Securing Sustainable Dendromass Production with Poplar Plantations in European Rural Areas

Call: H2020-BBI-JTI-2016

Grant Agreement Number: 745874

Deliverable

D5.2 Integration of LCA in value chain establishment: Methodological approach

Deliverable type:	Report
WP number and title:	WP5 (Life Cycle Assessment)
Dissemination level:	Public
Due date:	30.09.2019
Lead beneficiary:	Wood K plus
Lead author(s):	E. Alejandro Perdomo (Wood K plus), Daniela Fürtner (Wood K plus), Franziska Hesser (Wood K plus)
Contributing partners:	IKEA Industry, Energochemica
Reviewers:	Matthias Meyer (TU Dresden)

Document History

Version	Date	Author/Editor	Description
0.1	13.09.2019	Alejandro Perdomo, Daniela Fürtner, Franziska Hesser	Initial draft and version for revision
0.2	26.06.2019	Matthias Meyer	Revised version
0.3	30.9.2019	Alejandro Perdomo, Daniela Fürtner, Franziska Hesser	Final version submitted

List of Abbreviations

Abbreviation	Denotation
AoP	Areas of protection
CED	Cumulative energy demand
CTL	Cut-to-length harvesting
D4EU	Dendromass4Europe
DLUC	Direct land use change
EoL	End of Life
ERP	Erosion Regulation Potential
FEU	fossil energy use
FU	Functional unit
GHG	Greenhouse Gasses
GWP	Global warming potential
ILUC	Indirect land use change
IPCC	International Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LWB	Lightweight Board
MDF	Medium density fibreboard
NBBM	New bio-based material
NBBM 1	New bio-based material 1 (Functionally Adapted Lightweight Board, FA-LWB)
NBBM 2	New bio-based material 2 (Eco-Fungicidal Moulded Fibre Parts)

NBBM 3	New bio-based material 3 (Bark-enriched wood plastic composite (WPC) profiles)
NBBM 4	New bio-based material 4 (Bark-enriched wood plastic composite (WPC) granulate)
NRCED	Non-renewable cumulative energy demand
ODT	Oven-dry tonne
PFEU	Primary fossil energy use
PLA	Polylactic Acid
PP	Polypropylene
R&D	Research and Development
SB	System Boundary
SE	System expansion
SEU	Secondary energy use
SRC	Short Rotation Coppice
TRL	Technological Readiness Level
TUD-ISSE	Institute of Soil Science and Site Ecology
USL	Universal soil loss equation
WP	Work package
WPC	Wood-plastic Composite
WPCG	Wood-plastic Composite Granulate

Bio-based Industries Consortium
Horizon 2020 European Union Funding for Research & Innovation
This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

Table of contents

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

1 Role and relevance of the deliverable within the project

Dendromass4Europe (D4EU) has the **mission** to establish sustainable, Short-Rotation Coppice (SRC)-based regional dendromass cropping systems on marginal land that feed into bio-based value chains and create additional job opportunities in rural areas.

In order to highlight the role and contribution of short rotation coppice (SRC) bio-based materials towards a European bio-economy, it is of importance to study the potential environmental impacts of the dendromass production and the four new bio-based materials (NBBM).

Dendromass4Europe follows the approach of accompanying the R&D activities and the value chain establishment with environmental (task 5.3) and socio-economic (task 5.3) assessments as well as eco-efficiency analysis (task 5.4). For this reason, a work package 5 “Life Cycle Assessment” is dedicated to this approach. The objectives set out for the LCA comprise:

- Establish an environmental system analysis for four NBBM in parallel to value chain creation (Lightweight board, moulded packaging material, bark-enriched wood plastic compound);
- Derive possible ranges of results on environmental aspects of SRC dendromass based materials of the four NBBM;
- Identify the scope for further system improvement in terms of eco-efficiency (link to task 5.4).
- Provide information to all project partners for the environmental optimization of the value chains to be developed.

The R&D activities and the value chain establishment are accompanied with environmental and socio-economic assessments. It is the aim to define a mutually accounting framework for the LCA (ISO 14040 series) and the socio-economic assessment (regional value added) in order to link the findings of the value chains. With that the metrics of eco-efficiency can be illustrated, which allows direct comparisons of the sustainability and supports the integrative hot spot analyses. Expected methodological options in LCA will be encountered systematically by sensitivity analysis. It is the aim to illustrate a possible range of results (NBBM 1-4) instead of a single point result which enhances system understanding and improvement towards sustainability.

The first step of an LCA study is to develop an adequate methodological framework. Thus, this progress report, which will be updated and finalized as D5.2 according to the DoA, presents an initial LCA framework. As LCA is inherently an iterative process, the continuous collection of data during the research and development (R&D) advancements of the project, will result in methodological adaptations. The iterative character of the LCA study will help on reflecting the R&D advancements and will support guiding the four new bio-based value chains towards optimizing environmental (task 5.2) and social (task 5.3) sustainability. This first progress report of Deliverable 5.2 illustrates the initial starting point for building the LCA model which is subject to iterative refinement through the project duration along with R&D advancements. The following is addressed:

- Implementation of goal and scope of the study;
- System boundaries are proposed as initial starting point for the iterative refinement;
- Definition of the functional unit and reference flows;
- Selection of environmental impact categories to begin with;
- Illustration of scenarios for the sensitivity analyses.

The results of this task are of value for the following WP’s:

- WP2 (Plantation operation and production stability – Task 2.3 (Harvesting and transportation)
- WP3 (NBBM 1, wood base: Functionally adapted LW board) – Task 3.1 (Industrial Scale Production Trials), Task 3.3 (process impact analysis)
- WP4 (New bio-based materials 2,3,4 (barked based)) – Task 4.5 (Developing a cost-effective technology for the separation of the fungicidal extract from the bark, Task 4.6 (Successful industrial production of sample moldings with natural fungicides) Task 4.8 (Testing and industrial production of prototypes adding correct proportions of the added components)
- WP5 – Task 5.3 (socio economic assessment) and 5.4 (eco-efficiency and hotspot analysis)
- WP7 (project management)

2 Project, task and research objectives

Dendromass4Europe (D4EU) aims at establishing sustainable, SRC-based regional cropping systems for producing agricultural dendromass on marginal land that feed into bio-based value chains and create additional job opportunities in rural areas.

The establishment of SRC for bio-based materials will not only provide new economic opportunities. Broad SRC research and development activities of the recent decades have shown several environmental advantages that arise mainly from the specific, multi-annual character of the SRC crops that allows a reduction of agricultural effort and impact while improving habitat, soil and groundwater quality of an agricultural landscape. Among the most common positive effects, the optimized energy-input to energy-output ratio of the cropping system (Manning et al. 2015), carbon sequestration, and reduction of greenhouse gasses (GHG) emissions compared to non-renewable production systems, are highlighted (Döpke, Moschner, and Hartung 2013; Griffiths et al. 2019). Besides these benefits, the establishment of SRC and the bio-based value chain also involves environmental challenges, as potentially reduced groundwater recharge, tilling of grasslands (Döpke et al. 2013). These must be analysed in order to provide guidance on the establishment of sustainable SRC value chains. In order to realize the key opportunities of improved eco-efficiency and ecologically compatible dendromass production and subsequently production of bio-based materials integrated research on the environmental performance is essential. Thus, through modelling and understanding the environmental performance of the D4EU production system, it is possible to derive knowledge based guidance to support decision making along the technical R&D of the project to mitigate environmental hot-spots or encounter environmental trade-offs.

The LCA attempts to identify sustainability levers within the value chains. These outcomes are of core value for the industrial partners and project developers, as the conclusions aim to support the decision-making of the different technological processes, and production management decisions from an environmental point of view – aiming at revealing the environmental and socio-economic optimization potentials of the value chains. Moreover, the findings will support the sustainability assessment of the value chain, which is related to tasks 5.3 (socio-economic) and 5.4 (eco-efficiency).

Consequently, as a first step of the LCA study (task 5.2), the objective of the progress report of task 5.2 is to develop and depict the initial methodological approach for performing the environmental assessment. A literature review on previous LCA studies, especially those focusing on bio-based systems, and R&D LCA was carried out in order to review the state-of-the-art.

3 Theoretical background

The environmental assessment method considered is developed using a system thinking approach, bearing in mind the LCA methodology described in the ISO 14000 series standards (ISO 2006). The LCA framework is used to assess the potential environmental impacts related to the different stages of a product life cycle, ideally, it covers all the processes involved from the extraction and production of raw materials, transportation, production of products, use phase and end of life phase (Tillman and Baumann 2004). The ISO 14040 standards (ISO 2006b) have been used as a reference for almost all practical and foundational work related to LCA. The standards present the main structure and guidelines carried in an LCA study. However, owing to the obvious increasing gain of knowledge on environmental assessment, the ISO standards, which are already more than a decade old, do not always cover all the latest methodological advances (Heijungs, Huppes, and Guinée 2010). Nevertheless, this approach has been widely recognized as one of the most important decision support tools for identifying environmental impacts in products systems (Klöpffer and Grahl 2014; Tillman and Baumann 2004).

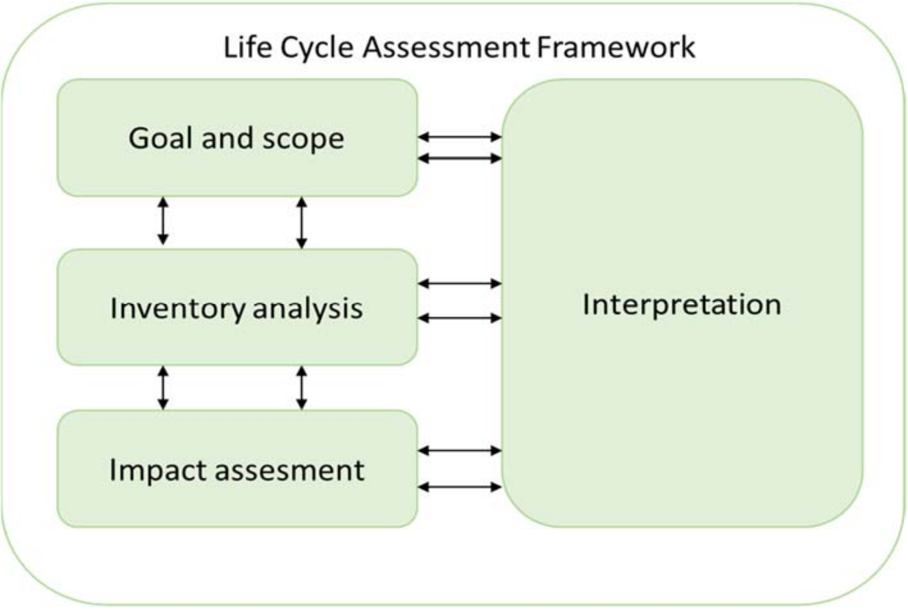

Figure 1 LCA Framework according to ISO 14040 (ISO 2006b)

The general ISO-LCA framework is represented in Figure 1. It consists of four interlinked phases, as: goal and scope, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and interpretation.

1) The first phase, goal, and scope, gives a clear description of the intended application of the study, it states the reasons why the study is being carried, the intended audience, the system to be studied, the functional unit and system boundaries, among other important matters.
2) The inventory analysis consists of collecting data of inputs and outputs of the studied system or product within the defined system boundaries.
3) As for the LCIA, this phase focus on translating the data from the LCI into their potential environmental impacts defined in the LCA
4) The last phase, life cycle interpretation, is where the findings of the previous phases are assessed regarding the defined goal and scope of the project. A more detailed description of each phase can be found in the ISO guidelines (ISO 2006a).

LCA is an iterative approach, meaning that each phase feeds and contributes to each other to reach a consistent and comprehensive study and results. The present LCA study starts by mapping and building a process model. The qualitative mapping of the processes under study is quantified (input and output flows are inventoried) and refined according to primary data collection and further development of the system under study. Within the course of iterations particular aspects of the LCA model may be re-visited, and a refinement of the quantified model is carried out in respect to the goal of the study. This iterative process is carried out multiple times until a robust model is obtained (Crawford 2011). The iterative character of an LCA supports the stepwise increasing level of data knowledge, system processes, system boundaries, and others along the Technological Reediness Levels (TRLs) (Hetherington et al. 2014). Performing an LCA during the R&D phase can result in several benefits, among them the following: Guide technical R&D, develop life-cycle thinking, support scale-up, direct future R&D activities; marketing purposes, demonstrate inclusion of environmental concerns, contribute to LCA knowledge (Lettner 2018).

Hence, in order to deal with performing an LCA during the R&D phase, it is proposed to implement an LCA approach which focuses on emerging technologies. Such as prospective LCA, which has an explorative character, and it does not search to give specific predictions (Jones et al. 2017). An important disadvantage is that due to the modelling of the technology at some future point, the LCA will always rely on assumptions and scenarios. Which represents a drawback in terms of uncertainties. Arvidsson et al. (2018), conducted a literature review on prospective LCA studies in order to provide recommendations on relevant methodological choices for evaluating emerging technologies. Two aspects can be highlighted. First the need for assessing a wide range of emerging technology alternatives that have the same function as the studied technology. And second, conduct a cradle to gate study of the selected promising emerging technologies.

Therefore, the present LCA is carried out in line with the development of the project and assessing different options in terms of assessment methodologies and processing alternatives. This integrated LCA approach requires clear communication between the stakeholders and the LCA practitioner in order to integrate new data, for instance, new technological advancements.

4 Method and Research design

The methodological framework described in section 3 is now put into practice for the environmental assessment of the value chains. Firstly, a detailed review of the D4EU project proposal, objectives, WP's and tasks was carried out. This information was used to build the phases studied in the LCA. Information from the WP's, and the different tasks, were crucial to setting the goal and scope of the study, as well as the sensitivity analysis which aims to illustrate a possible range of results. Moreover, the LCA was built upon information obtained through a literature review of previous published studies. Particularly, those focusing on bio-based systems, as these present their own distinctive features in LCA, which will be discussed in the following sub-chapters.

The information used for the analysis of S1 and S2 was gathered by an initial collaboration with the project partner IKEA Industry, and from the D4EU proposal. The collaboration with IKEA took place during a visit to the IKEA site in Slovakia. The analysis of the environmental burden distribution is dependent on the case study or scenario to be evaluated. Thus, the method of environmental burden distribution will be applied correctly depending on the defined scenario (Chapter 5.4).

4.1 Goal of the study

The goal of this LCA is to determine the potential environmental impacts of the new bio-based value chains and potential sustainability levers. This is done in order to support the establishment value chains, focusing on relevant impact categories to especially grasp the effects of land use. Moreover, the LCA seeks to identify hotspots and derive levers to reduce the potential environmental impacts along with the R&D. The results of the LCA are of value for all the project partners involved in the D4EU project, as its findings will present quantifiable environmental information which is of use during the decision-making process. The results of the LCA study will be presented through a detailed report in which a sensitivity analysis of different technological options will result in feedback and suggestions for R&D of the D4EU project.

Accordingly, the following goals in task 5.2 are set out:

- Establish an environmental system analysis for four NBBMs in parallel to value chain creation (Functionally Adapted Lightweight Board, eco-fungicidal moulded fibre packaging material, bark-enriched wood plastic composite (WPC) profiles and granulate);
- Derive possible ranges of results on environmental aspects of SRC dendromass based raw materials of the four NBBM;
- Identify the scope for further system improvement in terms of eco-efficiency (link to task 5.4).
- Provide information to all project partners for the environmental optimization of the value chains to be developed.

4.2 Scope or the study

4.2.1 System Boundary

According to the ISO series, the system boundaries definition is an iterative process. It consists of drawing a preliminary system boundary, and as the project develops further refinements are made through the inclusion of new information (Suh et al. 2004). The life cycle presented in Figure 2, is a general representation of the entire system, the sub-systems will be presented during the development of each study. The general processes considered are: the production of dendromass, NBBM1, NBBM2, NBBM3, NBBM4. The analysis considers the materials, energies, environmental emissions to water, land and atmosphere, environmental burdens associated with land use, land use change and biodiversity.

It is proposed to implement a modular approach of the system which allows the analysis of individual unit processes, instead of calculating several pathways. The approach consists in dividing the production system into modules (sub-systems), which are related to the life cycle stages. Each module can be then calculated as a standalone system (Lettner 2018). Similar methodologies have been implemented in different studies (e.g. Food and Agriculture Organization 2015; Lettner 2018; Steubing et al. 2016). This approach allows to assess each identified life cycle stage individually, and to connect the selected stage to other life cycle stages, or to techno-logical alternatives. Also, it facilitates the identification and addition of input/output flows, such as products and co-products; which easies the integration of further life cycle stages, and technological advancements. Consequently, for this study, the system is divided based on their inputs/outputs, thus five subsystems are identified. Such as dendromass production, NBBM 1, NBBM 2, NBBM 3, NBBM 4 (S0-S4).

A further sub-division of the system is done on the basis of which part of the system can be directly influenced by the decision maker, and which cannot. This categorization is termed the foreground system and the background system, respectively. A graphical depiction of the system can be visualized in Figure 2.A similar system boundary approach, which considers a modular approach is also used for the task 5.3 (Socio-economic assessment).

The mapping of the system under study was started. Prior to the environmental quantification of the NBBM a qualitative description of the value chains (referred to as systems under study) is necessary. Starting with the foreground system, initial generic flow charts were developed for each NBBM. The overview is illustrated in Figure 2. These preliminary flow charts do not yet contain all the detail of the life cycle. One reason is that the technologies and products, considered in D4EU are under constant development. Based on the stepwise defined life cycle stages and flow charts, modules compiled of unit processes were started to be mapped to structure the data inventory and assessments. This approach provides the opportunity to assess the life cycle stepwise as the value chains mature.

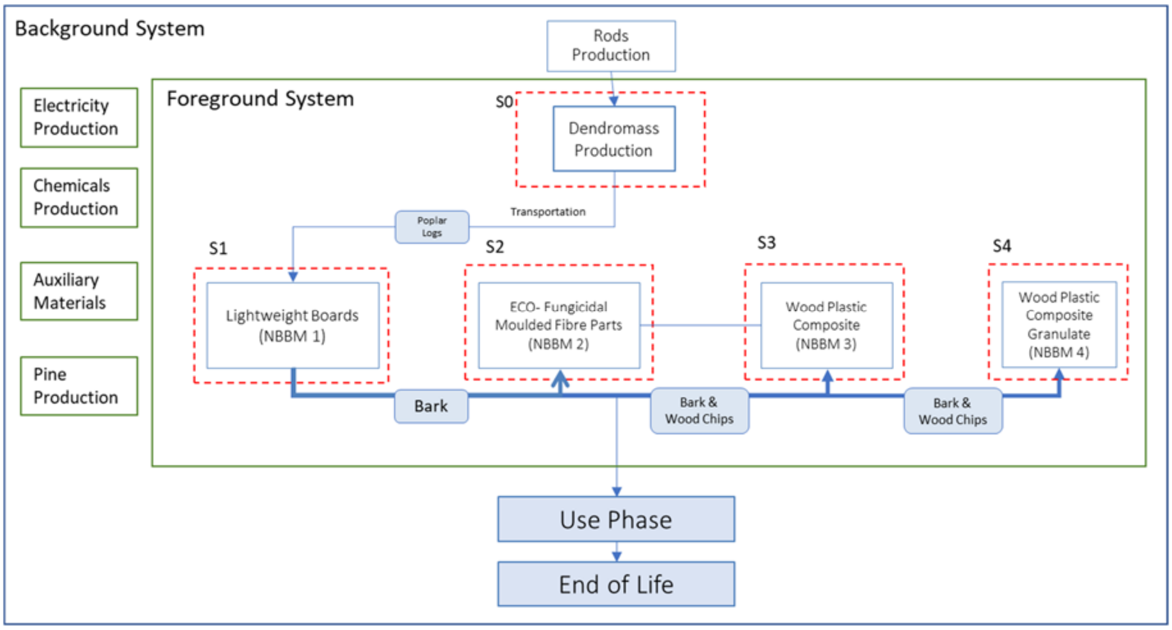

Figure 2 Schematic of Bio-Based SRC dendromass based Value Chain

Figure 2 represents the first schematic of the new bio-based materials (NBBM's) SRC-based value chains. The system starts with the production of poplar dendromass through short rotation coppice (S0). The dendromass is then transported and used for the production of NBBM 1, lightweight boards (S1). Hereafter, poplar bark, which is a by-product of S1, is transported and used for the production of NBBM 2 Eco-fungicidal moulded fibre parts. Simultaneously to NBBM2 production, a share of the poplar bark, and additionally a share of poplar wood chips (from tree crowns – 'brown chips' containing bark, also a by-product of S1), is transported and used for the production of NBBM 3 (S3) and NBBM 4 (S4) bark-enriched wood plastic composite (WPC) profiles or granulate, respectively.

4.2.2 Functional Unit

A literature review of previous LCA studies was carried out to obtain information on the FU's used in related studies, and to consolidate the lessons learned from other LCA's. The review concentrated in analysing the definition of FU, scope and measured impact categories. Thus, it was possible to understand the focus given to the FU depending on the study goal, SB and reference system. The literature review was carried out by searching articles in the databases google scholar and scopus (Elsevier). The selection of articles was based on the relevance of the studies. Thus, the eligibility criteria were based on LCA studies which focused on SRC, wood-based board production and WPC.

It must be noticed that due to the ongoing R&D phase, particularly for NBBM 2, 3 and 4, defining their FU's is of greater challenge. Hetherington et al. (2014) discuss the issue of establishing a suitable functional unit at R&D phase, where for instance the future application of the product is not always clearly defined. Thus, the researchers suggest to depict multiple functional units where necessary and choose the FU unit together with the development of the project. Therefore, the FUs for NBBM 2, 3 and 4 will be improved in accordance with the results and the development of the WP's and expected deliverables. The function and FU of each product are defined in chapter 5.

4.2.3 Environmental Burden Distribution

The system under study can be considered as a multiple-function system, consisting of multiple-inputs and outputs. Multiple-input systems, are those that require different inputs materials (of different properties), to produce the desired product. Multiple-output systems are defined as those systems that produce more than one functional output (Azapagic and Clift 1999). This complexity presents the challenge of allocating the environmental burdens amongst all the products and co-products (Guo 2013). Some of the allocation methods used in previous studies are: allocation by economic value, carbon counting, closed-loop allocation, allocation per mass and cut-off rule (Guo 2013; Klöpffer and Grahl 2014). From a hierarchical order, it is recommended that allocation methods should be avoided if possible, instead, system expansion should be applied (ISO 2006a). However, as discussed by Pawelzik et al. (2013) all approaches have their own intrinsic pitfalls, and can lead to significant different results. Accordingly, the case study is framed as a multi-output system of five product systems. Such as, dendromass production, functionally adapted lightweight boards (NBBM1), eco-fungicidal moulded fibre parts (NBBM2), bark-enriched wood plastic composite (WPC) profiles (NBBM3) and granulate (NBBM4). Similar to other wood industry manufacturing processes, the studied value chains deliver several products and co-products. As an example, the production of NBBM1 also generates other valuable products like brown wood chips (used for energy production) and bark (used for energy, and NBBM 2,3 and 4). Dealing with this type of systems requires a cautious decision on how to distribute the related environmental burdens. Particularly for wood-based products, since a chosen allocation method can strongly influence the results (Dolezal, Mötzl, and Spitzart 2014). For this study a mass allocation is initially applied. The effects of applying other allocation approaches will be studies in the sensitivity analyses. As the value chain is in an ongoing development phase, selecting a general functional unit (FU) which represents the entire system will not be adequate.

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

4.3 Life cycle inventory (LCI)

The present study reflects on previous LCA studies which focus particularly on bio-based products and/or systems. Consequently, it attempts to focus on analysing the most relevant environmental related indicators related to bio-based production systems.

An important step during the LCI is the data collection. This phase requires a systematic procedure which includes all inputs and outputs related to the processes within the system boundary. Furthermore, one should consider that the data is not always directly collected by the LCA practitioner. Thus, different data collection strategies, such as data sheets, telephone calls, and checklists, among others, will be used. By working closely with the project partners, both qualitative (e.g. system structure, improvements) and quantitative (e.g. amounts of energy) data are collected. In this phase a continuous process is run, thus it is planned to accumulate data and add the required complexity and detail as the project advances. A useful approach is to divide the data collection into primary and secondary data. Primary data is collected directly from the industry sources. As for secondary data, this is obtained from publicly available data bases and publications (e.g. technical data sets, project reports, scientific studies). Moreover, corresponding with the system's flow (Fig. 1), it is planned to gather the data in the same order as the process, thus starting with the dendromass production system, and subsequently the NBBM1, NBBM2, NBBM3, NBBM4 systems, respectively. A further helpful strategy is to structure the data collection depending on the type of data, thus the following division is proposed: input, outputs, energy and emissions. This will consequently help the LCA practitioner, industrial partners and other relevant stakeholders to have a clear understanding of the information exchange structure.

The LCI phase is crucial to the project results. Particularly, the level of detail of data collected is determinant for the accuracy of the LCA results (Recchia et al. 2011). To guide the quality of the data, it is of help to define data quality indicators (Guo 2013). The following are used as reference:

- Precision: measures the variability of the data used for each data category
- Representativeness: helps to indicate the degree to which the data set reflects the true measurement of the population of interest.
- Completeness: indicates the system boundaries and all the flows entering, exiting and within the system.

Moreover, the following data quality parameters are considered:

- Technological data: qualitative and quantitative primary data from consultations with project partners; laboratory data (when no primary data is available), literature data from previous studies or databases.
- Geographical coverage: data is collected from the industries location, such as Slovakia (Malacky, Nováky) and Poland (Łódź). Also, if necessary laboratory and other data (e.g. Fuel consumption for transportation) is retrieved from project partners in Germany, Italy or Hungary. If data is not available from the mentioned sites, data within the European Union is given priority. Finally, an expansion to consider global data is taken as a last resource.

The data collection process has already started. Meetings for data collection with the project partner IKEA Industry, and Energochemica took place to obtain information concerning dendromass production, NBBM1, NBBM3 and NBBM4 system. The next data collection steps are in line with the project development and its respective work packages.

4.4 Life cycle impact assessment

The following stage is the life cycle impact assessment (LCIA). In this phase, the results of the LCI are associated with selected impact categories to describe the inventory results into environmentally relevant information (Tillman and Baumann 2004). Converting these data into a number of relevant impact categories provides a clearer understanding of the systems impacts and thus, helps to provide answers to the goal of the study and decision making process (Rosenbaum et al. 2015).

In line with the goal and scope phase of the LCA, the first step of the LCIA is the selection of the impact categories and category indicators to be evaluated. Nevertheless, regardless of the cruciality of this phase, there is no standard framework to guide the selection of the impact categories (Guinée, Huppes, and Heijungs 2001). Most studies follow suggestions given by the ISO 14044 (2006) guidelines, these are the following: (i) the selection of indicators should be consistent with the goal and scope of the study. (ii) it is requested to present a justification for the selected indicators, and (iii) it must be in congruence with the environmental spheres affected by the production system. It must be also reflected that inherent to the iterative nature of an LCA study, additional categories can be added as new information of the system is obtained. Furthermore, several authors have proposed default lists of impact categories which facilitate the case specific identification process. A common procedure found in several LCA studies (e.g. Mirabella, Castellani, and Sala 2013; Heller, Keoleian, and Volk 2003; Suter, Steubing, and Hellweg 2017) is to use a default list and then select those categories which help to answer the goal and scope of the study.

These default lists are mainly divided by either representing a midpoint or endpoint model. Bare et al. (2000, p. 323), defines the terms midpoint and endpoint as: “A midpoint indicator can be defined as a parameter in a cause-effect chain or network (environmental mechanism) for a particular impact category that is between the inventory data and the category endpoints”, “Endpoint characterization factors (or indicators) are calculated to reflect differences between stressors at an endpoint in a cause-effect chain and may be of direct relevance to society’s understanding of the final effect, such as measures of biodiversity change”. A range of these lists and their characterization models have been introduced to software tools such as, CML 2001 and ReCiPe (midpoint-oriented methods) and Eco-indicators 99 (endpoint-oriented methods) (Guinée 2015).

Considering the suggestions presented previously, the selection of the impact categories is firstly screened by its contribution to the goal and scope of the study, and focusing on the most crucial impact categories relevant to the system under study. This will help to reduce uncertainties, and a possible sub-optimization of the environmental burdens produced.

In line with the project a focus is set on the potential environmental impacts related to the land use and land use change. The impact categories climate change and water scarcity are further connected to land use. Thus, this task was started by preparing an overview of the current methodological approaches to assess land use. This will ensure consistency of the goal and scope of the LCA within this project (desk research in progress). Apparently, the mentioned impact categories are the most debated ones within LCA of bio-based product systems (Filzmaier, 2019). This is also due to several multi stakeholder initiatives that were identified to drive the debate. For the sensitivity analysis, the range of discussed methodologies will be included. The characterization of land use is challenged by limited knowledge, uncertainty due to current methodological developments and limited inventory data availability.

In order to obtain information on previously selected impact categories, a valid starting point is to examine previous studies on bio-based material systems. For instance, Martin et al. (2018) reviewed scientific published studies of LCA of bio-based products, referring to established frameworks, interviews with industry experts and open space workshops, to determine the most relevant environmental indicators that should be evaluated in bio-based systems. A similar study by Pawelzik et al. (2013) derives a set of similar indicators. Based on this background, the following Table 1, presents a preliminary summary of the environmental categories which are considered as 'study-specific' impacts.

Table 1 Critical environmental Indicators for Bio-Based Systems

Environmental Categories	Unit
Energy use	MJ
Climate Change	kg CO2 eq.
Land Use	m³; CO2 eq.; number of species….

4.5 Interpretation

The interpretation phase is the fourth and final phase in the LCA study. It will combine the results of the LCI and the LCIA to determine the environmental impacts of the value chains. Particular emphasis is given to answer the defined goal of the study; thus, it is expected to identify environmental impact hotspots of the production systems. The main steps carried in this phase are the following: identification of significant issues, evaluation of results, drawing conclusions, explaining limitations (Crawford 2011). To support the interpretation, sensitivity analysis considering the hotspots and sustainability levers will be carried out.

During the interpretation phase the results will be characterised, and presented in a graphical format through diagrams. Aggregation of the results is used to present a comparison of the potential environmental impact categories for the different study cases. The results of the interpretation phase will be communicated to all project partners in the D4EU project. Thus, not only the presentation of detailed and complex environmental information will be given, but also more simplified formats (such as handouts). Moreover, the interpretation phase involves the iterative process of reviewing and revising the goal and scope of the study. In the same manner, it provides space for feedback of the project partners (further explained in chapter 7).

5 Results

5.1 Dendromass production

SRC is the agricultural practice used for the production of the dendro-biomass, i.e. stem wood, and wood chips (secondary product), which have the function to be the material for the production of NBBM's and for energy production, respectively. Usually, in studies of agricultural systems, the FU of area (e.g. ha) or mass-based (tons of dry matter) is used. Table 2 presents the summary of the FU used in different SRC LCA studies. Consequently, based on previous studies of SRC LCA's, and on the function of the studied system (provide dendromass for NBBMs), a mass-based FU unit of 1 ton of dry poplar, is selected. This FU offers a reference to which the inputs and outputs of the system can be related to, and allow the comparison to for instance other agricultural methods. It as well offers a link, as the reference flow, between S0 and S1.

Table 2 Related LCA studies on SRC

Related LCA studies on SRC				
	Goal	**FU**	**Impact Categories**	**Scope**
(Bacenetti, Pessina, and Fiala 2016)	Assess the environmental impact of the harvest solution for SRC plantation with 2-years cutting time	1 ton of fresh matter harvested	CC, OD, PM, POF, AD, TE, FE, ME, MFRD	Cradle to Gate
(Schweier et al. 2017)	Evaluate the environmental impacts of technological, agronomic, and environmental aspects of bioenergy production from hybrid poplar SRC cultivation on marginal land in southern Germany	1^6 grams of produced wood chips	GWP, EP	Cradle to Gate
(Fantozzi and Buratti 2010)	LCA study about household heat from Short Rotation Coppice wood pellets combustion	1 MJ	GWP, OD, AD, EP, PS, EWC, EWA, ESC, HTA, HTW, HTS	Cradle to Gate
(Caputo et al. 2014)	Quantify the fossil fuel inputs and greenhouse gas balance of the willow biomass (Salix spp.) cropping system in New York State	1 oven-dry tonne (odt) of willow biomass	GHG	Cradle to Gate
(González-García et al. 2012)	Study the environmental impacts of Italian poplar plantations	1 odt	ADP, AP, EP, GWP, OD, HT, FE, ME, TE, POF	Cradle to Gate

Description of impact categories abbreviations. AD = Acidification, ADP = Abiotic depletion potential, ARD = Abiotic resource depletion, CC = Climate change , EP = eutrophication, EU= energy use, ESC = Ecotoxicity soil chronic, ET = eco-toxicity, EWA = Ecotoxicity water acute, EWC = Ecotoxicity water chronic, FE = fresh water aquatic ecotoxicity, FE = freshwater eutrophication, GHG = Greenhouse gasses , GWP = Global warming potential, HH = Human Health, HT = Human toxicity, HTA = Human toxicity air, HTS = Human toxicity soil, HTW = Human toxicity water, LU = land use, ME = marine aquatic ecotoxicity, ME = marine eutrophication, MFRD = mineral, fossil and renewable resource depletion, NE = Nutrient Enrichment, OD = ozone depletion, PM = particulate matter, PO = photochemical oxidation, POF = photochemical ozone, PS = Photochemical Smog, PS= Photochemical Smog, TE = Terrestrial eco-toxicity, TE = terrestrial eutrophication

The production of poplar wood is the initial stage within the foreground system. Figure 3 and 4, present a graphical representation of the system processes and input-output flow respectively. The system starts with the preparation of land for planting the poplar rods. Thus, the activities of grass cutting, heavy disking, ploughing, and harrowing are carried out. After the land is ready, the planting of the rods takes place, this is normally done using a combined application of manual work and machinery. The next step is weed control, which is carried out using a disk harrow, this is done during the 1st year, 2 times during the 2nd, 3rd and 4th year. For the 5th year onwards, normally no weed control is needed. When required, herbicides are used depending on the gravity of case. Singling, partially also pruning, is done manually with the objective of selecting and supporting one dominant shoot, this step is performed every time after harvest. As for the harvesting step, this is done using machinery in an interval cycle of every 5 years. Here the output is separated into the poplar logs and the wood chips, wood tops and branches (wood residues). The poplar logs are stored on field and delivered to IKEA industry for the creation of NBBM1, this is done depending on required demand.

The dendromass production system (S0) delivers two valuable outputs. Poplar logs and the wood residues. The main product is considered to be the poplar logs used for NBBM1, as for the wood residues, this can be considered to be the co-product of the system.

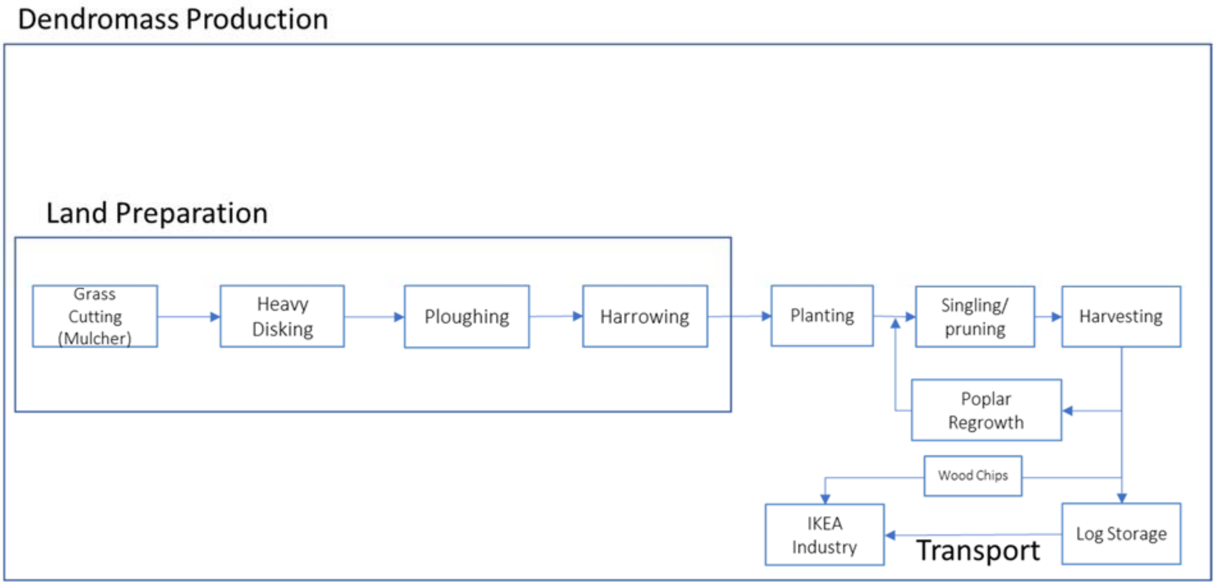

Figure 3 Dendromass production, Foreground system S0

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

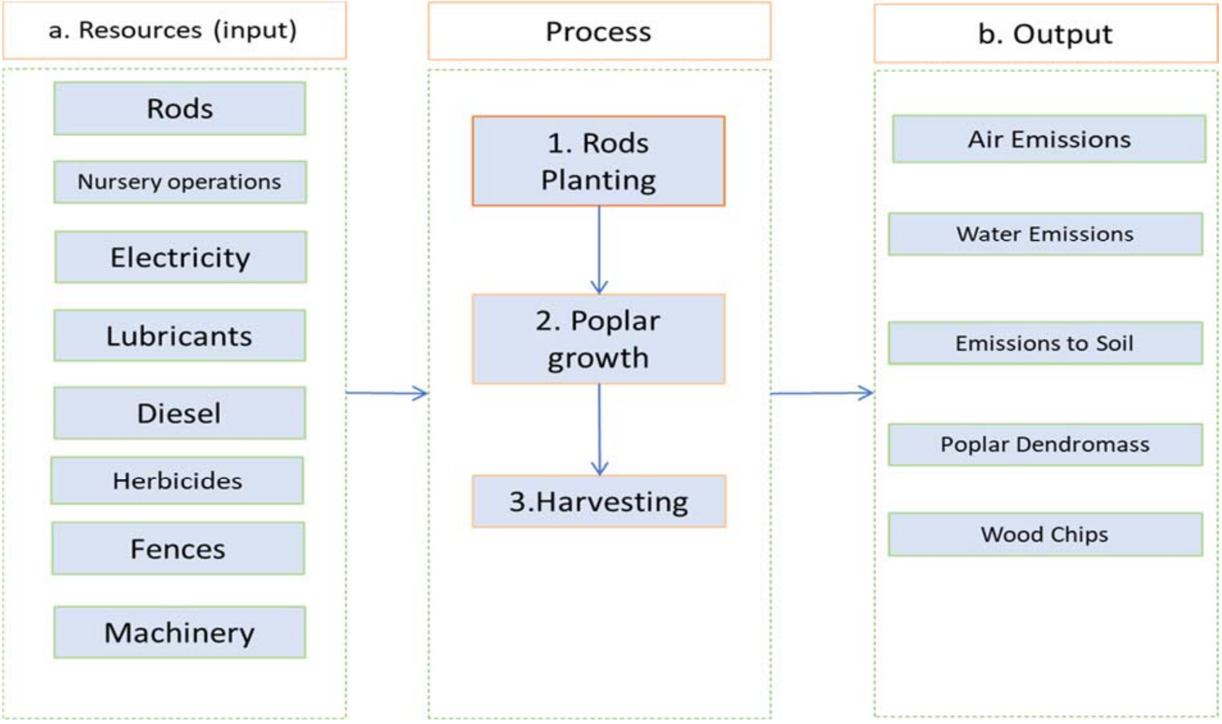

Figure 4 Input-Output flow of Dendromass production

5.2 NBBM 1 (Functionally Adapted Lightweight Board)

One of the relevant aims of producing Lightweight boards (LWB) with SRC poplar, is to reduce economic costs and environmental burdens by substituting other wood sources as pine. The produced LWB have several applications, they can serve as furniture parts, building material, among other functions. Moreover, LWBs are an alternative to other materials such as fiberglass, plywood, veneer sheets and particle board. In order to define an appropriate FU, it must be considered that the functions of the LWB during its life cycle vary dependant on the use given to the LWB. Thus, knowing the precise function requires a further study on the product which the LWB are used for. However, this is out of the scope of this study. A suggested methodology by FPInnovations (2015), is to specify a declared unit, which allows for interlinkages with upstream and downstream process. However, a full life cycle is not possible, instead a cradle to gate system is considered.

Consequently, within these limitations, it is proposed a declared unit of 1m^3 of finished LWB which fulfils similar technical requirements than its counterparts. Previous similar LCA studies refer to a similar FU. (Table 3). The reference flow is considered to be the poplar dendromass for the production of LWB.

Table 3 Related LCA studies on Lightweight Board Production

Related LCA studies on Lightweight Board Production				
	Goal	**FU**	**Impact Categories**	**Scope**
(Puettmann et al. 2013)	Determine energy and material inputs and outputs associated with the production of medium density fibreboard (MDF)	1 m^3 of MDF	GWP, OD, AD, PS, EP	Cradle to Gate
(McDevitt and Grigsby 2014)	Quantify the various pollution and resource use data associated with the full life cycle of MDF made with petrochemical adhesive (urea formaldehyde resin) and that of a bio-based adhesive (lignin–protein composite) from industrially available plant-based ingredients	1 m^2 of MDF	ET, LU, AC, EP	Cradle to Grave
(Rivela et al. 2006)	This work aims to generate comprehensive Life Cycle Inventory for the manufacture of MDF.	1 m^3 of finished MDF	ET, AC, EP, LU	Cradle to Gate
(Piekarski et al. 2017)	Environmental cradle-to-gate life-cycle of one cubic meter MDF panel by means of a life-cycle assessment (LCA) study	1.0 m^3 of MDF with average thickness and average density	GWP, AD, OD, HT, ARD	Cradle to Gate
(Iritani et al. 2015)	Assessing the environmental performance of a wardrobe built from medium density particleboard	40 kg of stored goods/5 years	GWP, OD, PO, AD, ET, HT, NE	Cradle to Gate
(Baptista et al. 2016)	Present a practical eco-efficiency framework related with the implementation of improvement strategies and help to set priorities to improve the company's environmental and economic performance	Finishing of 1m^3 of MDF boards	GW, AD, OD	Cradle to Gate
(Kouchaki-Penchah et al. 2016)	Provide a comprehensive LCI data for manufacturing of MDF to detect the environmental hotspot throughout the manufacturing process	1 m^3 of finished MDF	ARD, AD, EP, GWP, OD, FE, ME, HT, TE, PO	Cradle to Gate

This life cycle stage (S1) consists of the production of lightweight board (LWB). Figure 5 and 6 depict the system processes and input/output flows, respectively. The LWB production starts by receiving the poplar logs from the SRC system (S0) and also pine wood coming from forests. The proportion between them is 70% pine and 30% poplar, which is a distribution based on volume. The next step is debarking the logs, here two outputs are obtained, the debarked logs and bark.

This last output is used for several purposes, partially it is used for the production of NBBM2, 3 and 4, the rest is burned for in-site process energy consumption and used as bio-energy. However, as the NBBM 2, 3 and 4 are under a research phase the proportions of bark used for biofuel and the bio-based products are not entirely known. Therefore, it is proposed to evaluate different future-oriented scenarios, which matches with the R&D of the ongoing value chains establishment. More on this last step will be further discussed during the formulation of scenarios.

As for the debarked logs, this is transported to the flaking process where wood flakes are produced. The output of this step is the flakes, and wood residues (e.g. brown wood chips). This last one is sent to the energy producing system where they are burned and used as for in-site process energy consumption. The same is carried with all the wood residues which can be recovered and collected in the LWB production system. The wood flakes are transported to a wet silo where they are stored, followed by the drying process and, subsequently, the drying of the flakes. The next step is the blending. Here additives (e.g. glue) are added. After a final size screening step, the flakes are sent to the board shaping process line. This starts by laying the flakes in layers, and then the steps of pre-press, and continues press are done. After this last step, the first LWBs are obtained. The process then continues to the final section which is the board finishing, here sanding, trimming, sawing to the right size and finally storage of the LWB is completed.

Three valuable outputs are considered within this system. First, the wood residues which are reinjected to the system as biofuel material. The bark which is partially used for process energy supply fuel, and for the production of other NBBM's. The final output is the manufactured lightweight boards

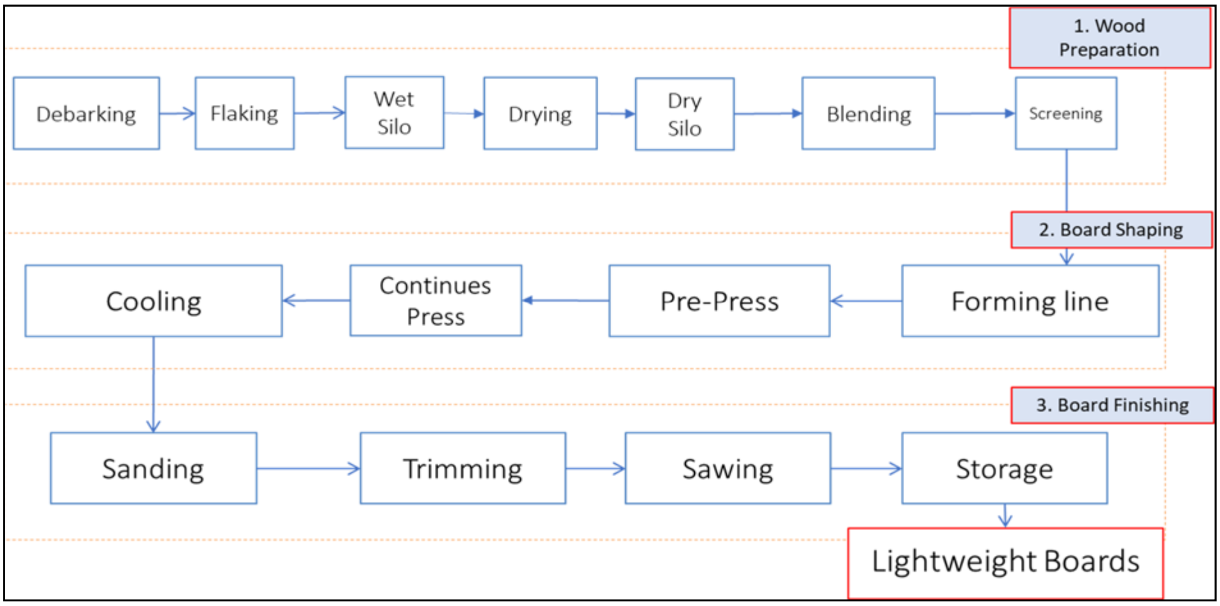

Figure 5 NBBM1 production process

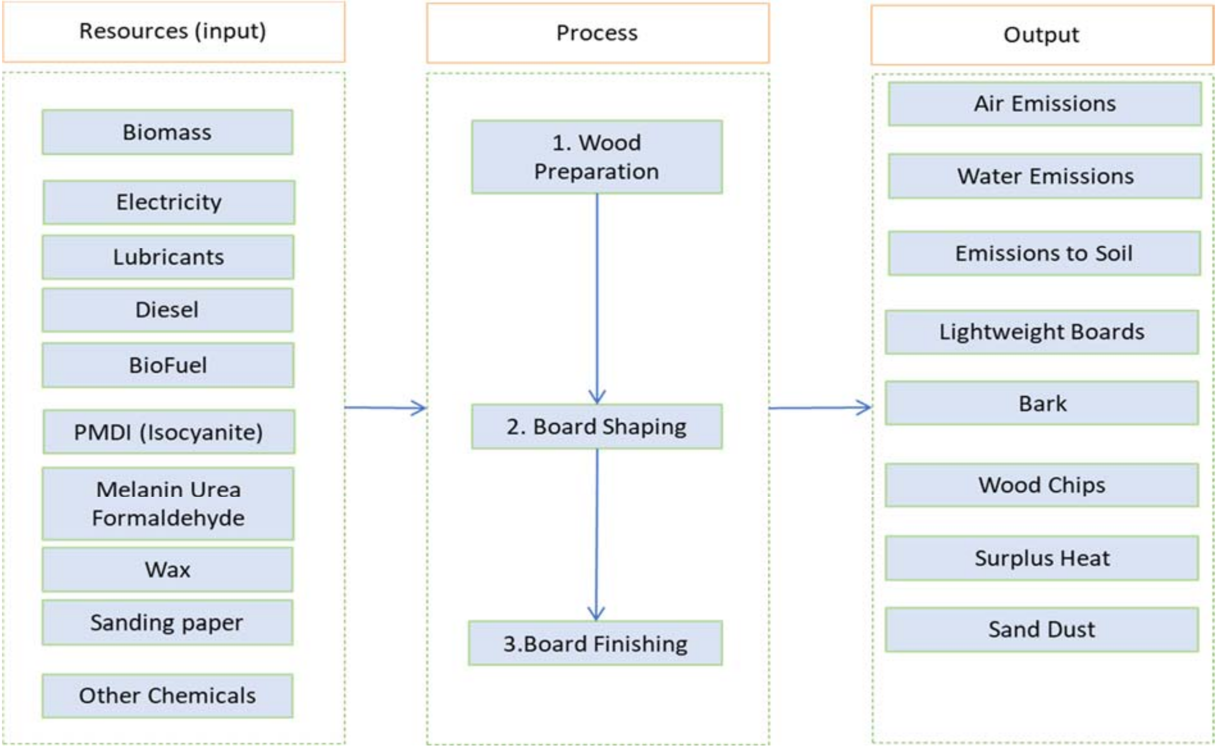

Figure 6 Input-output flows of NBBM1

5.3 NBBM 2 (Eco-Fungicidal Moulded Fibre Parts)

Bio-based fungicidal product is used to prevent the growth of mold on packaging materials. The product is expected to prevent mold for at least six months. Communally, based om fossil-oil or synthetic barrier polymers as ethylene vinyl alcohol (EVOH) copolymers and polyvinylidene chloride (PVDC), polyolefins (polyethylene), and waxes are used (Khaoula, Elmira, and Stephane 2009; Rastogi and Samyn 2015). Figure 7 presents a first modelling of the input-output and involved process for producing the fungicidal product.

A fitting FU is the size of a packing material sprayed or added with a fungicide, which resits mould for 6 months. Table 4 presents a summary of the FU used in comparable LCA studies, which focused in the environmental assessment of coating materials.

Table 4 Related LCA studies on different coating materials

Related LCA studies on different coting materials				
	Goal	**FU**	**Impact Categories**	**Scope**
(Häkkinen et al. 1999)	Outline the service life systematics of coated exterior claddings in connection to environmental assessment	1m^2 of Coated exterior cladding during 100 years	GHG, EU, ME, MFRD	Cradle to gate
(Strömberg 2004)	Show how the environmental impact of the coatings on exterior wood depend on the spread in the coatings' service lives	1 m^2 coating on exterior wooden panels over a period of 50 years	GHG, EU, AD,	Cradle to gate

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

(Fufaa et al. 2013)	Assess the environmental performance of the utilization of nano-based wood treatments	0.01 m^2 of coated exterior wooden cladding with a reference life span of 50 years	CC, HT, EU, AD ET	Cradle to gate
(Hischier et al. 2015)	The establishment of a comprehensive ecological comparison of facade coatings with and without manufactured nanomaterials (MNM)	1 m^2 of (indoor or outdoor) wall during a period of 80 years	GWP, AD, ET, HT, Human health	Cradle to grave

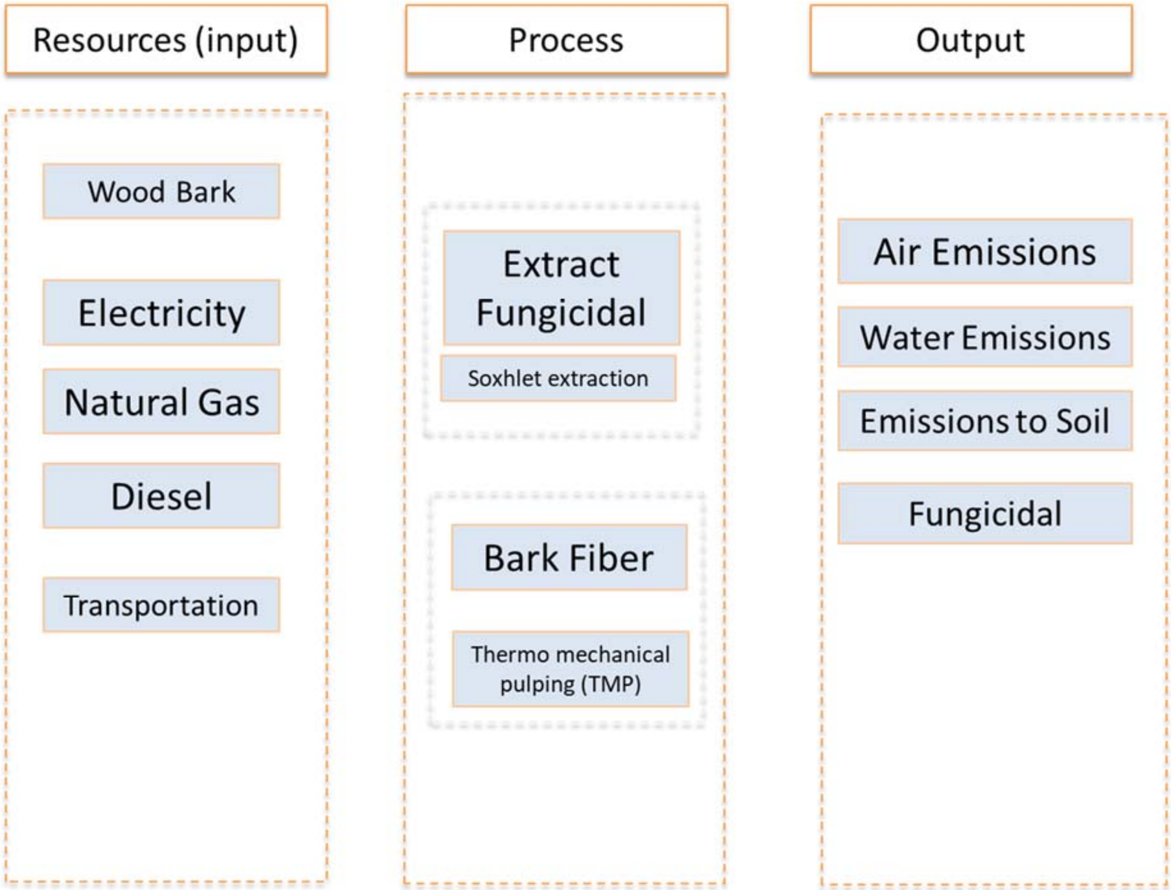

Figure 7 Input – Output Fungicidal (NBBM2)

5.4 NBBM3- Bark-enriched wood plastic composite (WPC) profiles

WPC are composite materials that are composed of a mixture of plastic and wood. The material is used for diverse outdoor and indoor constructions. Such as, flooring, door frames, fences, windows, fencing panels, decking or siding. A summary of previous selected FUs is given in Table 5. Figure 8 and 9 present a first modelling of the input-output and involved process for producing the fungicidal product.

Functional unit options are:

- 1 m^3 of WPC, comparing other WPC which has a different wood (e.g. non-SRC produced wood)
- The production of 1 material using the WPC (1m^3)

Table 5 Related LCA studies on WPC LCA.

LCA studies on WPC		
	Goal	**Functional Unit**
(Beigbeder et al. 2019)	Evaluate the environmental impacts of EoL phase of two biocomposites in France	1 ton of biocomposite waste
(Lorite et al. 2017)	Provide information about the environmental profile of the novel material and to evaluate its benefits and disadvantages compared to conventional plastic materials	providing customers with 100 000 kg of fresh fruits during one year
(Sommerhuber et al. 2017)	Assess the potential environmental impacts of different waste management strategies	1 t of post consumer WPC
(Gu et al. 2018)	Determine the feasibility of replacing flax with bamboo fibres	1 kilogram of flax/PP composites
(Qiang et al. 2014)	Potential environmental impacts of the PLA-based WPC	1000 kg of transport pallet manufactured with the PLA-based WPC
(Korol, Burchart-Korol, and Pichlak 2016)	Compare the environmental impacts of analysed materials including the phases from raw material extraction to plastic pallet production	the production of one standard plastic pallet made from PP different composites with different shares and types of filler
(La Rosa et al. 2014)	Evaluate the main environmental impacts related to the production of an eco-sandwich panel containing cork, hemp and bio-based epoxy resin as natural materials. A comparison with a traditional sandwich composite made of glass fiber, petroleum-based epoxy resin and polyurethane, was carried out	eco-sandwich panel sized 0.400 x 0.400 x 0.02m

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

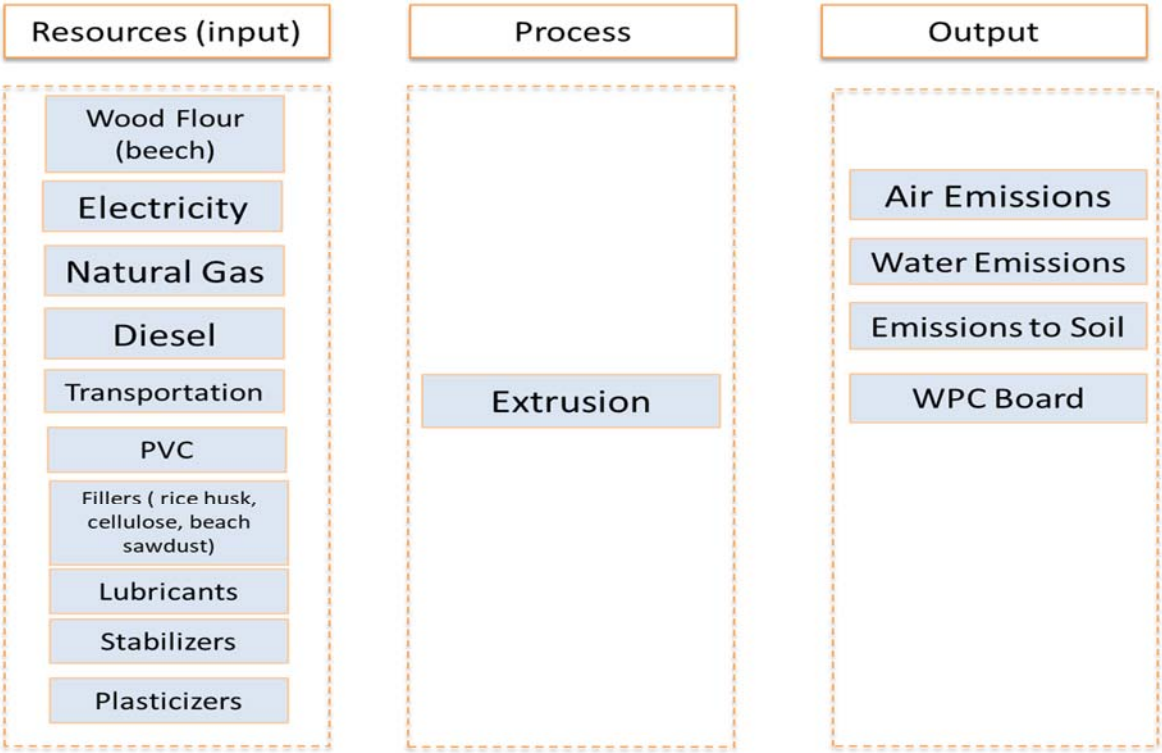

Figure 8 Input – Output for WPC Boards (NBBM3)

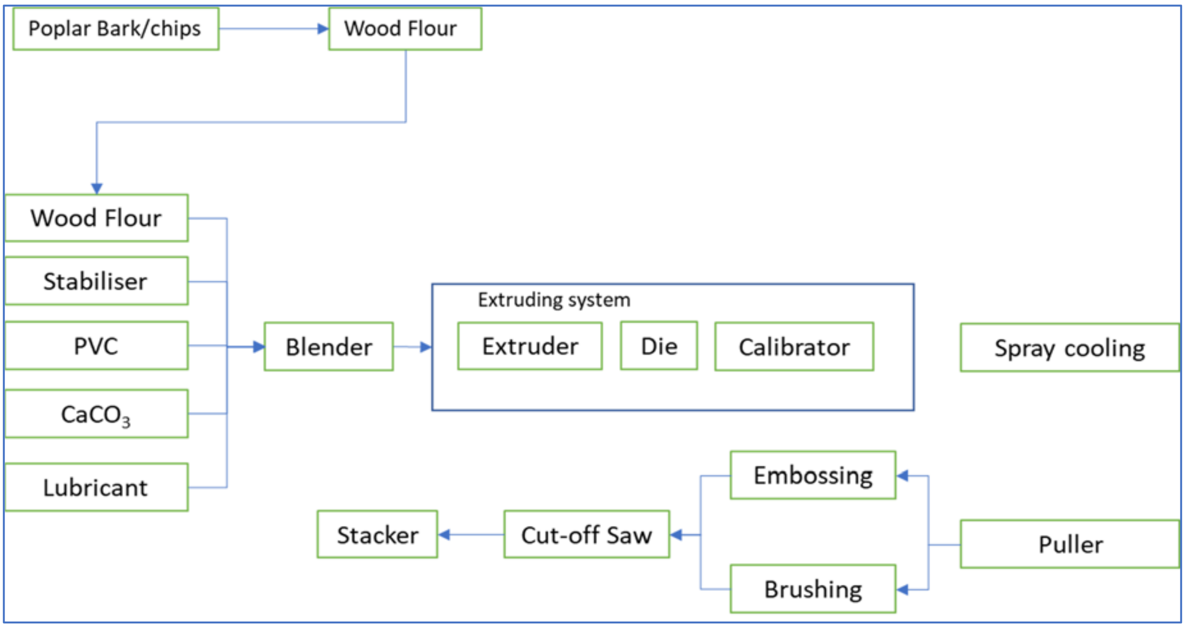

Figure 9 WPC Boards (NBBM3)- Process

5.5 NBBM4- Bark-enriched wood plastic composite (WPC) granulates

The production NBBM4 and its functional unit (FU) is similar to NBBM3. As a reference for LCA studies, table 5 is of reference. Consequently, a FU of 1m^3 of wood plastic composite granulate, is considered. A depiction of the Input-Output and involved production process is presented in Figure 10 and 11.

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

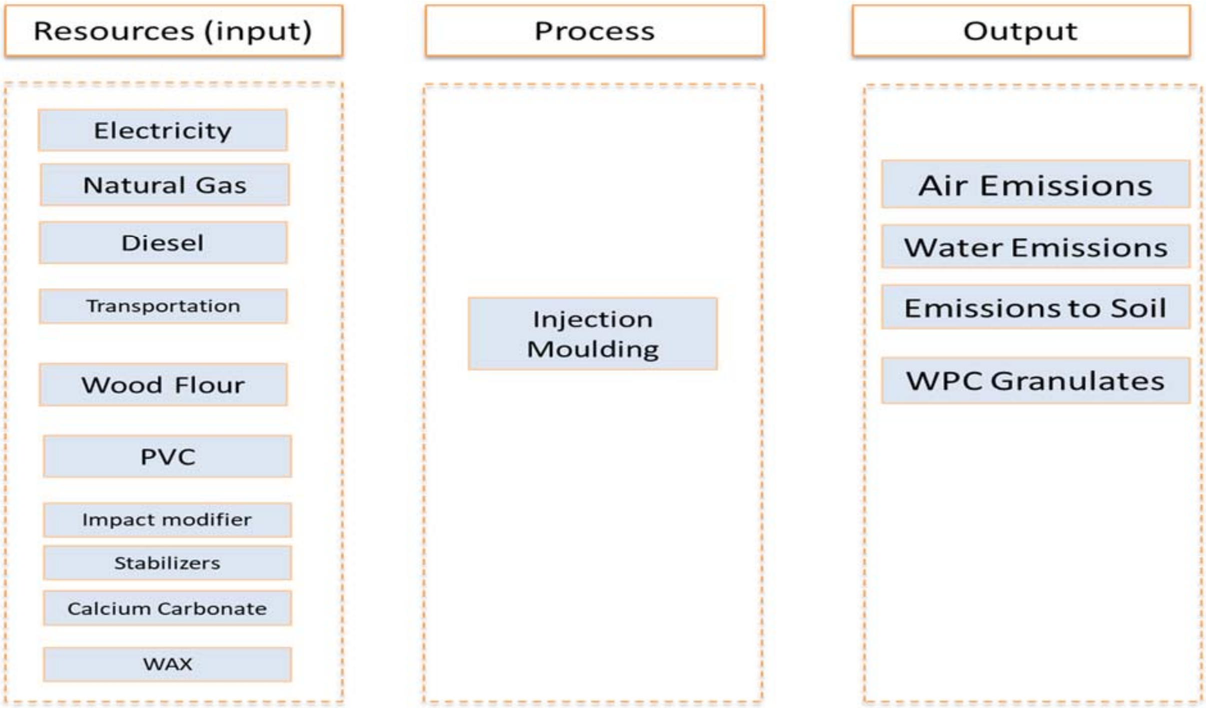

Figure 10 Input – Output for WPC Granulates (NBBM4)

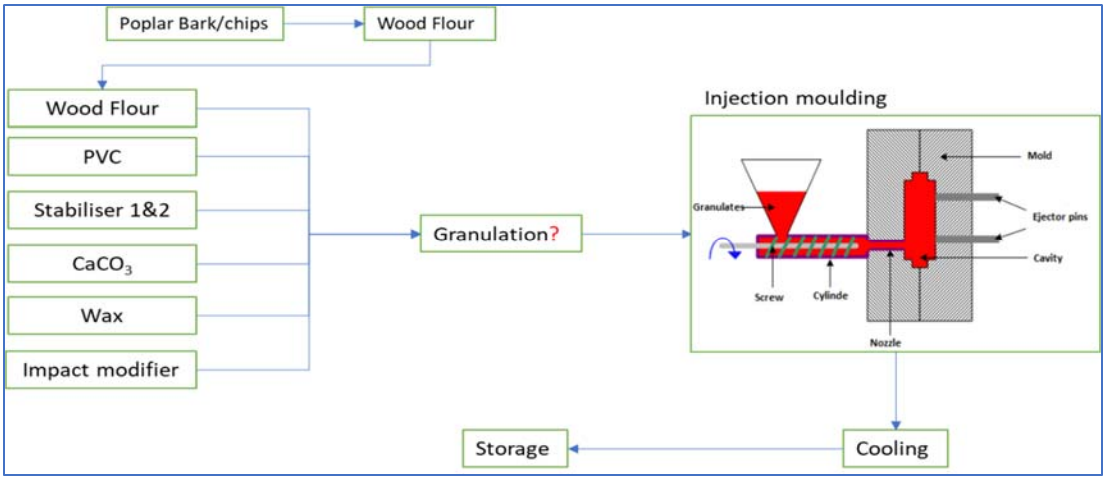

Figure 11 WPC Granulates (NBBM4) - Process

5.6 Sensitivity Analysis

This study aims to analyse a range of possible results instead of a single point in order to derive the space of opportunities for the further developments. By studying a variety of scenarios, the LCA study focuses on providing several options that allow the environmental improvement of the system. Consequently, the focus is on system optimization during the R&D phase, instead of product comparison. On this basis, a sensitivity analysis will be conducted. Based on the analysis of the different work packages, which focused on obtaining information about possible technological or system alternatives, an initial set of scenarios is proposed. This set of scenarios is open to modifications depending on new knowledge of the system, which is obtained during the different data collection phases. These are the following:

5.6.1 Dendromass production system

a. Land as it was before (reference system), to compare different options of land use, the case of comparing the SRC system with a reference system is proposed. The reference system is considered to be the land-system as it was before it was used for SRC. For instance, agricultural land used for energy crops. To decide on which reference system to use, it was first discussed with the project partner IKEA on the different types of land use which were previous to the establishment of SRC plantations. However, to decide on an overall representative reference system, further information is required. Therefore, it is planned to request detailed information about previous land status to the project partner IKEA.

b. Harvesting methods, based on task 2.3 (Harvesting and transportation), tree harvesting methods are studied. Further information is expected by Deliverable 2.1 (Report of harvesting ad supply chains) by CNR-IVALSA. The following options are considered:
   - Cut-to-length (CTL) multi-tree harvesting
   - Whole-tree harvesting
   - Chain flail technology

a. Glue alternatives, one of the concerns during board production is the use of glue due to its possible toxicity level and consumption levels. This is perceived within task 3.3 (Process impact analysis). Thus, this scenario will provide information on the environmental performance of alternative glue use.

b. Debarking of logs during harvesting process, as part of task 3.2 (adaptation of log deck to feed logs into process) it is proposed to study the environmental impact of having a debarking system at the field, instead of having it at IKEA facilities.

c. Energy use, based on task 3.3., it is of use to analyse the alternative energy supplies during the production the LWB. The use of electricity and gas have been highlighted in its importance as it broadly affects the environmental impacts assigned to energy-consumption (Piekarski et al. 2017; Rivela et al. 2006).

5.6.2 NBBM 2

a. Bio-fungicidal addition to packaging material, corresponding with task 4.3 (Development of treatment method for fixing the fungicides in bulk), it is proposed to study the following approaches:
   - Add bark, straight to the structure of the molded fibre parts
   - to apply the isolated substances to finished products.

b. Method of fiber extraction, in connection with task 4.5 (developing a cost-effective technology for the separation of fungicidal extract from bark), the following methods of fiber extraction will be studied:
   - double screw extrude
   - thermo-mechanical pulping

c. Energy alternatives, to support task 4.6 (Successful industrial production of sample mouldings with natural fungicides) it is planned to assess different energy alternatives (e.g. use of renewable energies) for the production of the sample mouldings.

d. Transportation, linked to task 4.5 (developing a cost-effective technology for the separation of fungicidal extract from bark) it is proposed to assess the case of extracting the fungicide di-

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

rectly at IKEA facilities, instead of in Pulpack. This case will presumably reduce the environmental burdens related to transporting the bark material from IKEA (Slovakia) to Pulpack (Poland).

5.6.3 NBBM 3 and NBBM 4

a. Polymer WPC & WPCG, in connection with Task 4.7 (Task 4.7: Identification of the required features of the bark as a component in the Wood Plastic Compo-sites (board and granulates)), this scenario compares the environmental performance of NBBM3 with its polymer counterpart which was defined in the Deliverable 4.1.
b. Additives, as part of the mixing for producing WPC different additives are added. As the proportions and types of additives used can have an important impact on the environmental performance of the value chain, it is proposed to evaluate its impact
c. Recipes (matrix/additives/filler), linked to Deliverable 4.1 (Formula 1), a variety of formulas which use different proportions of e.g. fillers will be assessed.
d. Energy Use, as the processes involved in the production of NBBM 3 and 4 can be energy intense, it is proposed to evaluate different energy mixes and different production parameters.

6 Risks, monitoring and evaluation

In order to consider potential unexpected results of the present investigations immediately, the risk management tools are further developed in D4EU. The risk management table of the project consortium is used by the Technical Steering Board of D4EU (coordinator with the industrial partners) as a tool for identifying the need for intervention. Adopting a recommendation of a reviewer, new pairs of risk and risk mitigation measures are currently developed and added by the present reporting partner WOOD K plus in collaboration with the TSB to ensure implementation of potential unfavourable LCA results (see table 6).

Table 6 Risk, Monitoring and Evaluation

Description of Risk:	Environmentally unfavourable results of the environmental and socio-economic assessments after benchmarking with the reference products as developed in Tasks 4.8 (Prototypes) and D4.4 (Formula I).
WPs Involved:	5, 4, and 3
Proposed Risk mitigation measures:	Feedback on the environmental and socio-economic assessments are provided to the partners after each refinement of the LCA model. The yearly GA meetings will be used to discuss the fur-there improvement potential and possibilities.

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

7 Deviations and next steps

No deviations are presented.

The next steps to develop the LCA study is the data collection process. Figure 12 presents a timeline of the data collection dates. For instance, primary data is intended to be collected during month 29 for the dendromass production system and NBBM1, NBBM3, NBBM4. Similarly, initial and primary data collection with other project partners takes place during the following months 29, 30, and 31. Moreover, the different deliverables of the project partners guide the further and more detailed data collection. A first LCA preliminary report is planned to be delivered by month 36. Furthermore, it is planned to carry out data collection together with task 5.3 as far as possible to save several resources (time, travel expenses, other costs, etc.)

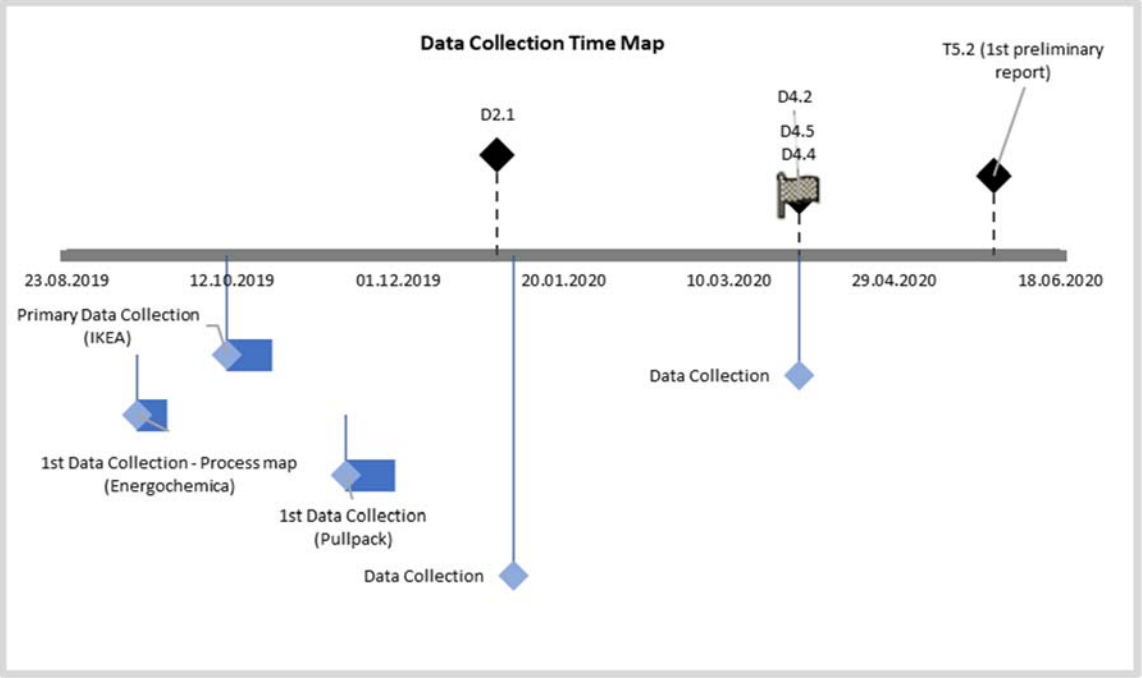

Figure 12 Timeline of relevant project deliverables

To communicate the progress and upcoming results of the LCA study, it is proposed to implement information feedback loops. These consist of sharing information to the project partners through a ppt report delivered every 5 months. The presentation of the reports, provide a space for feedback which seeks to improve the development of the LCA study and thus its results. It is planned to join the TSB meetings.

8 Conclusion and recommendations

It must be highlighted that as the value chains are currently in an R&D phase, not all processes, interlinkages and data are fully known. In order to rank the current maturity and further progress of the technological value chain, the concept of technological readiness level (TRL) is of use (Mankins 1995). As for the studied bio-based system, the activities of the value chains fall within different levels which has implications on the LCI. For NBBM 1, it is considered to be in between TRL 5 and 7 Meaning that the system prototype has been demonstrated, and the technology is being applied but is still under a R&D phase where new technologies might be integrated. As is the case with the proposed log deck for debarked poplar logs (Deliverable 3.1-Results of technical trails), and possible further material improvements (Deliverable 3.3 – Report on costumer survey). For NBBM 2, 3 and 4, they are considered to be within TRL 5. Which implies that the 'technology is validated in an industrial relevant environment in the case of key enabling technologies'. The assignment of the TRL level is done by analysing the WP and the timeframe of the different deliverables of each NBBM.

9 References

Arvidsson, Rickard and Magdalena Svanström. 2016. “A Framework for Energy Use Indicators and Their Reporting in Life Cycle Assessment.” *Integrated Environmental Assessment and Management* 12(3):429–36.

Arvidsson, Rickard, Anne Marie Tillman, Björn A. Sandén, Matty Janssen, Anders Nordelöf, Duncan Kushnir, and Sverker Molander. 2018. “Environmental Assessment of Emerging Technologies: Recommendations for Prospective LCA.” *Journal of Industrial Ecology* 22(6):1286–94.

Bacenetti, Jacopo, Domenico Pessina, and Marco Fiala. 2016. “Environmental Assessment of Different Harvesting Solutions for Short Rotation Coppice Plantations.” *Science of The Total Environment* 541:210–17.

Baptista, A. J., E. J. Lourenço, J. P. Pereira, F. Cunha, E. J. Silva, and P. Peças. 2016. “EcoPROSYS: An Eco-Efficiency Framework Applied to a Medium Density Fiberboard Finishing Line.” *Procedia CIRP* 48:170–75.

Bare, Jane C., Patrick Hofstetter, David W. Pennington, and Helias A. Udo de Haes. 2000. “Midpoints versus Endpoints: The Sacrifices and Benefits.” *The International Journal of Life Cycle Assessment* 5(6):319–26.

Beigbeder, Joana, Lata Soccalingame, Didier Perrin, Jean Charles Bénézet, and Anne Bergeret. 2019. “How to Manage Biocomposites Wastes End of Life? A Life Cycle Assessment Approach (LCA) Focused on Polypropylene (PP)/Wood Flour and Polylactic Acid (PLA)/Flax Fibres Biocomposites.” *Waste Management* 83:184–93.

Breton, Charles, Pierre Blanchet, Ben Amor, Robert Beauregard, and Wen Shao Chang. 2018. “Assessing the Climate Change Impacts of Biogenic Carbon in Buildings: A Critical Review of Two Main Dynamic Approaches.” *Sustainability (Switzerland)* 10(6).

Caputo, Jesse, Steven B. Balogh, Timothy A. Volk, Leonard Johnson, Maureen Puettmann, Bruce Lippke, and Elaine Oneil. 2014. “Incorporating Uncertainty into a Life Cycle Assessment (LCA) Model of Short-Rotation Willow Biomass (Salix Spp.) Crops.” *Bioenergy Research* 7(1):48–59.

Cherubini, Francesco, Glen P. Peters, Terje Berntsen, Anders H. Strømman, and Edgar Hertwich. 2011. “CO2 Emissions from Biomass Combustion for Bioenergy: Atmospheric Decay and Contribution to Global Warming.” *GCB Bioenergy* 3(5):413–26.

Crawford, Robert H. 2011. *Life Cycle Assessment in the Built Environment*. Vol. 111.

Dirzo, R. and E. Mendoza. 2008. “Biodiversity.” *General Ecology* 368–77.

Dolezal, Franz, Hildegund Mötzl, and Christina Spitzart. 2014. “Survey of Allocation Methods in Life Cycle Assessments of Wood Based Products.” *World Sustainable Building Conference* 157–64.

Döpke, Katharina, Christian R. Moschner, and Eberhard Hartung. 2013. “Environmental Aspects of Short Rotation Coppices - A Literature Survey.” *Landtechnik* 68(1):33–37.

Eggleston, Simon, Leandro Buendia, Kyoko Miwa, Todd Ngara, and Kiyoto Tanabe. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Vol. 5. Institute for Global Environmental Strategies Hayama, Japan.

Fantozzi, Francesco and Cinzia Buratti. 2010. “Life Cycle Assessment of Biomass Chains: Wood Pellet from Short Rotation Coppice Using Data Measured on a Real Plant.” *Biomass and Bioenergy* 34(12):1796–1804.

FPInnovations. 2015. “PRODUCT CATEGORY RULES (PCR) For Preparing an Environmental Product Declaration (EPD).”

Fufaa, Selamawit .., Bjørn Petter Jellea, Rolf André Bohnea, and Carine Grossriederc. 2013. *LCA OF NANO-COATED WOODEN CLADDINGS UTILIZING ACCELERATED AGEING TEST RESULTS*.

Goedkoop, M. J., R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, and Van Zelm R. 2013. “ReCiPe 2008, A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level; First Edition Report I: Characterisation; 6 January 2009.” 133.

González-García, Sara, Jacopo Bacenetti, Richard J. Murphy, and Marco Fiala. 2012. “Present and Future Environmental Impact of Poplar Cultivation in the Po Valley (Italy) under Different Crop Management Systems.” *Journal of Cleaner Production* 26:56–66.

Griffiths, Natalie A., Benjamin M. Rau, Kellie B. Vaché, Gregory Starr, Menberu M. Bitew, Doug P. Aubrey, James A. Martin, Elizabeth Benton, and C. Rhett Jackson. 2019. “Environmental Effects of Short-Rotation Woody Crops for Bioenergy: What Is and Isn’t Known.” *GCB Bioenergy* 11(4):554–72.

Gu, Fu, Yitao Zheng, Wujie Zhang, Xing Yao, Deng Pan, Alecia Sze Mun Wong, Jianfeng Guo, Philip Hall, and Nusrat Sharmin. 2018. “Can Bamboo Fibres Be an Alternative to Flax Fibres as Materials for Plastic Reinforcement? A Comparative Life Cycle Study on Polypropylene/Flax/Bamboo Laminates.” *Industrial Crops and Products* 121(January):372–87.

Guinée, Jeroen B. 2015. “Selection of Impact Categories and Classification of LCI Results to Impact Categories.” Pp. 17–37 in *Life Cycle Impact Assessment*. Springer.

Guinée, Jeroen B., Gjalt Huppes, and Reinout Heijungs. 2001. “Developing an LCA Guide for Decision Support.” *Environmental Management and Health* 12(3):301–11.

Guo, Miao. 2010. “Life Cycle Assessment (LCA) of Light-Weight Eco-Composites.”

Guo, Miao. 2013. *Life Cycle Assessment (LCA) of Light-Weight Eco-Composites*. Springer Science & Business Media.

Häkkinen, T., P. Ahola, L. Vanhatalo, and A. Merra. 1999. “Environmental Impact of Painted Exterior Wooden Cladding.” *VTT Julkaisuja* (834):1–84.

Heijungs, Reinout, Gjalt Huppes, and Jeroen B. Guinée. 2010. “Life Cycle Assessment and Sustainability Analysis of Products, Materials and Technologies. Toward a Scientific Framework for Sustainability Life Cycle Analysis.” *Polymer Degradation and Stability* 95(3):422–28.

Heller, Martin C., Gregory A. Keoleian, and Timothy A. Volk. 2003. “Life Cycle Assessment of a Willow Bioenergy Cropping System.” *Biomass and Bioenergy* 25(2):147–65.

Hetherington, Alexandra C., Aiduan Li Borrion, Owen Glyn Griffiths, and Marcelle C. McManus. 2014. “Use of LCA as a Development Tool within Early Research: Challenges and Issues across Different Sectors.” *International Journal of Life Cycle Assessment* 19(1):130–43.

Hischier, Roland, Bernd Nowack, Fadri Gottschalk, Ingrid Hincapie, Michael Steinfeldt, and Claudia Som. 2015. “Life Cycle Assessment of Façade Coating Systems Containing Manufactured Nanomaterials.” *Journal of Nanoparticle Research* 17(2).

Hoekstra, A. Y. and A. K. Chapagain. 2007. “Water Footprints of Nations: Water Use by People as a Function of Their Consumption Pattern.” *Integrated Assessment of Water Resources and Global Change: A North-South Analysis* 35–48.

Iritani, D. R., D. A. L. Silva, Y. M. B. Saavedra, P. F. F. Grael, and A. R. Ometto. 2015. “Sustainable Strategies Analysis through Life Cycle Assessment: A Case Study in a Furniture Industry.” *Journal of Cleaner Production* 96:308–18.

ISO. 2006a. “Environmental Management — Life Cycle Assessment — Principles and Framework - ISO 14040.”

ISO. 2006b. “ISO 14040: Environmental Management — Life Cycle Assessment — Principles and Framework. Technical Committee ISO/TC 207.” *Environmental Management* 3(1):28.

Jones, Christopher, Paul Gilbert, Marco Raugei, Sarah Mander, and Enrica Leccisi. 2017. “An Approach to Prospective Consequential Life Cycle Assessment and Net Energy Analysis of Distributed Electricity Generation.” *Energy Policy* 100:350–58.

Kalt, Gerald, Andreas Mayer, Michaela C. Theurl, Christian Lauk, Karl Heinz Erb, and Helmut Haberl. 2019. “Natural Climate Solutions versus Bioenergy: Can Carbon Benefits of Natural Succession Compete with Bioenergy from Short Rotation Coppice?” *GCB Bioenergy* (May).

Khaoula, Khwaldia, Arab-Tehrany Elmira, and Desobry Stephane. 2009. “Biopolymer Coatings on Paper Packaging Materials.” *Comprehensive Reviews in Food Science and Food Safety* 9(1):82–91.

Klöpffer, Walter and Birgit Grahl. 2014. *Life Cycle Assessment (LCA)*. John Wiley & Sons.

Korol, Jerzy, Dorota Burchart-Korol, and Magdalena Pichlak. 2016. “Expansion of Environmental Impact Assessment for Eco-Efficiency Evaluation of Biocomposites for Industrial Application.” *Journal of Cleaner Production* 113:144–52.

Kouchaki-Penchah, Hamed, Mohammad Sharifi, Hossein Mousazadeh, and Hamid Zarea-Hosseinabadi. 2016. “Life Cycle Assessment of Medium-Density Fiberboard Manufacturing Process in Islamic Republic of Iran.” *Journal of Cleaner Production* 112:351–58.

Lettner, Miriam. 2018. “RETHINKING TECHNOLOGY AND PRODUCT DEVELOPMENT IN THE CONTEXT OF THE EMERGING BIOECONOMY: THE CONCEPT OF SUSTAINABLE INNOVATION READINESS LEVEL (SIRL).”

Levasseur, Annie, Pascal Lesage, Manuele Margni, and Réjean Samson. 2013. “Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment.” *Journal of Industrial Ecology* 17(1):117–28.

Liptow, Christin, Matty Janssen, and Anne Marie Tillman. 2018. “Accounting for Effects of Carbon Flows in LCA of Biomass-Based Products—Exploration and Evaluation of a Selection of Existing Methods.” *International Journal of Life Cycle Assessment* 23(11):2110–25.

Liu, Weiguo, Zhonghui Zhang, Xinfeng Xie, Zhen Yu, Klaus Von Gadow, Junming Xu, Shanshan Zhao, and Yuchun Yang. 2017. “Analysis of the Global Warming Potential of Biogenic CO2 Emission in Life Cycle Assessments.” *Scientific Reports* 7(January):1–8.

Liu, Weiguo, Qiuan Zhu, Xiaolu Zhou, and Changhui Peng. 2019. “Comparative Analyses of Different Biogenic CO 2 Emission Accounting Systems in Life Cycle Assessment.” *Science of the Total Environment* 652:1456–62.

Lorite, Gabriela S., João Miguel Rocha, Noora Miilumäki, Paula Saavalainen, Tuula Selkälä, Gabriel Morales-Cid, M. P. Gonçalves, Eva Pongrácz, Cristina M. R. Rocha, and Geza Toth. 2017. “Evaluation of Physicochemical/Microbial Properties and Life Cycle Assessment (LCA) of PLA-Based Nanocomposite Active Packaging.” *LWT - Food Science and Technology* 75:305–15.

Manning, David Butler, Albrecht Bemmann, Michael Bredemeier, Norbert Lamersdorf, and Christian Ammer. 2015. *Bioenergy from Dendromass for the Sustainable Development of Rural Areas*. John Wiley & Sons.

Martin, Michael, Frida Røyne, Tomas Ekvall, and Åsa Moberg. 2018. “Life Cycle Sustainability Evaluations of Bio-Based Value Chains: Reviewing the Indicators from a Swedish Perspective.” *Sustainability (Switzerland)* 10(2).

Masson-Delmotte, Valérie, Hans-Otto Pörtner, and Jim Skea. 2018. *IPCC Report Global Warming of 1.5 ⍰C*.

McDevitt, James E. and Warren J. Grigsby. 2014. “Life Cycle Assessment of Bio- and Petro-Chemical

Adhesives Used in Fiberboard Production.” *Journal of Polymers and the Environment* 22(4):537–44.

Milà I Canals, Llorenç, Jonathan Chenoweth, Ashok Chapagain, Stuart Orr, Assumpció Antón, and Roland Clift. 2009. “Assessing Freshwater Use Impacts in LCA: Part I - Inventory Modelling and Characterisation Factors for the Main Impact Pathways.” *International Journal of Life Cycle Assessment* 14(1):28–42.

Milà i Canals, Llorenç, Joan Romanyà, and Sarah J. Cowell. 2007. “Method for Assessing Impacts on Life Support Functions (LSF) Related to the Use of ‘fertile Land’ in Life Cycle Assessment (LCA).” *Journal of Cleaner Production* 15(15):1426–40.

Mirabella, Nadia, Valentina Castellani, and Serenella Sala. 2013. “Life Cycle Assessment of Bio-Based Products: A Disposable Diaper Case Study.” *International Journal of Life Cycle Assessment* 18(5):1036–47.

Owens, J. W. 2001. “Water Resources in Life-Cycle Impact Assessment: Considerations in Choosing Category Indicators.” *Journal of Industrial Ecology* 5(2):37–54.

Pawelzik, P., M. Carus, J. Hotchkiss, R. Narayan, S. Selke, M. Wellisch, M. Weiss, B. Wicke, and M. K. Patel. 2013. “Critical Aspects in the Life Cycle Assessment (LCA) of Bio-Based Materials - Reviewing Methodologies and Deriving Recommendations.” *Resources, Conservation and Recycling* 73:211–28.

Peñaloza, Diego. 2018. “The Influence of System Boundaries and Baseline in Climate Impact Assessment of Forest Products.” 160–76.

Pfister, S., A. Koehler, and S. Hellweg. 2009. “Assessing the Environental Impact of Freshwater Consumption in Life Cycle Assessment.” *Environmental Science & Technology* 43(11):4098–4104.

Piekarski, Cassiano Moro, Antonio Carlos de Francisco, Leila Mendes da Luz, João Luiz Kovaleski, and Diogo Aparecido Lopes Silva. 2017. “Life Cycle Assessment of Medium-Density Fiberboard (MDF) Manufacturing Process in Brazil.” *Science of the Total Environment* 575:103–11.

Pradinaud, Charlotte, Stephen Northey, Ben Amor, Jane Bare, Lorenzo Benini, Markus Berger, Anne Marie Boulay, Guillaume Junqua, Michael J. Lathuillière, Manuele Margni, Masaharu Motoshita, Briana Niblick, Sandra Payen, Stephan Pfister, Paula Quinteiro, Thomas Sonderegger, and Ralph K. Rosenbaum. 2019. “Defining Freshwater as a Natural Resource: A Framework Linking Water Use to the Area of Protection Natural Resources.” *International Journal of Life Cycle Assessment* 24(5):960–74.

Puettmann, Maureen, Elaine Oneil, Earl Kline, and Leonard Johnson. 2013. “Cradle to Gate Life Cycle Assessment of Oriented Strandboard Production from the Southeast.” (Iso 2006):1–23.

Qiang, Tao, Demei Yu, Anjiang Zhang, Honghong Gao, Zhao Li, Zengchao Liu, Weixing Chen, and Zhen Han. 2014. “Life Cycle Assessment on Polylactide-Based Wood Plastic Composites Toughened with Polyhydroxyalkanoates.” *Journal of Cleaner Production* 66:139–45.

Rastogi, Vibhore and Pieter Samyn. 2015. “Bio-Based Coatings for Paper Applications.” *Coatings* 5(4):887–930.

Recchia, Lucia, Boncinelli Paolo, Enrico Cini, Marco Vieri, Francesco Garbati Pegna, and Daniele Sarri. 2011. *Multicrireria Analysis and LCA Techniques*. Springer.

Rivela, Beatriz, Almudena Hospido, M. Teresa Moreira, and Gumersindo Feijoo. 2006. “Wood and Other Renewable Resources (Subject Editor : Jörg Schweinle) Life Cycle Inventory of Particleboard : A Case Study in the Wood Sector.” *International Journal* 11(2):106–13.

La Rosa, Angela Daniela, Giuseppe Recca, John Summerscales, Alberta Latteri, Gulia Cozzo, and Gianluca Cicala. 2014. “Bio-Based versus Traditional Polymer Composites. A Life Cycle

Assessment Perspective.” *Journal of Cleaner Production* 74:135–44.

De Rosa, Michele. 2018. “Land Use and Land-Use Changes in Life Cycle Assessment: Green Modelling or Black Boxing?” *Ecological Economics* 144:73–81.

Rosenbaum, Ralph K. 2016. *Selection of Impact Categories, Category Indicators and Characterization Models in Goal and Scope Defi Nition*. Goal and S.

Rosenbaum, Ralph K., Michael Z. Hauschild, Anne Marie Boulay, Peter Fantke, Alexis Laurent, Montserrat Núñez, and Marisa Vieira. 2015. *Life Cycle Impact Assessment*.

Røyne, Frida, Diego Peñaloza, Gustav Sandin, Johanna Berlin, and Magdalena Svanström. 2016. “Climate Impact Assessment in Life Cycle Assessments of Forest Products: Implications of Method Choice for Results and Decision-Making.” *Journal of Cleaner Production* 116:90–99.

Schweier, Janine, Saúl Molina-Herrera, Andrea Ghirardo, Rüdiger Grote, Eugenio Díaz-Pinés, Jürgen Kreuzwieser, Edwin Haas, Klaus Butterbach-Bahl, Heinz Rennenberg, Jörg Peter Schnitzler, and Gero Becker. 2017. “Environmental Impacts of Bioenergy Wood Production from Poplar Short-Rotation Coppice Grown at a Marginal Agricultural Site in Germany.” *GCB Bioenergy* 9(7):1207–21.

Sommerhuber, Philipp F., Jan L. Wenker, Sebastian Rüter, and Andreas Krause. 2017. “Life Cycle Assessment of Wood-Plastic Composites: Analysing Alternative Materials and Identifying an Environmental Sound End-of-Life Option.” *Resources, Conservation and Recycling* 117:235–48.

Strömberg, L. 2004. “Integrated Life-Cycle Design of Coatings on Exterior Wood. Part 2: Life-Cycle Assessment.” *Surface Coatings International Part B: Coatings Transactions* 87(3):211–20.

Suh, Sangwon, Manfred Lenzen, Graham J. Treloar, Hiroki Hondo, Arpad Horvath, Gjalt Huppes, Olivier Jolliet, Uwe Klann, Wolfram Krewitt, Yuichi Moriguchi, Jesper Munksgaard, and Gregory Norris. 2004. “System Boundary Selection in Life-Cycle Inventories Using Hybrid Approaches.” *Environmental Science and Technology* 38(3):657–64.

Suter, Florian, Bernhard Steubing, and Stefanie Hellweg. 2017. “Life Cycle Impacts and Benefits of Wood along the Value Chain: The Case of Switzerland.” *Journal of Industrial Ecology* 21(4):874–86.

Tillman, A. M. and H. Baumann. 2004. “The Hitchhikers Guide to LCA.” *Lund, Sweden: Studentlitteratur AB*.

United Nations. 2016. *Biodiversity and the 2030 Agenda for Sustainable Development Biodiversity Is Essential for Sustainable Development*.

10 Appendix – Impact categories

10.1 Land Use

Land use is perceived as one of the most important environmental impacts to be measured. High relevance is giving due to the project goals, its scientific upsurge, and the intrinsic importance of measuring the effects resulting from using the land for dendromass production. Intended and unintended environmental impacts, such as biodiversity loss or gain, water use, land and other ecosystem services, biogenic carbon emissions, and other units of analysis are encountered due to land use and land use change.

Direct land use change (DLUC) and indirect land use change (ILUC) are two typical differentiations maid in LCA studies. DLUC refers to the intentional modification of land for the cultivation of dendromass, food or feed. Whereas ILUC, is known as the unintentional change of land occurred outside the production area, which is induced due to the production of dendromass feedstock. The present study focuses only on the effects of DLUC, this due to a large number of uncertainties related to the characterization models and data accuracy in ILUC assessments (Pawelzik et al. 2013; De Rosa 2018).

An agreed approach to incorporate land use in LCA studies is however missing. Nevertheless, an approach is to consider a group of characterization factors, which concerns land use. In the following subchapters, a description of the considered DLUC units of analysis is presented.

10.1.1 Biogenic carbon

In order to calculate the impact of carbon on issues as climate change, the carbon cycle of the system needs to fully consider all associated carbon flows. For biomass-based products, there is an increasing discussion on current methods for assessing a product carbon life cycle and, the significance of temporal system boundaries. Common LCA methodologies, such as ISO (2006) and the IPCC guidelines for national GHG inventories (Eggleston et al. 2006), have been criticised for not accounting properly the carbon flows in bio-based product systems. Mainly, concerning an incorrect computation of carbon from biomass, also known as biogenic carbon. The argumentation is that the carbon stock exchange between the biogenic carbon produced is equal to the carbon intake of newly produced biomass. Which results in a carbon neutral balance. Meaning that if the biogenic carbon coming from, for instance, bio-based material combustion, would be accounted for, it will result in double counting (Levasseur et al. 2013). However, during the last years, this argumentation has been highly disputed. Particularly, due to the time dependency of carbon release (carbon decay) and, the difference between unit process of carbon uptake dynamics and biogenic carbon emissions (Liu et al. 2019; Røyne et al. 2016). Carbon which is released, before being captured by biomass regrowth, spends time in the atmosphere and thus contributes to global warming (Cherubini et al. 2011). For instance, Liptow et al. (2018) presents empirical evidence through an LCA study on bio-based polyethylene packaging. The results show that when considering the biogenic flows and time dependency, profound effects on the results for global warming potential are presented. Therefore, if biogenic carbon flows are not accounted for, system sub-optimization is highly probable.

For fast growing trees, like poplar in SRC plantation, the carbon stocks produced as a result of the production system are restored in a short period of time after harvesting (Kalt et al. 2019). However, this does not necessarily mean that SRC systems have no climate impact related to biogenic carbon flows. Cherubini et al. (2011), recommends that before drawing general conclusions other related factors, such as: displacment efficiency, rotation management, time and spatial boundaries, land-use changes and other life cycle related conseuqences, need to analyzed. For example, Kalt et al. (2019) draw conclusions on the impact that assumed displacement factors have on carbon flow calculations.

Several methods which include carbon cycles and temporal differentiations for LCA studies have been proposed. Breton et al. (2018) presents a review of twenty methods, that have been developed since 2009. Among all the studies, two methods are highlighted due to their ability in including all GHG and produce numerous metrics. These methods are: Dynamic LCA (DLCA) (Levasseur et al. 2013) and GWPbio (Cherubini et al. 2011). Both methods have been further developed and applied to multiple case studies (e.g. Martin et al. 2018; Røyne et al. 2016; Liptow, Janssen, and Tillman 2018; Liu, Zhang, et al. 2017).

Concerning bio-based material SRC production systems, there are few studies which analysed the effect of different biogenic carbon accounting systems. Most studies focus on bioenergy production, such as the study by Liu et al. (2019), who compares the difference of including the GWPbio in an LCA, with a conventional LCA. Results present the relevance of including a correct accounting of biogenic carbon, as this will deliver more realistic results on the climate change impact category, and thus for a correct comparison between bio-based system with other production systems.

In contrast to bio-energy systems, studies which account for carbon flows in bio-based material systems should also include the biogenic carbon contained within the material itself (Pawelzik et al. 2013). This carbon storage is generally temporal, two relevant processes can be distinguished. First, for long lasting materials, stored carbon would delay the radiative forcing effects and thus could help offsetting current carbon emissions. Secondly, this carbon will be at some point released to the atmosphere and thus add to the total emissions. The accounting and influence of these two interlinked processes, highlights the imminent importance of considering the variable time within a bio-based LCA study. Peñaloza (2018) expands on this topic by investigating the influence of spatial and temporal system boundaries on forest products using an LCA study. Using the method of DLCA, the author discusses the difference in the climate impacts, considering a time horizon, especially for long-life products.

On this base, accounting for biogenic carbon, as carbon stored within products, and carbon emission after the product's end of life, will add to a more realistic calculation to the land use environmental impact.

10.1.2 Biodiversity

Biodiversity represents the variety of life that encompasses our ecosystems. It includes all the plants, animals, fungi, microorganisms, their genetic and phenotypic variation, and the habitats which they are part of (Dirzo and Mendoza 2008). This diversity of life on Earth is considered as essential for sustainable development and human well-being (United Nations 2016). The use of land for biomass production, among other factors, can potentially affect and accelerate biodiversity loss. Therefore, several characterization methods have been proposed. These methods focus on different stressors, such as acidification, ecotoxicity, land use, climate change, eutrophication, and climate change (Pawelzik et al. 2013). In terms of land use, biodiversity can be affected by the occupation and transformation of land. The first refers to the effects caused by the use of the land (e.g. agriculture), and the second covers the consequences of changing the land from its previous state to a modified system.

In order to account for biodiversity in LCA studies, different characterization models have been proposed. Among them, the ReCiPe method (Goedkoop et al. 2013) is widely recognized. This method is based on energy, matter and information flows. It differentiates twelve different types of land use, and tree levels of land intensity. Moreover, it calculates an endpoint characterization factor, which accounts for the potentially disappeared fraction of species, and species density for in studied ecosystem.

As part of WP 1 (land evaluation, remediation and farm cooperation), task 1.3 (environmental impact assessment and monitoring), the project partner DAPHNE has developed an initial biodiversity monitoring. The data obtained from this outcome is fundamental for the biodiversity assessment of the LCA. Thus, further collaborations with DAPHNE will take place.

10.1.3 Water use

For the production of biomass and the different industrial processes, the use of water is considered as a potential concern. Water is one of the most valuable natural resource for our existence, and with the rise of agricultural biomass it is likely that the required amounts of water also increase (Pradinaud et al. 2019). Particularly, water becomes even a more strategic resource in many regions of the world where water scarcity is already an issue. Water resources have a central role in poverty alleviation, human civilization and economic development.

In terms of methods to assess the water use in LCA studies, two general categories are understood. First, a group of methods which treat water as an abiotic resource, meaning that only the volumes (flows) of water or its contamination are accounted (Goedkoop et al. 2013; Hoekstra and Chapagain 2007; Owens 2001). The second group, are those which account for the impact of water use and pollution of different areas of protection (AoP), as: human health, ecosystem quality, and natural resources (Pradinaud et al. 2019; Milà i Canals, Romanyà, and Cowell 2007; Milà I Canals et al. 2009; Pfister, Koehler, and Hellweg 2009).

For bio-based materials systems, Pawelzik et al. (2013) proposed that the method developed by Pfister et al. (2009) should be favoured. This method is a midpoint assessment, and it considers the cause and effect relationship between water consumption and the different AoP. A more in-depth analysis of this and other methods is carried during the LCA study.

In relation to the project development, WP1 will contribute to the data required for the water use assessment. WP1 identifies the nutrient and water availability of dendromass production. And also, the soil water availability under different meteorological conditions. Thus collaborations with the project partner, Institute of Soil Science and Site Ecology (TUD-ISSE), are in hand with the development of the LCA study.

Moreover, considering the interlinkages between task 5.2 (environmental assessment) and 5.3 (socio-economic assessment). The calculation of water use, and its relationship with the AoP derives important results for not only the environmental side, but also for its effects on the social aspects (e.g. health) and the economical perspective (e.g. water for agriculture).

10.1.4 Soil degradation

This refers to any undesirable change of the soil characteristics, like loss of productivity, physical or chemical degradation and erosion. Soil degradation will then result in further external requirements, to recover productivity (e.g. the use of fertilizers). Weather related erosion, as wind and water are considered to be the most imperative. One of the key factors affecting soil erosion is, land cover, either natural or human induced (Cebecauer and Hofierka 2008).

Several methods to assess soil erosion have been proposed. For instance, Núñez et al. (2013) proposed a soil erosion indicator which considers three intensity categories based on a universal soil loss (USL) equation. Also, Saad et al. (2011) proposed a method based on the ability of an ecosystem to stabilize soil and to prevent accumulation of sediments downstream. Consequently, the Erosion Regulation Potential (ERP), which is also based on the USL equation was proposed. More recently, Thoumazeau et al. (2019) proposed a model named the LANCA ® model, this is based on the assessment of five characterization factors, as erosion potential, Infiltration reduction potential, physicochemical filtration reduction potential, groundwater regeneration reduction potential and biotic production loss potential. Notwithstanding the importance of soil degradation on DLUC, several of the communally applied LCI methodologies (e.g. CML, Eco-indicator, IMPACT) do not consider soil erosion.

As part of WP1, task 1.2 (site/ landscape evaluation and monitoring) data on soil dynamics and soil nutrient contents, among others will contribute to the assessment of soil degradation.

10.2 Climate change

The impact category, climate change, refers to the influence of human activities on the warming of the climate system. Also termed anthropogenic global warming. GHG emission are the principal cause of climate change. Other sources, are aerosol emissions and terrestrial albedo. Some of the direct consequences of climate change are: sea level rise, damages to ecosystems, extreme meteorological events, rising of minimum and maximum temperatures, and also several indirect effects, as: health risk, biodiversity loss, resources crises, and others. The most recent report from the IPCC warns against the likelihood that global warming will reach 1.5°C, between 2030 and 2052. The risks associated with this increase, are expected to be catastrophic for life as we know (Masson-Delmotte, Pörtner, and Skea 2018). Thus, LCA studies present an important contribution to knowledge of the influence that production systems have on climate change.

The most common characterization factor for climate change is the Global Warming Potential (GWP). It represents the cumulative radiative forcing of a GHG to a specific time horizon, relative to the same value calculated for carbon dioxide (CO_2). The four main GHGs considered are CO_2, methane (CH_4), nitrous oxide (N_2O) and halocarbons (Rosenbaum et al. 2015). The GWP represents a midpoint characterization, the values are normally calculated for different time horizon, for instance 20, and 100 years (Guo 2010).

Another approach to calculate the effect of a system on climate change are those referred to endpoint methods. These, focus on a broad range of impacts, such as perturbations in rainfalls, warmer oceans, marine productivity, malnutrition and other consequences resulting from the warming climate. To model endpoint factors is however complex. They are attached to several uncertainties related to cause and effect pathways, and to difficulties in predicting how climate change adaptation will develop (Rosenbaum et al. 2015).

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union´s Horizon 2020 research and innovation programme under grant agreement No 745874.

10.3 Energy Use

This input category targets to reveal how much energy is required to produce a product or service. The main importance of studying the energy use impact category are: (i) the use of energy for sustaining human wellbeing, (ii) the finite energy resources, (iii) enhancement of energy efficiency of a system (Arvidsson et al. 2018; Rosenbaum 2016). In order to assess this impact category, several different energy use indicators are identified. These indicators are the following: non-renewable energy consumption, renewable energy consumption, embedded fossil energy, cumulative energy consumption, primary energy demand and consumption, among others. In order to select a set of indicators for the assessment of energy use, the methodological framework proposed by Arvidsson and Svanström (2016) is of help.

The mentioned framework was developed based on previous literature which focused on life cycle energy use of bio-based materials. It accounts for four types of energy inputs, which are categorized depending on the origin of the energy (renewable or no-renewable sources), primary or secondary energy, and the intended use of the energy (e.g. for electricity, as a material, etc). From this, five energy use indicators are proposed, cumulative energy demand (CED), fossil energy use (FEU), non-renewable cumulative energy demand (NRCED), primary fossil energy use (PFEU), secondary energy use (SEU).