trend during extraction and after-use, while red line represents the impacts before harvesting (weighted average for the different sites). We added an explication.
CO_2 emissions for end-of-life of white peat with a time horizon of 100 years. Model based on Cleary et al., 2005	Kari Minkkinen: which peat? or black and white peat average?	White peat. We explained it.
GHG emissions are caused by an oxidation of the peat in situ that causes a degradation of the peat resource. This degradation has been calculated beginning from the upper heating value of black and white peat reported in Table 4 (an average value for black and white peat of 10.55 MJ/kg CO_2 has been considered).	Michael Hauschild: Is this additional to what occurs from the peat when the bog is undisturbed?	Yes, it is the degradation occurring during peat harvesting.
In this study four options are included: restoration, rehabilitation, afforestation and agriculture	Michael Hauschild: Insert relevant chapter reference	Ok, we did it.
This is the scenario represented by the pre-harvesting conditions of the peatland. Impacts from this stage are considered to be avoided (therefore the subtraction in the equation). The type of peatland will determine the level of biodiversity in the reference scenario.	Michael Hauschild: Why would there be a change of biodiversity in the reference scenario – because the bog is not in steady state as concerns biodiversity?	There is no change of biodiversity in the reference scenarios. Biodiversity of before harvesting conditions is used as a reference, to calculate biodiversity changes of a peatland during harvesting and after-use. References scenarios are considered as avoided impacts, the approach is the same as climate change.
Reference scenarios have been subtracted by assuring that the agriculture as before use has not been moved elsewhere	Michael Hauschild: I don't understand this, please rephrase	The transformation of a drained cultivated peatland into an extracted peatland could cause the shift of the cultivated peatland elsewhere. In that case you would only move emissions of cultivation and at the same time you would have emissions from peat extraction. We assumed that emissions from a drained cultivated peatland are not moved elsewhere after a peat bog opening. Anyway, we deleted the sentence as it was not clear and very useful for the understanding of the reader
The unit used to express the Ecosystem quality indicator in IMPACT2002+ is PDF/(m2 .y).	Michael Hauschild: Should be PDF.(m2 .y) i.e. proportional to both pdf, area and duration	OK, we corrected it.
• *Degraded peatland has a biodiversity equal to 10% of the pristine*	Arina Schrier: Have assumptions been based on literature? If so, please add	The following approach (based on expert judgment working assumptions) has been developed

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bog biodiversity; • *Drained cultivated peatland has a biodiversity equal to 25% of the pristine bog biodiversity;*	refs. If not, were are ass. Based on?	internally at Quantis by the experts that have co-authored the IMPACT 2002+ methodology, integrating inputs from discussions with Dr. Heinrich Höper (expert on GHG emissions from peatlands) and outcomes from available literature on GHG for peat (Hagberg and Holmgren, 2010; Alm et al., 2007). We wrote this explication in the report.
The following approach (based on expert judgment working assumptions) has been developed internally at Quantis by the experts that have co-authored the IMPACT 2002+ methodology, and outcomes from available literature on GHG for peat (Hagberg and Holmgren, 2010; Alm et al., 2007).	Kari Minkkinen: Really? What do these publications have to do with biodiversity? There are articles about peatland biodiversity and management impacts, e.g. Laine et al. 1995 (J.app. Ecol. 32:785-802).	Ok, we deleted the sentence. We reformulated it by writing: integrating inputs from discussions with Dr. Heinrich Höper (expert on GHG emissions from peatlands).
Figure 18: Conversion from reference scenario biodiversity level to land use impact scores. Working assumptions.	Michael Hauschild: Previous figure had number 18? Figures need to be renumbered from here	OK, we did it.
Figure 22 reports land use impact scores trends for restoration.	Michael Hauschild: No, it does not. Do you mean Figure 23?	Figure 20. We corrected it.
2.7.6 Black and white peat transport to mixing plant	Arina Schrier: I would expect a paragraph on the indicator Human Health, of which transport is a part.	In this session we present the assumed data, we do not present the method IMPACT2002+ and its indicators. We presented CO_2 assumptions made for peatland, assumptions made to IMPACT2002+ impact assessment method for the Ecosystem quality, and other assumptions made to transports, etc.
2.10 Data and assumptions for all the growing media constituents (other than peat)		
Table 6: Bulk densities and moisture contents of the different growing media constituents analysed in this study	Kari Minkkinen: You should use the term "bulk density" as dry mass/fresh volume, i.e. no water included in the mass. If you do not, this may lead to misinterpretation that the C% given, is of the fresh mass, when it should be from the dry mass. Elke Meinken: To avoid misunderstanding the bulk density should be given both on fresh and dry weight basis	Ok, we specified fresh and dry bulk densities.
1 Coir pith production and processing	Michael Hauschild: section 2.8.2?	Yes, we corrected it.
2.8.5 Perlite production and processing *Primary data includes*	Kari Minkkinen: I guess the land use-change impacts (loss of green area, biodiversity	We considered land use occupation impacts, they are secondary data coming from

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extracted area, fuel consumption and machines used.	etc?) of perlite mining are small, but are they insignificant?	ecoinvent (perlite, at mine). Land use occupation is not insignificant if we consider Ecosystem quality indicator.
Data concerning rice cultivation and harvesting, rice drying and refining come from Blengini et al., 2009.	Kari Minkkinen: How did you allocate the land-use impacts to the hulls? 100%, proportion of masses or something else? OK, by market price. Add here a reference to chapter 2.10. to help the reader.	Ok, we added the text: Economical allocations reported in Table 15 were used for the different by-products.
Density of rice hulls has been defined equal to 110 kg/m^3 (dry material).	Elke Meinken: 110 kg/m^3 is for fresh material	Ok, we corrected it.
Concerning N2O emissions during degradation, we considered that 1.5% of nitrogen content is emitted as N2O (Schmid et al., 2000).	Kari Minkkinen: N_2O emission will not occur by itself. It usually requires denitrifying conditions and high N content. Therefore this is a very rough and probably wrong assumption	As constituents have a nitrogen content, they could emit N_2O during their degradation. We considered here the conservative assumption that this emission could occur.
Table 10 (previous Table 7): Distances for distribution of growing media to final customer	Arina Schrier: Do I understand it correctly that this is the distribution (equal distances for the diff. growing media) after mixing and table 7 shows transport distances before mixing?	This is the distribution after mixing plants while table 7 (that now is Table 10) shows transport distances before to mixing plants.
2.10 Allocation rules		
Table 12: Economical allocations factors used in this study	Michael Hauschild: So how are these used – should they be multiplied by the first-order by product allocation factor?	The whole coconut has 2 by-products, nuts and husk, with 58% and 42% as economical allocation factors, respectively. The husk has 2 other by-products: fibres and coir pith, with 73% and 27% as economical allocation factors, respectively. Consequently, 2 processes were built in Simapro: the first was husk production (with the whole coconut as input) while the second was coir pith production (with the husk as input). Please refer to Appendix A for more details. We added an explication in the caption of the table.
Table 12: Economical allocations factors used in this study	Michael Hauschild: Why do these differ from the allocation factors for wood by-products in Table 11?	Ok, we corrected them.
2.11 Life cycle impact assessment method		
2.11 Life cycle impact assessment method	Arina Schrier: Merge with paragraph 2.7.3?	The LCA report must follow the ISO structure: first data and assumptions, data quality assessment, allocation procedures and after the impact assessment method and finally the results.

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The IMPACT 2002+ method is applied both at midpoint and at damage level. *The 18 midpoint categories considered are:*	Arina Schrier: Additional information can be found in Humbert et al 2009 etc, however, I would expect at least a categorized (per impact category) input parameter set. The list on page 68 is nice, but a table per indicator would be much better. Model uncertainties?	Ok, we added a table describing which midpoint contributes to each endpoint (Table 16: Midpoint and damage category considered in IMPACT 2002+ method).
The six damage categories considered are: *• Human health* *• Ecosystem quality* *• Climate change* *• Resources* *• Water withdrawal* *• Water turbined (i.e., for hydropower)*	Michal Hauschild: Climate change is also not a damage category – it is only modelled till midpoint and is as such the same as the midpoint category global warming.	Ok, we added the Table 16: Midpoint and damage category considered in IMPACT 2002+ method.
2.12 Data Quality Analysis		
Reliability: (also called precision)	Kari Minkkinen: "precision" does not tell if data is biased	Ok, we deleted the word precision.
2.13 Critical review process		
2.13 Critical review process	Kari Minkkinen: took part to the last round only.	Ok, we added this sentence: The four expert took part to the last round only.
3 Results & Discussion		
3.2 Comparison among growing media at damage level		
Comparison among growing media at damage level	Arina Schrier: This is not true. Climate change is not the same as carbon footprint. N2O for example has nothing to do with carbon footprint. Would change wording here. The indicator (or the factor that is being influenced) is ‘ climate’ as mentioned before, not climate change.	Ref. Climate change: this is the name of the damage category of IMPACT2002+. Carbon footprint, as we usually use, accounts for main greenhouse gases as CO_2, CH_4, N_2O. Anyway, we deleted it.
Figure 29: Results for growing media within application 1 (chart for Climate change)	Elke Meinken: Please use the same scale on the y-axis as in figure 32-35	If we use the same scale for Climate change results for application 1, we cannot see anymore the differences of the impacts among Mix 1.1, 1.2 and 1.3. That is why for this chart we used a different scale. Please consider that the aim is not to compare chart for Climate change for the 1st application with climate change results for the 2nd application, but to compare mixes within same application only. That is why we prefer to give the possibility to the reader to see the differences among the impacts of

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		the different mixes within same application. Anyway, we applied the same scale to the other charts, when possible.
	Arina Schrier: For all figs: please give the graph a meaningful title and give the Y-axes a right name and units. E.g. the graph Application 1: Growing media for fruity veg. Ecosystem Quality (PDF*m2*y/m3)means now that the ecosystem quality of mix 1.3 is high, which is not true. What is meant is that the impact on EQ is high in mix 1.3. Another point: Why is there no information on uncertainties of the estimates? Uncertainty needs to be tested before you can say something on significance of differences. In the tekst often the word ' significant' is used, with no underlying information. Are T-tests being performed,a nd at what P-level? How is the model undertainty? Why not error bars in the figs? Another point: in the figs. Of ' climate change' the titel is not correct. Climate change is not expressed in kg CO2 eq/m3, but emissions are. Climate change is usually expressed in degrees temperature increase and other climatic variables. Would change the title in ' emissions of greenhouse gases'…	Ecosystem quality is the name of the indicator in IMPACT 2002+ (Jolliet et al. (2003) and Humbert et al. 2010). Same thing for Climate change. Concerning the uncertainty analysis, we performed it. Please refer to section 3.5.
Peat land use impacts have been calculated considering instead 4 different categories of before use (as explained in paragraph 2.7).	Elke Meinken: Which of the 4 categories is taken for the calculations in figure 31 – 35? Or did you take the mean of the 4 categories?	We considered a weighted average of the 4 categories. This average has been calculated on the basis of the information collected through the questionnaires by the EPAGMA companies.
Furthermore, the underlying inventory data has higher uncertainties for Human health and Ecosystem quality than for Climate change. This has to be taken into account in analysing these results. Differences in Climate change results may be statistically significant, contrary to differences in Human health and Ecosystem quality that, for	Michael Hauschild: Could you be more specific: could the observed differences in ecosystem quality in Figure 31 be insignificant?	Ok, we performed an uncertainty analysis. Please refer to section 3.5.

the same relative value, might probably be statistically insignificant due to large assessment uncertainties.		
Figure 30: Results for growing media within application 2	Elke Meinken: Please use the same scale on the y-axis as in figure 31	Ok, for Ecosystem quality indicator we used the same scale for all the applications, because we can see differences among mixes results even if we change it.
For Human health, relatively speaking the Mix 3.2 has the highest impacts even if, considering the uncertainties associated to this indicator (as above mentioned), differences are not very significant.	Arina Schrier: What is not very significant?!?! Also earlier in this chapter the word 'significant' is used improperly. Michael Hauschild: Please be consistent and more precise here, if you can. If differences for Human health (and ecosystem quality) are not significant for applications 1 and 2, they are certainly not significant here either	Ok, we reformulated by avoiding the use of the word significant.
For Human health, the mix that seems to stand out from the others is the Mix 4.1 (50% white peat, 30% green compost, 20% rice hulls) because of the high quantity of green compost, that highly contributes to those two indicators because of the emissions of N-compounds from the processing.	Michael Hauschild: Difference to mix 4.4 is not larger than difference between mix 4.4 and mix 4.2.	Ok, we reformulated the interpretation of the results.
If we consider Human health, we can say that mixes do not show significantly different impacts. Mix 5.3 (100% peat) has impact lower than the other mixes, even if the difference is not very significant, while Mix 5.4 (10% bark, 30% green compost, 20% wood fibres, 10% rice hulls, 30% coir pith) seems to stand out from the others.	Michael Hauschild: You just said that there is no significant difference?	Ok, we reformulated by avoiding the use of the word significant.
3.3 Detailed results for black and white peat		
Figure 34 and 35 report the contribution of each stage to the global impacts for black and white peat. We present here the following indicators: Human health, Ecosystem quality, Resources, Climate change, and the midpoint categories Aquatic acidification and Eutrophication.	Michael Hauschild: The patterns are so alike for the two peat types that I suggest you consider to discuss they jointly in order to avoid much repetition	Ok, we discussed them jointly.

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Ecosystem quality: the most impacting stages are distribution, processing and extraction. Distribution impacts depend on distances and quantity transported. Transportation work is expressed in kg.km. Consequently, the higher the density of the constituent, the higher are the impacts. That is why distribution impact for black peat is higher than for white peat. Same considerations as white peat can be done for the other stages.	Michael Hauschild: Not clear which considerations	Ok, we reformulated.
Aquatic acidification and aquatic eutrophication: most impacting stage is the distribution because of the emissions during transports.	Kari Minkkinen: A new damage category? Arina Schrier: Not consistent with the indicators that/damage categories of page 69. Is this not included in ecosystem quality?	Ok, we deleted these two indicators (midpoint categories) in order to be consistent with previous damages categories presented for mixes.
Climate change: the most impacting stage is the end-of-life.	Kari Minkkinen: Please check the N2O parameter values (see fig. 15).	OK, we checked and corrected them.
Application 1: Mix 1.1 (100% peat) decreases its impacts and differences to other mixes increase significantly. Ranking continues to be the same. *Application 2: Mixes 2.1 (50% black peat and 50% white peat) and 2.2 (80% white peat and 20% perlite) significantly decrease their impacts, but ranking remains the same.* *Application 3: Mixes 3.1 (20% white peat and 80% black peat) and 3.4 (80% white peat and 20% perlite) significantly decrease their impacts and the difference between them increases, making Mix 3.1 less impacting than Mix 3.4 (because Mix 3.1 contains more peat).*	Michael Hauschild: I suggest that you restrict the use of the term “significant” to statistical contexts that when you discuss whether a difference is statistically significant or not	Ok, we reformulated by avoiding the use of the word significant.
3.4 Sensitivity analysis results		
Figure 38, Figure 39 and Figure 40 report results calculated using ReCiPe impact assessment method (ReCiPe World H/H).	Michael Hauschild: You must explain what World H/H is, e.g. in a footnote.	Ok, we added this explication in footnote: ReCiPe World H/H refers to the normalization values of the world with the weighting set belonging to the hierarchic perspective. More information on http://www.lcia-recipe.net/.

3.4.2 Sensitivity analysis 2: use of ReCiPe method instead of IMPACT2002+Ranking of the other Mixes (3.2, 3.3 and 3.4) is opposite with IMPACT 2002+ results	Elke Meinken: This is not true: see figure 33	Ok, we reformulated it as follow: Ranking of the other Mixes (3.2, 3.3 and 3.4) is in line with IMPACT 2002+ results
Application 5: 5.4 is the least impacting followed by 5.1, 5.3 and 5.2 (20% bark and 80% black peat). According to IMPACT 2002+, the least impacting is 5.3 (40% white peat, 60% black peat), followed by 5.4. Mixes 5.1 and 5.2 are the most impacting and they have almost same results.	Elke Meinken: This is not true: see figure 35	Ok, we reformulated.
Concerning the Human health indicator, green compost decreases its impacts, while wood fibres increase. These differences change the ranking for growing media containing these constituents.	Elke Meinken: I can't catch it. Please give an example.	Ok, we reformulated and added an example.
Table 14: Sensitivity analysis scenarios for bark allocation factors	Michael Hauschild: Difference between Reference scenario and Sensitivity analysis 1?	We corrected the figures in the table for reference scenario.
3.4.4 Sensitivity analysis 4: Ecosystem quality indicator with pristine bog as reference scenario	Kari Minkkinen: It is unclear to me how were the different scenarios in peat calculated. Was the white/black peat impact an average impact of all possible reference scenario-harvesting-after-use chains? Or how??? Please add description in methods.	Main results of the study consider a weighted average of the different before use and after-uses scenarios (as explained in section 2.7.2). Results presented in sensitivity analysis 4 takes into account only one type of reference scenario: the pristine bog.
4 Conclusions		
General remark	Arina Schrier: See remarks on the first pages. General remark: EPAGMA wants to understand the environmental impacts associated with the composition of the growing media for the various applications (fruity veg., pot plants etc): the link to application is missing in the conclusion. I would add a table with the mixes per application and then the results for the 4 impact categories and maybe a ranking on which mix has the lowest impact.	Ok, we reformulated the conclusions. We added general conclusions for growing media.

	Arina Schrier: Not the growing media in itself have impact, the harvesting, processing, distribution, use and degradation have impact.	When we talk about the growing media impacts we talk about the life cycle impacts of the growing media.
To reduce impacts of a growing media we could therefore imagine changing the growing media composition, substituting one constituent with another. It is however important to consider that this may influence the function of the mix and, as stressed in the report, growing media are comparable only if they fulfill the same function. If we change the growing media composition, we might not have the same growing conditions and consequently they would be not comparable anymore. This is why the constituents were not directly compared in this study and why they shouldn't be. *For the professional grower in the horticultural industry, the most important factor is that the growing medium functions well under the growing conditions (Altmann, 2008). The choice of a growing media composition is limited by technical considerations. In substituting a peat-based mix by a peat-free mix it is wise to consider whether the obtained crop quality is the same. If it is not the case, growing media are not comparable because they are not functional equivalent.*	Michael Hauschild: A lot of repetition of the importance to maintain functional equivalence for comparisons – remove redundancy	Ok, we reformulated the conclusions by separating them into 2 parts: conclusions of the study and outlook. We tried also to avoid redundancy, trying to stress less on the importance to maintain equivalence.
Choice of growing media is mainly influenced by the type of soil and the type of crops	Elke Meinken: I don't understand, because growing media are used instead of soil.	Ok, we reformulated as follow: Choice of growing media is mainly influenced by the type of crops.
Growing media constituents, other than peat, play and will continue to play a subordinate role as compared with peat.	Kari Minkkinen: Unless environmental legistlation to prevent the use of peatlands should occur, which is a possibility and probably one reason for doing this study in the first place.	Yes, this is true.
Cleary, J et al. (2005) Greenhouse Gas Emissions from Canadian Peat Extraction, 1990-2000: A Life‐cycle Analysis, Ambio, volume 34, issue 6, pp.	Elke Meinken: Please name all authors. Kari Minkkinen: Please give all author names.	Ok, we reformulated as follow: Cleary, J., Roulet N., Moore T.R. (2005) Greenhouse Gas Emissions from Canadian Peat Extraction, 1990-2000: A Life‐cycle Analysis, Ambio, volume

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456-461		34, issue 6, pp. 456-461
Appendix G: Summary of GHG emissions for black and white peat		
Figure 57: GHG summarized emissions for black and white peat (GWP 100 years)	Michael Hauschild: Why only totals for white peat and not black peat?	The aim of this chart is to allow the reader to calculate black or white peat impacts by using different reference and after-use scenarios combination. Total impacts for white peat are given as example of calculations only. Same calculations could be done for black peat but they are not shown for lack of space.
	Kari Minkkinen: Is the presented GHG impact (e.g. 31, mix 1.1) the average of the three green total-bars?	Peat of Mix 1.1 considers a weighted average of all the reference scenarios and after-uses. Consequently, it does not take into account only the 3 scenarios presented as example in Appendix G.
	Kari Minkkinen: Values in the end-of-life are not the same as in Fig. 14, where CO2 has values of 200 and 130 (here 180 and 90)?? In addition there were impacts of N2O emissions.	Figure 59 represents the Climate change indicator results, while Figure 14 represents only CO2 emissions. Figure 59 takes in consideration all the greenhouse gases, i.e. CO2 and N2O for peat calculated with a dynamic approach, i.e. a variable weight (characterization factor) over time of each greenhouse gases.

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Appendix F: System boundaries of the constituents

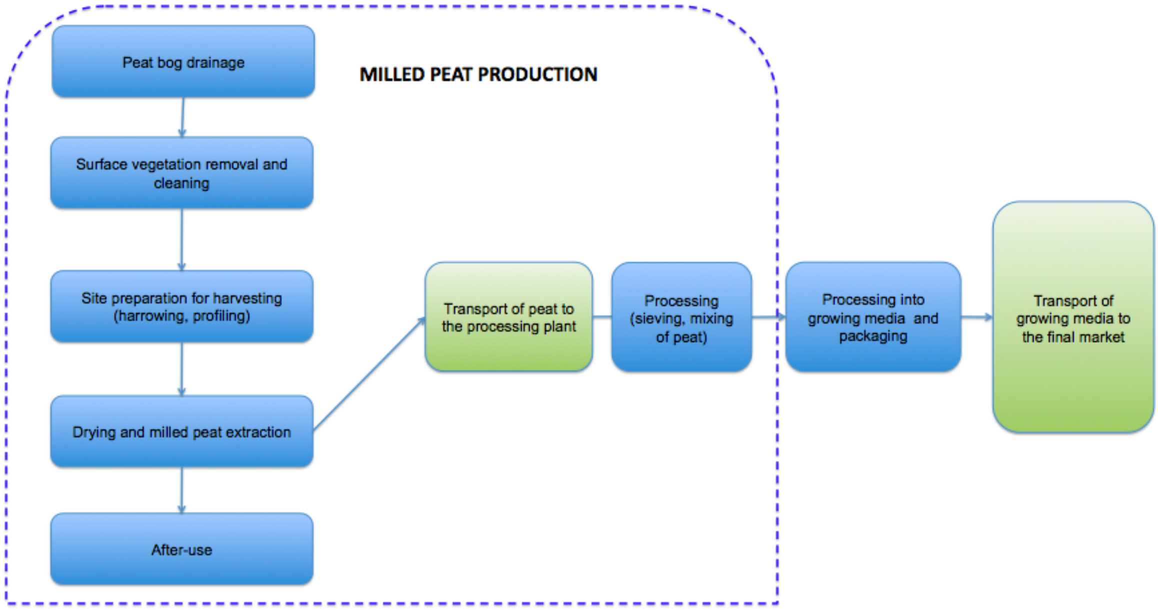

Figure 52: System boundaries of milled peat production

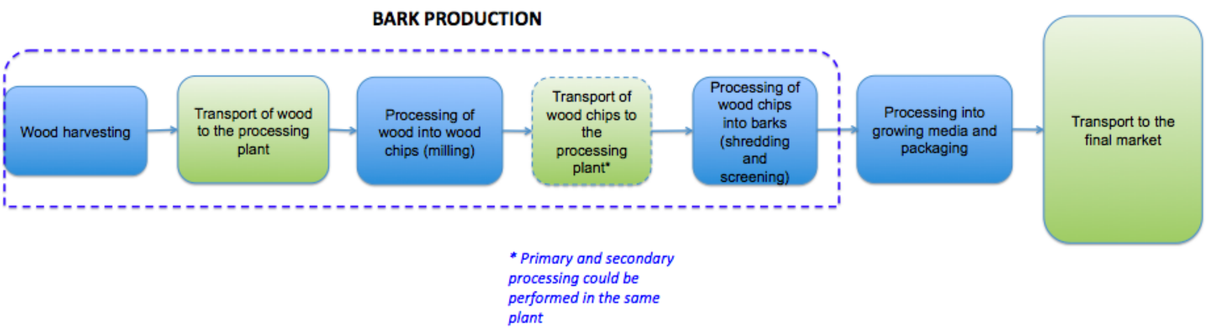

Figure 53: System boundaries of bark production

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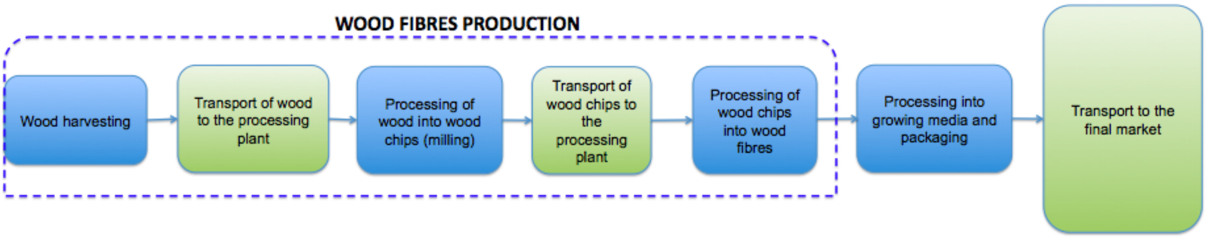

Figure 54: System boundaries of wood fibres production

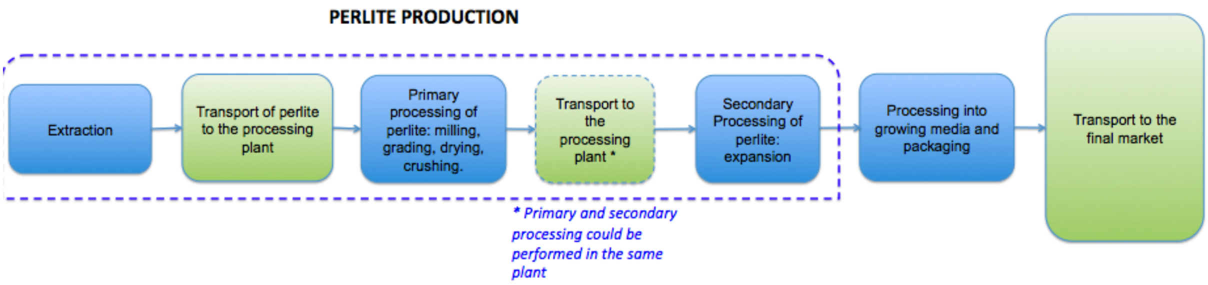

Figure 55: System boundaries of perlite production

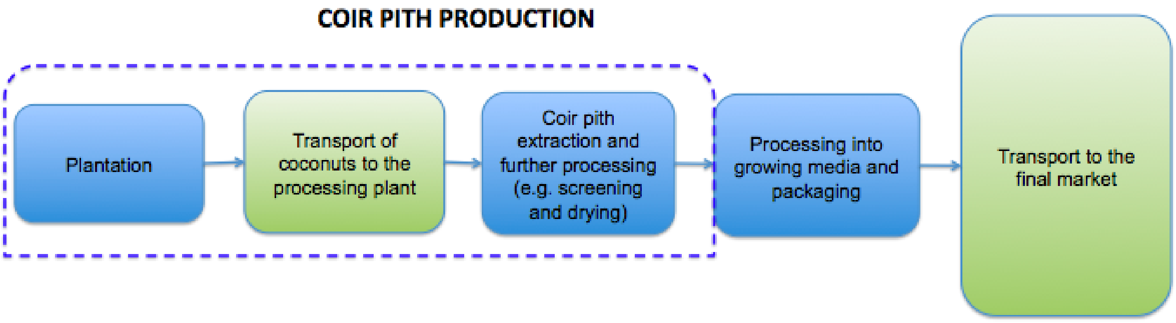

Figure 56: System boundaries of coir pith production

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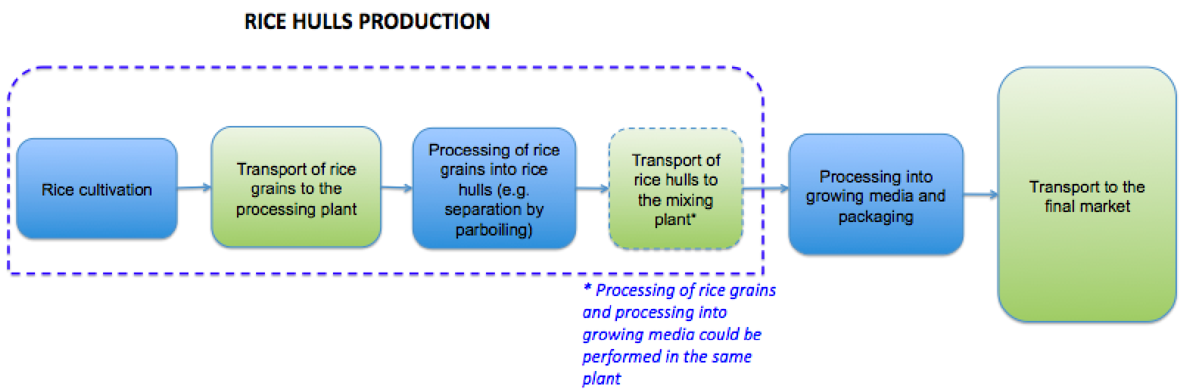

Figure 57: System boundaries of rice hulls production

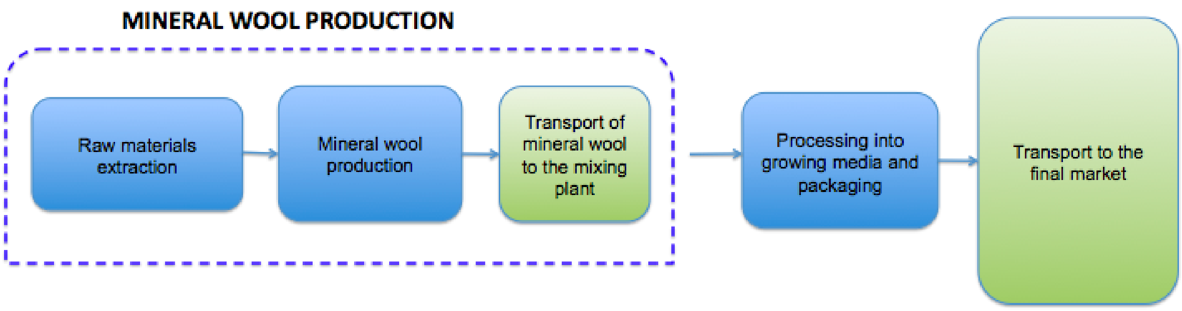

Figure 58: System boundaries of mineral wool production

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Appendix G: Summary of GHG emissions for black and white peat

Figure 59 reports a summary of GHG emissions for each stage of black and white peat life cycle. These results are not averaged and so the sum of all the stages impacts does not give the total impact. It is possible to calculate its own impact by considering the proper percentages of before use categories and after-uses objectives realization. Reference scenarios are represented with negative values because they are avoided impacts and have to be subtracted to the total impact.

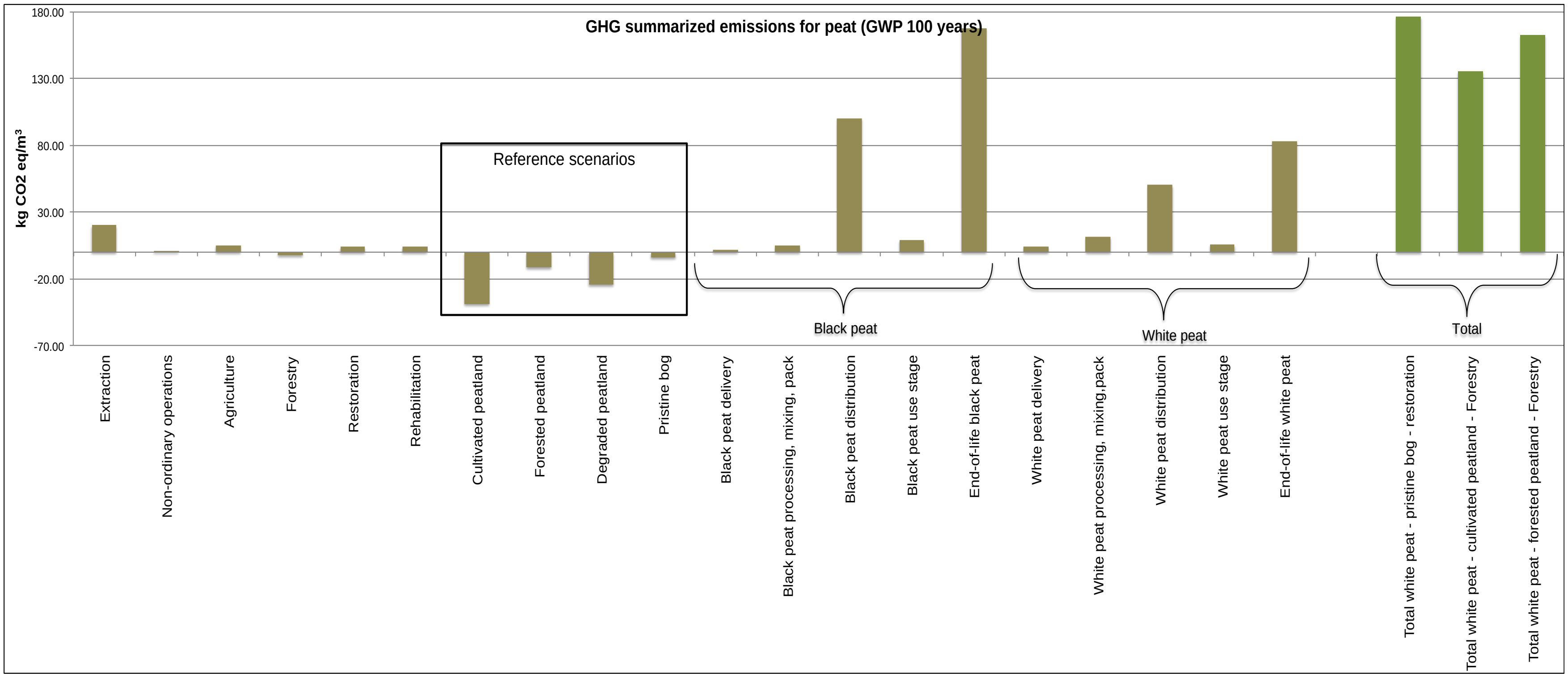

Figure 59: GHG summarized emissions for black and white peat (GWP 100 years)

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Appendix H: Compost characteristics and main assumptions for waste degradation

Input elemental composition (g/kg)	
Total water	500
Total C	290
Total H (anhydrous)	38
Total O (anhydrous)	145
Total N	10.0[25]
Total P	3.35
Total K	12.15
Total others	1.5
C/N ratio	30
Input chemical (non-water) composition %	
Lignin	16%
Cellulose	81%
Lipids	1%
Proteins	0%
Sugar/starch	0%
Ashes	2%
C degradation	
% of C degraded	30%
Fraction into CH4	0.40%
Fraction into CH3-CH2-OH	0%
Fraction into CO_2	99.6%
H degradation	
% of H degraded	30%
O degradation	
% of O degraded	30%
N degradation	
% of N degraded	24%
Fraction into NH3	90%
Fraction into N2O	5%
Fraction into N2	5%

[25] High uncertainties on the initial composition and high sensitive of the model to the N content

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