ASSESSING AND APPLYING BIOTIC PRODUCTION INDICATORS IN THE FOREST INDUSTRY

Lappeenranta–Lahti University of Technology LUT

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ABSTRACT

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Assessing and applying biotic production indicators in forest industry

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79 pages, 5 figures, 12 tables and 2 appendices

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Keywords: Land use, biotic production, life cycle assessment, life cycle impact assessment

This Master's thesis is part of European Union's Orienting project, as part of which land use indicators are analysed and developed to be suitable in new Life Cycle Sustainability Assessment methodology. The study evaluated biotic production indicators and how they could be developed. Background related to the topic was acquired from literature and interviews with Stora Enso representatives, from which forest industry's point of view was achieved. Two biotic production indicators were chosen for closer evaluation, and of which the more suitable was selected to be applied in the case study.

Objective of the study was to give recommendations on how biotic production indicator could be developed to match forest industry's needs better. Indicator was evaluated with the help of the case study, where liquid packaging board container production's impacts to three countries' biotic production were assessed. According to observations made during the modelling process, development recommendations were given related to the applicability and the result interpretation.

As a result, targets for development were found from both terminology and impact assessment method. The terminology differs significantly between used database, impact assessment framework and applied indicator, which complicates the life cycle modelling process. In addition, the indicator cannot evaluate impacts from land transformation, which can affect significantly to final results, depending on the case.

TIIVISTELMÄ

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Kalle Kinnunen

Bioottisen tuotannon indikaattorien arviointi ja soveltaminen metsäteollisuudessa

Diplomityö

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79 sivua, 5 kuvaa, 12 taulukkoa ja 2 liitettä

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Diplomityö on osa Euroopan Unionin Orienting projektia, jonka osana maankäytön indikaattoreita tarkastellaan ja kehitetään uuteen, kestävän elinkaarimallinnuksen, viitekehykseen soveltuviksi. Työ tarkasteli bioottisen tuotannon indikaattoreita ja niiden kehitystarpeita. Taustaa aiheeseen liittyen hankittiin kirjallisuudesta, sekä haastattelusta Stora Enson kanssa, josta saatiin näkökulmaa suoraan metsäteollisuuden toimijalta. Kaksi bioottisen tuotannon indikaattoria valittiin lähempään tarkasteluun, joista sopivampi valittiin käytettäväksi tapaustutkimuksessa.

Työn tavoitteena oli antaa suosituksia, joiden mukaan bioottisen tuotannon indikaattoria voitaisiin kehittää vastaamaan metsäteollisuuden tarpeita paremmin. Indikaattoria tarkasteltiin tapaustutkimuksen avulla, jossa mitattiin nestekartonkipakkauksen vaikutuksia kolmen maan bioottiseen tuotantoon. Mallinnusprosessin aikana tehtyjen havaintojen perusteella annettiin kehitysehdotuksia käyttökelpoisuuteen sekä tulosten tulkintaan liittyen.

Tuloksena kehityskohteita löydettiin sekä terminologiasta, että vaikutustenarviointi menetelmästä. Terminologia eroaa merkittävästi käytetyn tietokannan, vaikutustenarviointi viitekehyksen sekä esitetyn indikaattorin välillä, joka vaikeuttaa elinkaarimallinnuksen tekemistä. Indikaattorilla ei myöskään pystytä huomioimaan maankäytön muutosta, joka voi tilanteesta riippuen vaikuttaa merkittävästi saatuihin lopputuloksiin.

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In Kerava, 6 September 2022

Kalle Kinnunen

ABBREVIATIONS

GDP	Gross Domestic Product
LCA	Life Cycle Assessment
PEF	Product Environmental Footprint
LCSA	Life Cycle Sustainability Assessment
REPA	Resource and Environmental Profile Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PEFCR	Product Environmental Footprint
EF	Environmental Footprint
AoP	Area of Protection
LANCA	Land Use Indicator Value Calculation
NPP	Net Primary Production
HANPP	Human Appropriation on Net Primary Production
SFM	Sustainable Forest Management
AWaRe	Available Water Resources
CF	Characterization Factor
PNV	Potential Natural Vegetation
CEENE	Cumulative Exergy Extraction from the Natural Environment
NDP	Natural Degradation Potential
STDV	Standard Deviation
WP	Work Package
SQI	Soil Quality Index

LADA Land Degradation Assessment Analysis

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1 Introduction

In today’s world, people are consuming more and more goods, services, and energy. This is due to population growth and increased standard of living. In 2021 population growth was 1,0% (Macrotrends 2022) and global gross domestic product (GDP) growth 5,7% (Bea 2022) compared to year 2020. The same trend has continued for years, which means that there is every year more people consuming more goods and services. In order to fulfil people’s needs, resources are needed. Some of them are renewable, and in some cases, the available amount is limited. Currently, society’s resource usage is not on a sustainable level. An example of that is Overshoot Day, which marks the date when humanity’s ecological resource and service needs have exceeded the amount that Earth can regenerate in that year. The date takes place earlier each year, and in 2021 that day was 29th of July. (Earth overshoot day 2022)

To produce different kind of commodities to fulfil people’s needs, land is needed. Buildings, trees or even fish demand certain area of land to exist. Land is one of globally limited resources that need to be cherished. If humanity runs out of land area, it will be difficult to meet people’s needs. One large consumer of land is forests, which provide extensive amount of raw material, and cover 31% of the world’s total land area (FAO 2020, 14). Forest industry is built around them. This business produces different kinds of products from wood raw materials. The industry is dependent on forests biomass production, which can be assessed with biotic production indicator.

Biotic production is an indicator, which measures how much a certain area of land can produce biomass annually. In forest industry it can be measured manually, by just tracking how much trees grow. In addition to that, biotic production has also been implemented into Life Cycle Assessment (LCA) framework, where biotic productions’ effects on land’s quality are considered. Several biotic production indicators have been developed, but currently none of them is widely accepted or fully applicable for LCA framework. To fully meet its purpose, the indicator needs to be further developed.

1.1 Background

This study is part of Operational Life Cycle Sustainability Assessment Methodology Supporting Decisions Towards a Circular Economy project, which is referred as ORIENTING project. It is EU-funded project led by Tecnalia, which is a Spanish research and technology development center. Project is also supported by several research institutes and companies, such as VTT and Stora Enso. Goal of the project is to develop life cycle sustainability assessment (LCSA) methodology, which covers all social, economic, and environmental aspects, and considers criticality and circularity. Project started on the 1st of November 2020 and lasts for three years. (European Commission 2020)

The project is divided into seven different work packages (WP), and each WP includes variable number of tasks, which are smaller entities, and together provide results for each WP. This study is part of the WP 2 – LCSA methodology, of which objective is to extent the product environmental footprint (PEF) framework towards LCSA as well as to develop and integrate indicators for LCSA. (European Commission 2020) This study is part of the task which develops an improved and consistent land use model, which includes integration of new or update of existing land use indicators, and suggestions to improve the land use framework in Environmental Footprint (EF). (Horn & al 2021, 100)

In the ORIENTING project, land use indicators are divided into four separate categories, which evaluate land usage from different perspectives. These categories are biodiversity, biotic production, erosion and soil organic carbon. Each of these categories have their own indicators and have to be developed individually. (Horn & al 2021, 63,73,83,90) In this study, focus is on the indicators considering biotic production. Biotic production defines the total amount of biomass that is produced by organisms in a given time, relative to an area (Horn & al 2021, 37). The more biomass the organism produces, the higher the biotic production is. It does not limit only to trees but can be measured also for example for tomatoes or sheep's wool.

1.2 Objective of the study

Biotic production is an essential indicator for forest industry, since it defines how much raw material can be produced. It has been studied in several papers, in which different approaches and indicators have been presented. These indicators have been viewed and critically evaluated as part of the ORIENTING project. As a result, indicators presented by Alvarenga et al. (2015) and Taelman et al. (2016) scored the best and are therefore the most promising indicators for biotic production assessment. (Horn & al 2021, 74) Due to that, these two papers are selected as the basis for further development recommendations.

Despite getting the best scores from evaluation, both Alvarenga's and Taelman's indicators have their shortages. For example, neither of the methods are compatible enough with life-cycle approach (Horn & al 2021, 74). Objective of this study is to give recommendations how biotic production indicator should be developed in the future to meet needs of forest industry. Analysis is made particularly about applicability of the impact assessment model and accuracy of achieved results. This study answers to a research question, which is:

- How biotic production assessment should be developed to be more applicable for forest industry?

1.3 Structure and limitations

This thesis consists of two parts: Theoretical and practical part. Theoretical part is carried out by gathering information from literature, and includes three chapters, of which first one explains and analyses LCA framework that is the framework in which indicator is used. Second chapter takes a look into the forestry sector and points out matters that should be considered in the indicator. That chapter includes also results from Stora Enso interview, where deeper understanding of forest industries point of views is achieved. Last theory chapter reviews papers provided by Alvarenga et al. (2015) and Taelman et al. (2016) which provide indicators for biotic production.

In the practical part the more suitable indicator is applied into the case study, in which LCA model for liquid packaging board container is made. Applicability of the indicator is evaluated during the modelling process, based on which development recommendations can be found. Ready model calculates indicator results, which describe impacts to biotic production. Also, these results are viewed and analysed, and flaws behind the results are noted. Based on these two viewpoints recommendations for development are given.

Case study is limited to consider land use in LCA only from biotic production point of view. Modelling is performed with Sulca software, and data is acquired from ecoinvent database. Analysis is established on the basis of these, and therefore, study do not take a stand on other databases and LCA software.

2 Significance of indicators in LCA

In the world, there are various resources available. Different resources have differing properties and can be used in several functions. These resources can be divided to different categories, based on their properties and intended use. The amount of some of these resources is not infinite, and when more sustainable resource consumption is pursued, actions need to be made. (Beylot & al 2020, 3-4) One tool to evaluate the material intensity of products or services is LCA. LCA points out potential environmental impacts, which are converted to be easily understandable with assistance of indicators. This chapter presents the concept of LCA and what kind of role indicators play when environmental impacts are assessed.

2.1 LCA as a methodology

LCA is standardized methodology, which assesses the potential environmental impacts of products or services throughout their whole life cycle (ISO 14040, v). Its history begins from the 1960s, when issues such as waste disposal and air pollution emerged. As a result, Resource and Environmental Profile Analysis (REPA) methodology was developed, and it was applied first time in 1960s. When understanding of environmental impacts increased, REPA was not sufficient for evaluation. So, the first international ISO standards was published in 1996, which included also impact assessment phase. When academic awareness increased further, flaws in the standards were recognized. (Soukka & al 2020) Thus, general methodological framework and guideless ISO standards for LCA were established in 2006 (Hauschild & al 2018, 19). These standards are still used when LCA study is conducted.

Currently there are two ISO standards that create the basis for LCA studies, ISO 14040, and ISO 14044. ISO 14040 sets principles and framework, and ISO 14044 requirements and guideline for conducting LCA study. (ISO 14040,1, ISO 14044,1) In these standards, the process of performing an LCA study is described precisely. That is extremely important, so that all LCA studies are in line, and can be compared to each other.

LCA study includes four phases, which are goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and interpretation. Goal and scope definition phase includes determination of several aspects, which are laying the foundation, and ensuring breadth, depth, and detail of the study. After the basis for the study is defined in goal and scope definition, LCI phase is started. It involves data collection and calculations, where relevant input and output flows of the studied product system are quantified. (ISO 14040, 1-2) In most cases, LCI is the most arduous part, since gathering all relevant data related to product system might be challenging. For example, large scale companies may have decentralized different functions, which makes data collection even harder.

After LCI is completed, LCIA can be started based on results from LCI. LCIA aims to evaluate potential environmental impacts by using the results from LCI. Impacts can be assessed from different perspectives, called impact categories, such as acidification, eutrophication, or global warming potential. In the last phase, interpretation, LCI and LCIA are considered together, and results are delivered consistently with goal and scope definition. It presents reached conclusions, explains selected limitations, and provides recommendations. (ISO 14040, 1-2) All four phases are strongly interconnected, which is illustrated in Figure 1.

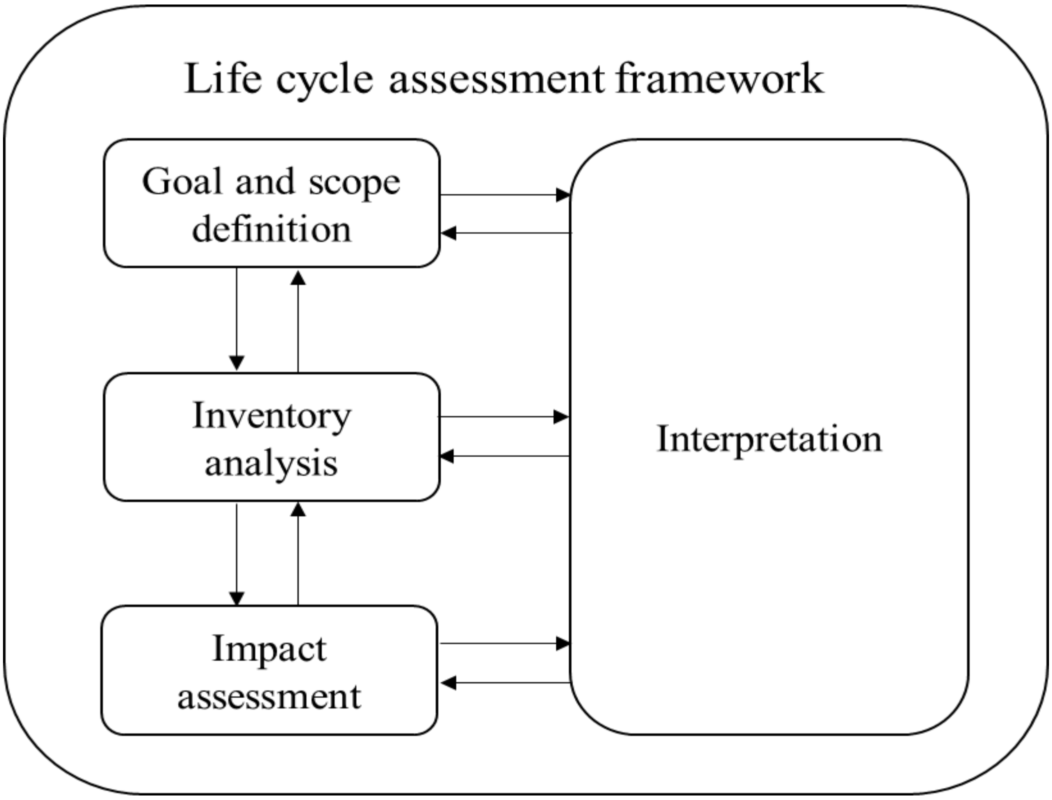

Figure 1. Life cycle assessment framework. (ISO 14040, 8)

As it can be seen from Figure 1, even though LCA phases are separated, they are still linked to each other. Interpretation is not limited to consider only results from impact assessment, but also to other phases. It is needed in each phase, to guide the study to right direction. Due to interpretation, also errors are noticed, and for example goal and scope definition can be modified to be in line with the rest of the study. So, interpretation is a significant part of the study, and works as a backbone to modify the work to be a comprehensive entity.

In addition to LCA methodology provided in ISO standards 14040 and 14044, life cycle impacts can be also assessed with Product Environmental Footprint (PEF) methodology. It is initiated by the European Commission and is part of the project that started in 2013 with pilot phase. (Sphera Solutions 2020) In 2018 Product Environmental Footprint Category Rules Guidance (PEFCR) was published, which provides detailed and comprehensive technical guidance on how to conduct a PEF study (European Commission 2018). PEF framework is based on a life cycle approach and includes four phases. The phases are goal and scope definition, LCI, LCIA and Environmental Footprint (EF) reporting. (Sphera

Solutions 2020) So in outline, structure of PEF study is very similar to the one presented in ISO standards.

Currently PEF framework is on transition phase, which started in 2019, and is planned to be completed by the end of 2024 (European Commission 2021, 7). Transition phase aims to provide a framework for monitoring the implementation of existing Environmental Footprint rules, developing new rules and new methodological developments. (European Commission A) PEF offers more harmonized approach for environmental information. A single set of rules is valid for the whole European market, where instructions for calculation are more specific and consistent. Consequently, studies are carried out in a similar way, and it is easier to compare studies between each other.

Overall, LCA is a tool which is used to recognize problematic phases in product systems life cycle, from environmental perspective. Examination can be limited to account only specific life cycle stages or relevant environmental impacts, depending on the study. Direct applications for LCA are for example product development, strategic planning or public policy making. (ISO 14040, 8) However, it does not serve solutions itself, but points out the issues that should be focused. Based on results achieved from LCA, actions can be made to improve the system.

2.2 Life cycle impact assessment

LCIA aims to evaluate the significance of a potential environmental impact, and it is separated into different elements. Three of the elements are mandatory and should be implemented in every LCA study. First mandatory part is selection of impact categories, category indicators and characterization models. Selection of these shall be consistent with the goal and scope definition. (ISO 14044, 7) These create the basis for impact assessment, and determine what environmental impacts are relevant related to the study, and how those are measured. The second mandatory element is assignment of LCI results, which is called classification. In this phase inventory results are reviewed to see what flows are affecting to selected impact category. When these relevant flows are defined, the last mandatory element, characterization can be done. It means that category indicator results are calculated.

Additional to mandatory elements, there are four optional elements. These are normalization, grouping, weighting and data quality analysis, and can be implemented after mandatory phases are completed. Normalization, grouping and weighting are elements that aim to observe results from different perspectives and give understanding of significance of caused impacts. Data quality analysis on its part does not concentrate to the results themselves, but into how reliable these results are. Data quality analysis can be implemented for example as uncertainty or sensitivity analysis. (ISO 14044, 20-22)

In the PEF framework, PEFCR defines list of recommended characterization models at midpoint level, including their indicator, unit, and source where CFs should be acquired. The list includes a total of 16 impact categories. Also, normalization and weighting factors for these categories are provided. (European Commission 2018, 159-164) Since factors are predetermined, comparability of different studies is enhanced significantly. When each PEF study follows these recommendations, results can be interpreted together, which will bring additional value for LCA practitioners.

Impact assessment can adopt either midpoint or endpoint approach. These are examples of characterization models, which provide indicators at different levels. Endpoint approach evaluates caused environmental impacts at the Areas of protection (AoP), such as human health or resources. Midpoint approach on its part assesses the environmental impact at a level in cause-effect chain from the release of substance or consumption of resource to the endpoint level. (Dong & Ng 2014, 1410) Due to these different approaches, impacts can be assessed on different levels. Overall, these elements and approaches create comprehensive framework for impact assessment, where impacts are calculated, but also evaluated and understood in the bigger picture.

2.3 Indicators and their necessity

As stated in the previous chapter, indicators are in a significant role in the impact assessment. Those are defined separately for each impact category and are called as category indicators. They give quantified representation of an impact category. (ISO 14040, 6) Indicators are strongly connected to three different terms: Impact category, characterization model and characterization factor (CF). Together these elements create a whole, whereby indicator results can be calculated.

Impact category selection defines what environmental impacts from LCI are considered. For example, if impact category is selected to be global warming, only greenhouse gas emissions are taken into account. In that case, category indicator would be global warming potential, which indicates potential environmental impacts resulted from greenhouse gas emissions. (Guinee 2015, 17) So, a category indicator is determined based on the selected impact category. When LCI results are converted into the unit of category indicator, CFs are used. CFs are derived from characterization models, which form an entity considering impacts affecting certain impact category. (ISO 14040, 5)

Indicators can assess impacts on midpoint or endpoint level. Midpoint level provides several impact categories when endpoint level considers only AoPs. However, midpoint level indicators can be aggregated into endpoint indicator, but in some cases, it might affect to results uncertainty. Yet, it has the advantage of providing more condensed information for decision makers. (Rosenbaum & al 2018, 167) It is good that indicators can be evaluated on both levels, so indicator results can be presented on a suitable way, depending on the study.

2.4 Land use in LCA

Land use is one of the impact categories in LCA, which assesses potential impacts caused by the use of land by humans. Changes in land use can have various affects from species composition changes to climate and water regulation. It affects to all key AoPs, which are natural resources, human well-being, and ecosystem quality. (Canals & Baan 2015, 198 & 202) Due to wide-ranging effects, land use is definitely significant topic.

It has been stated that land use-related impacts represent one of the main challenges in LCA, since the methodology was originally developed to assess industrially manufactured processes and services. (Soukka & al 2020, 5). Also, Sala et al. (2019) and Vidal Legaz et al. (2017) have pointed out that the specification of a common land use cause-effect chain is a significant research gap. Considering the significance of the topic and presented shortages in impact assessment, this is an issue that certainly needs to be focused on.

LCA impact assessment considering land use follows the life cycle initiative of the Society for Environmental Toxicology and Chemistry of the United Nations Environmental Programme (UNEP-SETAC). UNEP-SETAC defines comprehensive framework and sets principles for global land use impact assessment, and so forms the basis for land use evaluation models. Currently land use impacts in LCA are evaluated based on LANCA (Land Use Indicator Value Calculation) method. (Horn & al 2021, 15 & 20). LANCA method represents CFs for impacts on ecosystem services that are country and land use specified. CFs are presented for five different impact categories, which are erosion resistance, mechanical filtration, physicochemical filtration, groundwater regeneration and biotic production. (Bos & al 2016, 13)

Background in land use assessment according to LANCA is based on concepts of land occupation and land transformation that are implemented according to Baitz (2002). Occupation means that land is used in the intended productive way and the properties of a piece of land are maintained. During transformation the properties of a piece of land are modified, to be suitable for an intended use. (Koellner 2013, 1190) These are specific depending on the case, since for example time, location and type of occupation are affecting the outcome. Land occupation and transformation are illustrated in Figure 2.

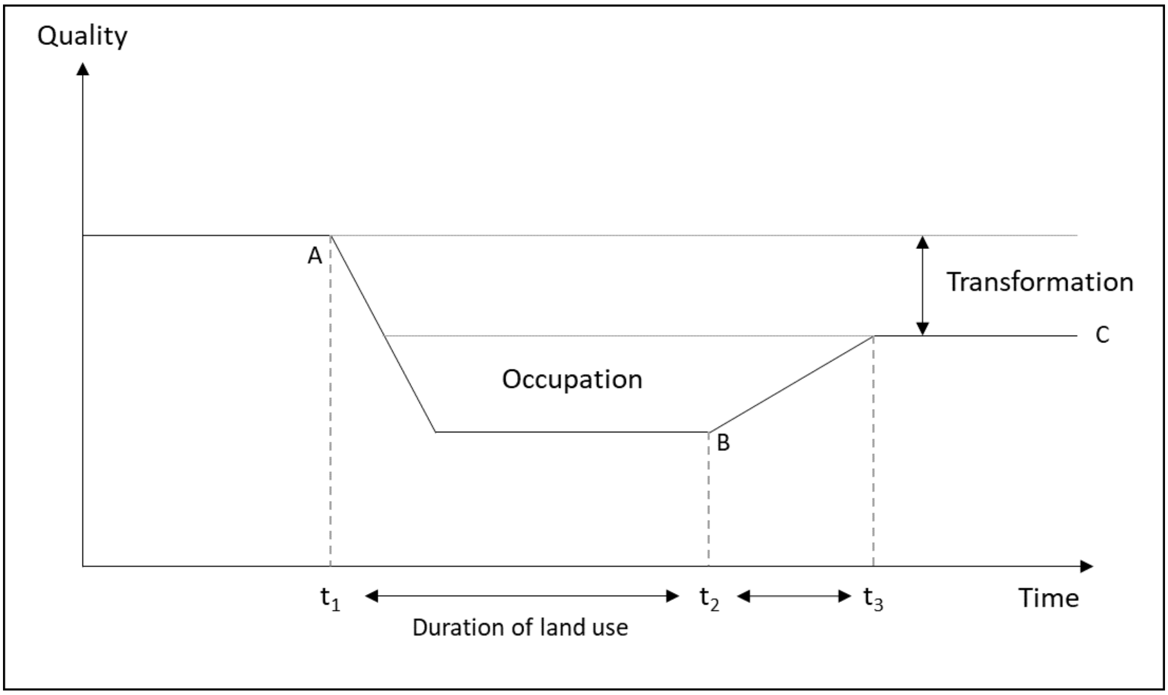

Figure 2. Land occupation and transformation. (Beck & al 2010, 39)

Figure 2 presents the basis for land use impact assessment. Point A is a starting point, where quality of the land is on certain level, and occupation have not yet started. After t_1, land use type is changed which affects the quality of the land and lasts until t_2. Land use ends at point B (t_2), which is followed by quality recovery. In t_3, land has reached its recovery potential and quality stabilizes on level C. Occupation is displayed between quality alteration and the parallel to the abscissa crossing C (Beck & al 2010, 16). Transformation can be seen as a difference between land quality before occupation, and after land recovery. If human appropriation enhances productivity, is quality alteration reversed compared to Figure 2.

When the roles of transformation and occupation of land in cause-effect chain are considered, they have a bit different consequence. In transformation biomass stocks are decreased because alteration is permanent. In occupation, the situation is different, since land is only modified and properties are maintained, which results as change in biomass production. In a bigger picture, the cause-effect chain in land use is complex, and changes may affect to several aspects of land simultaneously. One impact causes the next one, and eventually also AoPs are affected. This is illustrated in simplified impact pathway in Figure 3, where phases concerning this study are highlighted in red.

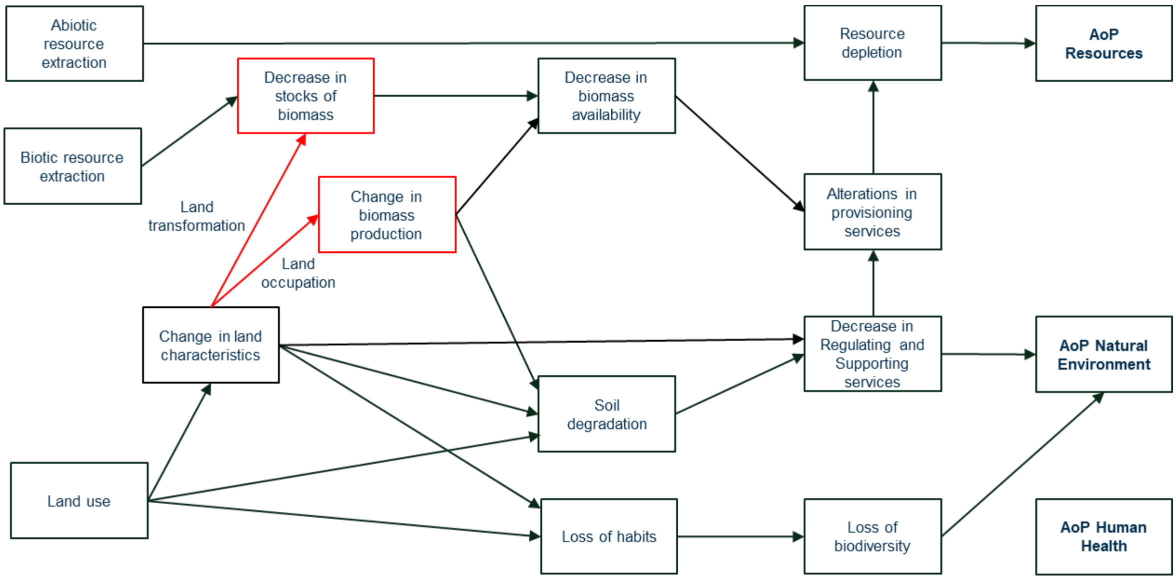

Figure 3. Simplified impact pathway. (Alvarenga & al 2015, 442)

PEFCR recommends that LANCA framework is used for land use LCIA at midpoint. Indicators for biotic production, erosion resistance, mechanical filtration and groundwater replenishment are included. In addition, indicator for Soil Quality Index (SQI) is presented, which is the result of the aggregation of these 4 indicators provided by LANCA. (Fazio & al 2018, 24) Those indicators have been pooled and re-scaled to obtain dimensionless SQI, a single score index, which accounts these four different properties presented in LANCA (Fazio & al 2018, 24). That simplifies LCA calculations since land use can be assessed with only one index. Yet, all four indicators have been included, so any of the aspects have not been neglected. Table 1 presents land use types, for which indicators have been defined in PEF.

Table 1. Land use types according to PEF framework. (European Commission B)

agriculture	mineral extraction site
agriculture, mosaic	pasture/meadow
arable	pasture/meadow, extensive
arable, fallow	pasture/meadow, intensive
arable, flooded crops	permanent crops
arable, greenhouse	permanent crops, irrigated
arable, irrigated	permanent crops, irrigated, extensive
arable, irrigated, extensive	permanent crops, irrigated, intensive
arable, irrigated, intensive	permanent crops, non-irrigated
arable, non-irrigated	permanent crops, non-irrigated, extensive
arable, non-irrigated, extensive	permanent crops, non-irrigated, intensive
arable, non-irrigated, intensive	shrub land
artificial areas	snow and ice
bare area	traffic area
construction site	traffic area, rail network
dump site	traffic area, rail/road embankment
field margins/hedgerows	traffic area, road network
forest	unspecified
forest, extensive	unspecified, natural
forest, intensive	unspecified, used
forest, natural	urban
forest, primary	urban, continuously built
forest, secondary	urban, discontinuously built
forest, used	urban, green areas
grassland	urban/industrial fallow
grassland, for livestock grazing	wetlands
grassland, not used	wetlands, coastal
grassland/pasture/meadow	wetlands, inland
industrial area	

As it is shown in Table 1, occupations comprise a wide range of different land use types from urban areas to crops and forests. That is needed, because land is used in various ways. Even if total of 57 land use types are noticed, it does not match fully with reality. Numerous of land use types exist, and same kind of land usages might have only slight differences. Therefore, two differing land uses may fit to the same category, despite differences in their properties. Depending on the land use type, it has been defined on variable accuracy, and some land use types have been defined in more specific manner than others. So, it is also possible that one land use type fit to two categories. As specific land use type should be selected, so more accurate results can be achieved. It is however good that also more wide categories exist, so every land use type can be matched.

Land use impact assessment is a complex topic, since there are many aspects that are affecting to quality of the land. Degradation may happen naturally or be man-made, caused impacts can be either negative or positive, and location and climate affect how well land is able to recover after usage. (Canals & Baan 2015, 201-202) In addition to these, there are several other aspects affecting to land usage. Therefore, CFs need to be developed carefully, so that they correlate with reality.

2.5 Biotic production

Biotic production is one part of the land use impact assessment in LCA, and it is also considered in the LANCA framework. Biotic production is bound to the concept of biotic resources, which is defined as living objects that are removed from the natural environment and play vital role for sustaining the livelihood of many people. Biotic resources are classified as renewable, and include for example fish, sheep wool or wood resources. (Schneider & al 2016, 187-188) Biotic production describes the productive potential of land and evaluates biomass production capacity of land in given time, relative to an area. (Horn & al 2021, 37) So, the more biomass certain piece of land can produce, the higher biotic production is.

Impacts of biotic production can be assessed with several indicators. However, most suitable of those is based on the term Net Primary Production (NPP). It is a key process for life on earth (Taelman & al 2016, 151) and describes the total primary productivity of the ecosystem minus the autotrophic respiration. NPP can be expressed in three different units, energy (J/m^2), carbon ($g\ C/m^2$) or dry organic matter (t/ha). (Beck & al 2010, 58) Other significant concept related to biotic production is Human Appropriation of Net Primary Production (HANPP) indicator. It was developed by Haberl & al in 2007 and assesses the intensity of land use. It measures the difference in the free NPP left for ecosystem between current land vegetation and a reference natural situation. (Taelman & al 2016, 148) Therefore, HANPP can define how much human intervention has affected to the NPP.

LANCA presents approximation for NPP factors in unit of kg/m^2*a. These factors are defined separately for different land use types, based on literature sources. Some of the factors are corrected depending on the type of use and degree of sealing. As a result, LANCA provides CFs for 58 different land use types, whereby indicator results can be calculated. (Bos & al 2016, 39)

3 Forest industry perspective

Forest industry is dependent on land, and the biomass growing on it. A share of 31% of the world's total land area is covered with forest, but resources are not distributed equally. More than half of the forests are in only five countries. (FAO 2020, xi) Nevertheless, it can be said that forests serve an abundant resource globally. Even if resource is ample, it needs to be nurtured. Since 1990 the world has lost a net area of 178 million hectares of forests. Loss rate have slowed through the years, but still between 2010 and 2020, 4,7 million hectares were lost annually. (FAO 2020, xi)

Overexploitation of the forest could lead to significant consequences. World's forests store over 660 gigatons of carbon, most of which is found in the living biomass and soil organic carbon. Total forest carbon stock has slightly decreased during past 30 years. (FAO 2020, xv) Too intensive forest usage would also have impacts to resource availability, especially in the long run. To secure permanent resources and limit negative impacts, sustainable forest management (SFM) is widely applied in forest industry.

3.1 Forest industry

Basic idea of forest industry is to convert timber into products. It is often divided to three major industries: pulp, paper and wood products. (Forest.fi 2019) In addition to these, there are also a lot of different kind of products, such as chemicals, granules and lignin, which are produced on a smaller scale. (Stora Enso 2022) Among development of processes and society, it is very likely that also other kind of applications for timber is found. To fulfill resource needs in all these sectors, available resources have to be used wisely.

Resources used in forest industry include whole trees, logging residues and processing residues. Whole trees form vast majority of the resources. Those consist of trees harvested from forests, plantations, orchards etc. and include trees that are harvested for energy, removed in thinning operations, due to disease or death and to reduce forest fire potential. Logging residues are referred as primary forest residues. Those are materials that are resulted from collection and harvesting operations of trees, and include treetops, twigs and branches. Processing residues are also called as secondary forest residues. Those extend by-products from processing, such as sawdust, bark, or black liquor. (Walsh 2014) To use available forest resources efficiently, it is important that both trees and produced residues are utilized. Those have different kind of properties, and can be used to produce different products, like for example pellets, which can be made from sawdust (Sitra 2020).

3.2 Sustainable forest management

SFM aims to ensure that forests supply goods and services so that both present and future needs are met, and it also contributes to the sustainable development of communities. Aim of the concept is to maintain and enhance the economic, social, and environmental values of all type of forests. As sustainable solutions and frameworks usually, also SFM is related to United Nations Sustainable Development Goals. Three goals that are associated with SFM are Clean Water and Sanitation, Affordable and Clean Energy, and Life on Land. (FAO 2022)

Forest management can be assessed throughout six broad objectives. These objectives are production, protection of soil and water, conservation of biodiversity, social services, multiple use, and other. Each objective reviews the forest management from different angle, and together those cover all the most significant topics related to SFM. Issues that are not included in the first five objectives are considered in other section. (FAO 2020, 57) Each objective is certainly extensive and extend wide range of issues. Together these objectives create comprehensive way to assess SFM, but also indicates what kind of issues need to be taken into account.

To meet these objectives in practice, different kind of actions can be implemented. One of the most common practices is forest management plan. (European Union 2018, 19) It identifies goals and performance targets for forest management. It also defines actions that are needed to achieve these goals. These actions extend for example forest harvest limitations, actions for protection, and development operations. (Kollert & Cedergren 2017, 1) Forest management plan forms framework that guides management of the forest in larger scale. If forest management plan is not implemented, there are several separate practices that can be applied, such as prevention mechanisms for forest fires, protection against pests or drought, and information collection for monitoring and evaluation purposes (European Union 2018, 19). Fundamentally both forest management plan and separate management practices aim to the same goal, which is healthier, sustainable, and diverse forest.

3.3 Differences of forests

Forests growing around the world are not uniform, which is result of various aspects. Based on climatic domain, forests can be divided into four categories: Boreal, temperate, subtropical and tropical domains. The tropical domain extends the largest proportion of world’s forest, 45%. Tropical forests are located around the equator, and majority of them are in the Africa and South America. The second largest proportion is boreal domain, which covers 27% of the forests, and are located to the northern latitudes. Temperate (16%) and subtropical (11%) domains compile rest of the forests, and are growing nearly side-by-side, mostly in North America, Central Europe and Eastern Asia. (FAO 2020, 14) Distribution of forests are presented in Figure 4.

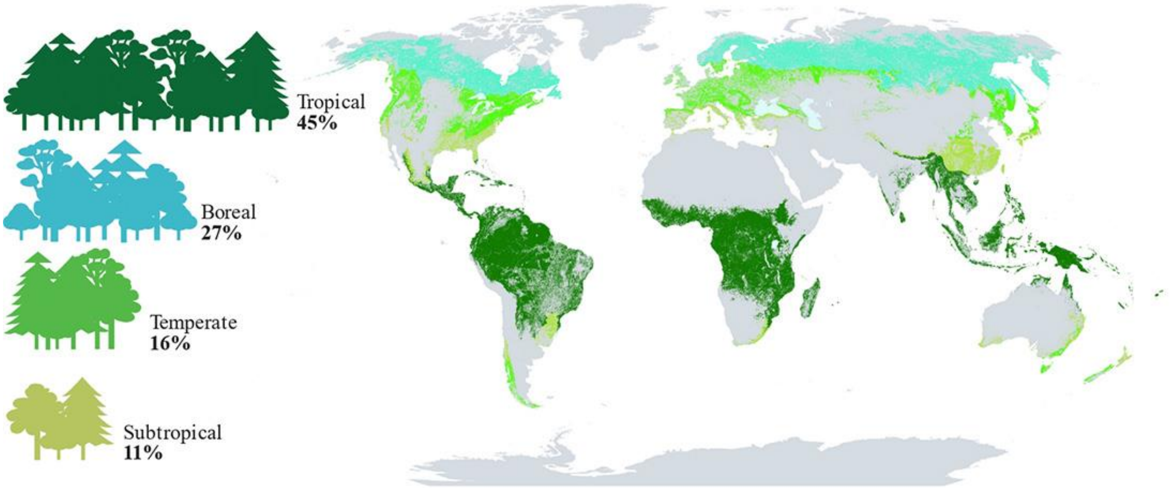

Figure 4. The global distribution of forests, by climatic domain. (Science buddies 2021)

As it can be understood, geographical location affects to forests type. Due to differing climatic conditions not only forests, but also living organisms and lifeless environment vary depending on the location. The ecosystem on its part creates circumstances, which are optimal for different kind of forest types. Wood from forests can be broadly divided into two groups: Softwood and hardwood. Softwoods are conifers and normally have needle like leaves and are often light in color. Hardwood has broad leaves, dark-colored wood and is mostly deciduous. (Asif 2009)

These two types have their own characteristics, which are differing from each other. Typically, hardwood's structure is more complex, which leads to increased growing time but also to it being more dense, heavy, and hard wearing. Hardwood may take even up to 150 years before it is ready to be harvested, when softwood usually reach that point in around 40 years. (Duffield Timber 2021) That is significant factor, which affects to hardwoods availability. Other noteworthy aspects are strength, durability, and workability (Duffield Timber 2021). If wood with low workability is processed, it will consume much more time and money compared to wood with higher workability.

Based on woods properties, it needs to be evaluated where certain wood type is smart to be used. Hardwood is used for example as construction material, in flooring and in boatmaking. Due to its strong and resistant attributes, it is suitable for applications which need assertiveness and durability for a long time. (Duffield Timber 2021) Softwood is used by the construction industry, but also to produce paper, pulp, and card products. However, there is a considerable variation between different species, and for example some hardwoods may be softer than most softwoods. (Speight 2020) Therefore application need to be evaluated individually for each species.

Forests can be divided into separate categories also based on how they are managed. Two main resource flows for forest industry are from managed forests and plantations, which are two totally different types of forests. In managed forests, people are acting intentionally in a way, which leads to increased production of wood products and services. Management can be applied by individual, state, municipality or even timber industry, and its intensity varies depending on landowners' objectives. (Grotta 2019A) Managed forests can account both naturally regenerating and planted forests. From naturally regenerating forests timber can become available for example via thinning, when in managed forests trees are cut after rotation period.

Active management of the forests have started around the 20th century, depending on the country (Metsähallitus & Manheim 2010). However, forests have already existed millions of years before that. It has been defined that carbon content of sustainable forestry remains unchanged in tree biomass over a complete rotation period (Sarthe & Gonzales-Garcia2014). Trees absorb and need carbon to grow, so it can be deduced that if forest type and carbon content remains the same, also the biomass production should be approximately the same.

Plantations on their turn are total opposite for naturally regenerated forests. In plantations multiple trees are planted at the same time, and in most cases, all the trees are the same species. Intended goal is to maximize the production of wood fiber, and usually trees are planted uniformly to maximize growing space and to ensure uniform growth. Advantage of plantations is that those are typically grown on a short rotation compared to managed forests, which gives opportunity to response to changing climatic conditions. (Grotta 2019B) On the other hand, there are some concerns related to plantations as well. Some of them are in developing countries or in dry areas. If timber is produced in poor countries, and then transported to wealthy countries to use, it increases inequality. Also, in dry areas irrigation is needed. If country suffers for water scarcity, it is not sustainable to use water resources to plantations, when water should be used for local people. (Grotta 2019B)

Plantations have firstly implemented in 1400s, but intensive breeding have been applied since 1950. (Turnbull, 3) Therefore their history is a lot shorter compared to natural forests. Plantations are not natural forest type and are planted to certain area. This means that land have previously been used for something else. Most of the plantations are made to abandoned agricultural land, but also to places, where it replaces native forests. (Boyle & al 2016) Therefore its impacts on land's quality varies depending on the original land use type.

Wilderness forests are areas, where forests, species, and nature's diversity are protected due to for example cultural heritage or national landscape. In these areas nature is left on its natural state, excluding maintaining actions. (Ympäristöministeriö) So, wilderness forests certainly are not remarkable source for wood-based industries. Same thing applies also for urban forests, which are comprised of trees in landscapes, along streets or parks (Grotta 2019C). Meaning of urban forests is mainly to increase living comfort and bring variety for landscape in urban areas. So, naturally number of trees in these areas is not very remarkable, and therefore cannot supply significant amounts of timber.

3.4 LCA and biotic production

Just like in other sectors, also in forest sector LCA is convenient tool to recognize where resource use and emissions can be limited. LCA techniques have been conducted since the early 1990s, but consistent and comprehensive LCA studies are still lacking in forest sector. In addition, conducted studies have showed differences between methodological assumptions and their subsequent results. (Klein & al 2015, 556) Due to that, final results are different, and most importantly cannot be compared to each other. Wider implementation of LCA could also bring additional value for the whole industry.

Raw wood products and biomass are widely declared as carbon neutral and renewable resource. However, production steps of these have impacts to environment due to for example machinery usage, management, and land use changes. (Duka & al 2017) Degree of renewability is dependent on the amount of non-renewable inputs into the product system. Trees and other plants can grow without human activities, but with the supply of raw material, non-renewable inputs are used. For example, fertilizer usage or site preparation can have a significant influence on the environmental impact of biomass products. (Klein & al 2015, 557) Therefore it is important to evaluate the whole product chain, even if used raw material is declared as renewable and carbon neutral.

As presented earlier, forests have wide range of differences that need to be considered in LCA. Just like any product, also forests can be assessed from various perspectives, such as climate change, land use or water use. Obviously results from each category are different since those are assessing different matters. For example, geographical location provides differing possibilities for trees to grow. In the areas that are suffering from water scarcity, usage of irrigation could affect drastically to results in water use category, but just slightly to climate change. Therefore, goal and scope definition phase is extremely important, so intended impact category is known. In that case relevant results to particular case are achieved. In studies where overall sustainability is assessed, weighting of indicator results need to be set in a way that it is in line with value-choices made. So, outcome is dependent on which impacts are wanted to evaluate and emphasize.

Impacts to biotic production are comprised of land occupation and transformation. Occupation needs to be considered for each forest type, but in case of transformation there is exception. For sustainably managed forests the quality change can often be considered as 0. This is due to modelling practice presented in ecoinvent database, where land use type do not change in case of sustainably managed forests, and therefore transformation for these forests can be excluded.

LCA framework overall is suitable for various kinds of assessments and can evaluate sustainability from several perspectives. Biotic production is just one indicator considering land use, and therefore cannot assess wider whole. It is good to note that aim of the indicator is not to assess sustainability comprehensively, but only the amount of biomass production. Earlier presented differences of forests are affecting to biotic production directly and more significantly than to LCA as a whole, since it measures productivity of the forest. To achieve reliable LCA results, these aspects need to be considered, and assumptions in the modelling process known. Indicator cannot be the same for every piece of land because the starting point is totally different depending on the area.

3.5 Stora Enso interview

To get a deeper understanding of forest industry’s points of view and their issues and concerns regarding biotic production assessment, an interview was held with Stora Enso. Annika Nordin, Vice President for sustainable forest management and Marjukka Kujanpää, Sustainability LCA manager from Packaging Materials division were interviewed regarding the questions presented in Appendix 1. Their expertise extended both forest and LCA points of view, so questions were answered from different perspectives. They brought up points that had already been considered in this thesis but provided also new viewpoints and ideas that could be applied or at least considered alongside biotic production.

Stora Enso evaluates biotic production of their forests extensively. They are aware of biotic production of each of the forest stand that is in their holding. The amount of biotic production is valuable data for the company, since it defines the availability of the resource, and indicates when forests need to be harvested. It is tracked for example with satellite images and airborne laser scanning. With these methods it is possible to measure growth in a very careful matter, almost on a tree basis. Biotic production is the most influential indicator from forest’s perspective, and it is definitely needed. However, it needs to be set in a way that is relevant for forest systems. (Annika Nordin 2022)

During the interview, several factors were pointed out that should be taken into account and included into the indicator. The biggest suggested object is that the future indicator must be able to recognize positive aspects as well. That emphasizes especially in forest industry since both companies and individuals aim to enhance forests productivity. To be applicable, the indicator has to also define reference scenario clearly. When the reference scenario is clear for practitioners, the indicator is easier to implement. (Annika Nordin 2022) Reference situation cannot be the same around the world, but it needs to be defined regionally. The smaller the regions are, the more accurate results are possible to achieve. Reference scenario definition affects directly to obtained results, so they should be carefully determined.

On regionalized CFs also local differences could be considered. For example, water scarcity is a big problem in some countries, and if irrigation is needed, it decreases significantly overall sustainability of the forest. Same applies also for example to nutrients and pesticides whose demand vary depending on the location. However, every aspect should not be included to the biotic production factor. For instance, soil organic carbon is assessed separately in Finland, and it functions well. On the other hand, it was also mentioned that aspect like biodiversity would not possibly be smart to include into the indicator. (Annika Nordin 2022) So, the indicator could consider local differences that affect directly to biotic production, and simultaneously to overall sustainability. However larger entities that do not affect directly to biotic production, could be assessed separately.

It was also questioned whether indicators from different models could be implemented as a part of biotic production assessment. As an example, Available Water Remaining (AWaRe) indicator could be included, so the biotic production indicator would assess sustainability more comprehensively. It was pointed out that recreational values could be included as well. Most likely people would like to be in a forest that is not so dense, and maybe has a small lake too. (Annika Nordin 2022) In case of plantations, the forest may be extremely dense and therefore biotic production is also significantly higher. However, it will not serve as a pleasant place to be, compared to most of the Nordic forests.

Despite extensive biotic production evaluation of their forests, Stora Enso has not applied biotic production assessment in any of their LCA models and therefore expertise related to this particular topic in LCA is rather poor. Stora Enso would like to apply this method, but they do not know how to do it and have found it quite complicated. (Marjukka Kujanpää 2022) That is a significant issue, since the object of the LCA is to give advice for users in decision making. If the indicator cannot be or is really complicated to implement, it does not fulfill its purpose, and will not offer any help.

However, Stora Enso has participated in projects where land use impact assessment has been applied via HANPP or other similar indicators. It has been noted that paper and board products are always getting lower scores, since forest is used as a resource. It has been wondered why land usage is such a negative thing in LCA, and if CFs are reflecting to it correctly. It is true that land use may have some negative aspects, but it also has positive ones. Especially in case of forest industry, where biomass production is aimed to enhance via sustainable forest management. It is questioned whether land usage is seen as too negative in the LCA. (Marjukka Kujanpää 2022)

3.6 Summary of forest industry point of view

Forests provide great amount of resources, which can be used to produce energy, goods and services. To have availability to these resources also in the future SFM is applied, which guides landowners to make sustainable choices. When this topic is evaluated from forest industries point of view, it is even more important issue, since their business is dependent on the forests. In addition, when sustainability is assessed from industry’s viewpoint, even larger perspective needs to be applied. It is totally different to acquire wood from local forest compared to plantation thousand kilometers away. In that case also wood’s quality and other properties may differ significantly. To function, forest industry needs to use its resources efficiently, and select used raw materials carefully.

LCA is a great tool when these improvements are pursued. However, to be useful, it needs to be possible to apply in a right way. Whole framework needs to be applicable, and used indicators have to correspond reality. In addition, used methods should be easy and clear to implement, to be able to achieve accessible additional value. In case where biotic production of forest belonging to forest company is compared to forest with no human appropriation, it is obvious that biotic production and naturalness are decreased. Therefore, definition of reference scenario is one of the most influential aspects. However, in most cases actions are made to increase biotic production. So, both negative and positive impacts need to be possible to assess.

4 Review of methods provided by Alvarenga et al. and Taelman et al.

This chapter takes look into Alvarenga et al. (2015) and Taelman et al. (2016) papers considering biotic production accounting in LCA. These two papers have been chosen under more specific examination because they were selected as the most promising methods in ORIENTING projects critical evaluation (Horn & al 2021, 74).

4.1 Alvarenga et al.

Alvarenga et al. paper considers global land use impacts on biomass production. Objective is to create LCIA method on land use impacts on NPP based on the HANPP approach. Paper provides CFs for both midpoint and endpoint approaches. Midpoint CFs are calculated by comparing NPP of plants occurring under current land uses with baseline scenario. In case of endpoint CFs backup technology concept is considered, and calculation of the marginal costs for additional biomass production through algae cultivation in the ocean is included. (Alvarenga & al 2015, 440)

The HANPP model evaluates how intensively a defined piece of land is used. That is done by comparing NPP of Potential Natural Vegetation (PNV) with the NPP left in the ecosystem after harvest. PNV describes vegetations state under current climate conditions without land use. In other words that defines natural potential for NPP, if there would not be human intervention. To calculate NPP left in the ecosystem after harvest, NPP of the actual vegetation is calculated and the biomass amount harvested for human purposes is subtracted. HANPP can be defined as the difference between natural potential NPP and the NPP left on the ecosystem after harvest. (Alvarenga & al 2015, 442)

Alvarenga et al. divide NPP into two cases: “actual NPP” and “natural potential NPP”. Actual NPP refers to the NPP of currently prevailing vegetation under current land use and with or without human intervention. That can mean for example infrastructure areas, agricultural lands or forests. Natural potential NPP is the NPP that would occur under current climate conditions in the hypothetical absence of direct human intervention. When natural potential NPP and actual NPP are known, HANPP can be calculated, which works also as midpoint CF. Calculation is presented in equation 1. (Alvarenga & al 2015, 422)

$$CF_{i,j}(midpoint) = HANPP_{LUC_{i,j}} = Natural\ potential\ NPP_{i,j} - Actual\ NPP_{i,j} \quad (1)$$

where *i* is the location and *j* the land use type in kg DM/m^{2}a. (Alvarenga & al 2015, 443)

To define spatial-differentiated CFs, data of natural potential NPP was obtained to have values for specific land uses within each country. Actual NPP was defined for cropland, pastureland, infrastructure land, wilderness, and forest. In addition to these land use types, actual NPP was defined for top six crops based on the production quantity and top six crops in global area harvested in the World. In total actual NPP was determined for 10 crops, since some of them were in the top for both categories. (Alvarenga & al 2015, 443)

In case of endpoint CFs both backup technology and alternative technology concepts were applied to reach ultimate quality limit of a certain resource. It is not straightforward to derive backup technology for biomass. Differing management practices are affecting NPP, and local constraints and land types are setting boundaries for biomass production, so it is challenging to find suitable backup technology that could be implemented to all types of land uses. As a result, seaweed production in the ocean was selected as the alternative biomass production technology. Average value for kilogram of dry matter was assumed to be 14.50 US$. Based on that it was possible to calculate endpoint CFs, according to equation 2. (Alvarenga & al 2015, 443-444)

$$CF_{i,j}(endpoint) = HANPP_{LUC_{i,j}} \times 14.50 \quad (2)$$

Both midpoint and endpoint CFs can be either positive or negative, since actual NPP can be higher or lower than natural potential NPP. If actual NPP is higher than natural potential NPP, it means that more biomass is produced, which can be achieved for example via irrigation, whereas lower actual NPP leads to less biomass produced. Positive CF means that human action leads to an environmental impact, and negative CF indicates an environmental benefit. CFs for both midpoint and endpoint indicators were produced at four levels: site-generic and biomass generic, site-specific and biomass-generic, site-generic and biomass-specific, and site-specific and biomass-specific. When CFs were created, their applicability were tested in case studies. (Alvarenga & al 2015, 444)

As a result, site-generic and site-specific CFs were created in a global scale for 162 countries, for four land use types and for ten particular crops. In case of forests, CFs were not possible to generate due to lack of data. (Alvarenga & al 2015, 444)

4.2 Taelman et al.

Taelman et al. considers accounting for land use in LCA and assesses the value of NPP as a proxy indicator. It has three objectives, which are: identify the land use activities, review and categorize indicators that have already been developed, and propose two proxy indicators. So, the paper defines background of concepts related to land use, which helps to understand cause-effect chains in environment. After that, evaluation of various indicators points out their advantages and drawbacks. Based on analysis of these two parts, reasonable proposal of new enhanced indicators can be given. (Taelman & al 2016, 143-144)

First, Taelman et al. present how land functions are defined in literature. Terminology is explained, and for example differences between land cover, land use, land occupation and land transformation are clarified. Land-based processes and resources are identified, and both natural and human appropriated affects are noted. Based on these, concept of land use is understood, and the paper proceeds to define how land use impacts are assessed. Study concentrates to environmental impacts, which can be assessed comprehensively in LCA. So, the study presents also the main principles of LCA related to this topic. (Taelman & al 2016, 144-145)

Significant part of the paper focuses to LCIA indicators that have already been developed and are assessing the environmental impact of land use. Review is divided into two categories depending whether indicator assesses impacts on the AoP natural resources or AoP ecosystem health and considers only the most applicable indicators that fit to LCA framework. In case of AoP natural resources total of six papers were reviewed, of which 5 considered natural biomass and one considered soil. AoP ecosystem health section reviewed 20 papers and had indicators considering ecosystem health from seven different perspectives: Biodiversity, erosion regulation, water cycling, erosion and freshwater regulation, water purification, climate regulation and soil quality. Most of the 20 papers concentrated on biodiversity, while other perspectives were evaluated in total of seven papers. (Taelman & al 2016, 147-150)

Review of indicators explains shortly methodologies that have been used and points out the differences between various approaches. Analysis of these indicators reveal their advantages that could be used also in the enhanced indicators. Due to complexity of the consequences related to land use, all the different impacts cannot be understood by applying just one indicator. However, it was recognized that NPP is a key process for life on earth, and it was proposed as good starting point for development of new indicators. It was noted that NPP is a good proxy midpoint indicator for the impacts on ecosystem services but can be also used as a proxy to determine biomass loss due to land use. (Taelman & al 2016, 151)

NPP-based LCA indicators were reviewed more deeply, based on which two concepts were selected: HANPP and naturalness (or hemeroby). Both indicators assess the same type of land use impacts, but the underlying structure is different. Also, CFs are spatially differentiated and calculated in exergy terms for both indicators. (Taelman & al 2016, 144)

Exergy defines the maximum useful work that can be extracted from a system as it reversibly comes into equilibrium with environment (Exergy economics). Impacts are accounted according to Cumulative Exergy Extraction from the Natural Environment (CEENE) method, in which the exergy content of the potential natural NPP is evaluated (Taelman & al 2016, 148-149).

HANPP approach is quite similar to the one presented by Alvarenga et al. but CFs are calculated in exergy terms. In addition, CFs are calculated for 40 land use types instead of 4 and for 169 countries instead of 162. Based on these, world map with 3680 zones was created, where each country's land use types are identified. To have exergy-based CFs, HANPP was multiplied with the biomass-to-exergy factor. Zone-dependent area-weighted averages of HANPP were calculated in spatial analyst tool, which represent the loss of NPP due to land use. NPP can be defined as the ratio between the NPP left in the ecosystem after harvest and the NPP of the potential vegetation, which is illustrated in equation 3. (Taelman & al 2016, 152)

$$CF_{occ,i,j} = NPP_{loss,x} = NPP_{0,x} - NPP_{t,x} = NP_{0,x} - NPP_{act,x} + NPP_{h,x} = \Delta NPP_{LC,x} + NPP_{h,x} = HANPP_x \quad (3)$$

where $CF_{occ,i,j}$ is the CF of land occupation impact on ecosystem health for land use type *i* in country *j* (further referred to zone x), $NPP_{loss,x}$ is the NPP loss due to land use in zone x (MJ_{ex}/m^2a), $NPP_{0,x}$ is the average potential NPP in zone x (MJ_{ex}/m^2a), the $NPP_{t,x}$ is the average remaining NPP for the natural environment after land use in zone x (MJ_{ex}/m^2a), $NPP_{act,x}$ is the average NPP of the actual vegetation in zone x (MJ_{ex}/m^2a), $NPP_{h,x}$ is the amount of NPP harvested in zone x (MJ_{ex}/m^2a), $\Delta NPP_{LC,x}$ is the impact on NPP due to human-induced land conversions in zone x (MJ_{ex}/m^2a) and $HANPP_x$ is the average NPP impact due to human land use in zone x (MJ_{ex}/m^2a). (Taelman & al 2016, 152)

Naturalness approach is used as a state descriptor of ecosystem, and the highest naturalness is equal to PNV in an undisturbed situation. It is linked to ecological aspects and is defined by set of descriptive conditions, such as water dynamics, the level of biodiversity and pollution. Due to naturalness's complexity, it cannot be expressed as a single quantifiable parameter, and an ordinal scale is applied. So, distinction between different land classes is made based on descriptive conditions. It is assumed that the more naturalness is preserved, the better it is for ecosystem health. Naturalness Degradation Potentials (NDPs) are determined for different land use types, and naturalness concept uses them for the calculation of CFs. NDPs are rendered on a scale of 0 to 1 and further assigned to all land occupation flows in the ecoinvent database. So, it is directly applicable for process based LCA. Indicator accounts for the share of natural NPP that is deprived due to land occupation and measures the artificial disturbance of the potential natural NPP. Calculation of CFs is presented in equation 4. (Taelman & al 2016, 152-153)

$$CF_{occ,i,j} = NPP_{loss,i,j} = NPP_{0,j} \times (1 - n_i) = NPP_{0,j} \times (NDP_i) \quad (4)$$

where $CF_{occ,i,j}$ is the CF of land occupation impact on ecosystem health for land use type i and country j, $NPP_{loss,i,j}$ is the total NPP loss due to land use type i in country j (MJ_{ex}/m^2a), $NPP_{0,j}$ is the average potential NPP (MJ_{ex}/m^2a) for country j, n_i is the naturalness of land use type i and NDP_i is the naturalness degradation potential of land type i. (Taelman & al 2016, 153)

As a result, indicators for HANPP and naturalness approaches are defined. The site-dependent CFs are provided for 3680 zones, and area of each zone, total area of the country covered by a specific land type, and standard deviation (STDV) of the CFs are calculated. Just like Alvarenga et al, also this study notes that it is possible to obtain negative CFs in cases where man-made ecosystem has a higher NPP than the potential natural ecosystem on the same location. Naturalness approach on its part does not get negative results, since it provides NDP values in scale from 0 to 1, where 0 refers to nature's own systems, and 1 to totally man-made systems. The area weighted NPP_0 values are provided in the supporting information of Alvarenga et al. 2013, and so CFs for naturalness are achieved. (Taelman & al 2016, 153)

4.3 Shortages and future perspectives

Even if both papers were selected as the most promising methods they have shortages that should be considered. Taelman et al. pointed out in their paper that four land use types used by Alvarenga et al. is not sufficient to be compatible with available product databases. Additionally, since CFs are not presented in exergy terms, direct comparison with other resource-related impact categories could be hampered. (Taelman & al 2016, 151) Taelman et al. have the same kind of challenges, since the number of CFs calculated in HANPP concept is greater than the amount of land occupation flows available in process LCA databases, and so is not directly applicable for LCA. (Taelman & al 2016, 153)

Alvarenga et al. recognized that their paper has several uncertainties due to assumptions made and lack of data and pointed out the lack of biomass differentiation since they are treated as the same (Alvarenga & al 2015, 448). Biomass differentiation was later solved in Taelman et al. paper by calculating of CFs in exergy terms, but there were still shortages and issues in that paper as well. Nevertheless, also Taelman et al. pointed that lack of reliable data is still an issue, and limits validation and cross-comparison and hinders the application of certain land use indicators in LCA. (Taelman & al 2016, 154)

In critical evaluation carried out in ORIENTING project different methods were evaluated through six criterion, which each included variable number of sub-criterions. Methods were evaluated in scale of 0 to 5, and marked as letters from A to E, A referring to the best and E to the worst score. In three criterion categories both methods scored A's, but in stakeholder acceptance, credibility and suitability, scientific robustness, and compatibility with life-cycle approach deficiencies were found. (Horn & al 2021, 50) Both methods scored nearly identical scores in each category, which is due to significant similarities of the papers.

According to critical review, the biggest development targets are in acceptance and credibility, which were evaluated to be overall only on mediocre level. (Horn & al 2021, 74)

In scientific robustness category, the sub-criterions that needed the most development were quality of the modelling data, land use intensity consideration, management practices consideration, and testing of CFs. In case of compatibility with life-cycle approach, evaluation assessed that life cycle thinking/approach was considered only in mediocre level. (Horn & al 2021, 74) That is a significant issue, since both methods were intended to be used exactly in LCA. However, most of the biggest development targets presented in critical evaluation was already noted in the papers themselves.

To make biotic production assessment more applicable in the future both Alvarenga et al. and Taelman et al. have provided thoughts about the future and given suggestions what should be considered. Both papers state that further research is needed on both LCA and land use impact assessment frameworks. Also links between various ecosystem processes and the relation with biodiversity are recommended to be clarified more deeply, to define indicator that corresponds reality. It is proposed to make one indicator, that would consider all land use impacts, but due to complexity of the issue it is extremely challenging. Therefore, weighting and combination of different indicators is rather the most applicable approach. (Taelman & al 2016, 154) So, presented development targets do not concern only indicators itself, but also the frameworks around the indicator need to be continuously improved.

5 Case study

This chapter describes implementation of case study considering liquid packaging board container product. In the study, an LCA model for liquid packaging container is created from cradle-to-gate. Case is carried out according to method presented in Taelman et al. (2015) paper, and impacts are assessed according to impact categories presented in ecoinvent, including only land use categories. Objective of the case study is to assess the applicability of the biotic production assessment method in LCA in practice and point out problematic issues. These findings act as the basis for the recommendations for development of the indicator further from LCA modelling point of view. Results of the case are evaluated and forming of them interpreted, from where recommendations for impact assessment model development can be found.

5.1 Background

Liquid packaging board container was selected as studied object since similar product is studied in ORIENTING project as well. LCA modelling is carried out with SULCA software, formerly known as KCL-ECO, which is sustainability tool for ecodesign, footprints and LCA (SimulationStore 2022). LCA model assesses impacts to biotic production caused from production of liquid packaging board container. Selected functional unit is 1 kg of liquid packaging board container without a cap, according to which the results are also presented.

Method presented by Taelman et al. is selected for LCIA. It is more suitable for this case study, since Alvarenga et al. do not provide CFs for forests. In addition to that more land use types are identified, and CFs for more countries are calculated. Because liquid packaging board container is produced from wood materials, it is significant that impacts from forests can be evaluated. Furthermore, larger quantity of land use types and countries makes achievement of more accurate results possible.

Data used in the case study is acquired from ecoinvent database, which is transparent and consistent life cycle inventory database (Ecoinvent 2022). Ecoinvent includes numerous of processes and provides accurate information what are the assumptions made behind the process. Processes are specified according to location, which varies from country specific processes to globally applicable ones. Furthermore, all input and output flows, and their properties are defined. The most suitable processes are selected from the database and connected to each other with mass or energy flows to form a set of processes needed for liquid packaging board container production.

ORIENTING project works as a background for the case study, and also includes case study, where Stora Enso’s liquid packaging board container product is evaluated from biotic production point of view. Stora Enso acquires their wood from European forests and eucalyptus plantations in Uruguay, Brazil and China (Stora Enso 2022). Finland, Sweden and Uruguay were selected as reference countries for wood supply because Stora Enso has operations in each of these. However, the used data is not company specific and therefore the results do not describe Stora Enso’s operations.

5.2 Modelling

Modelling was started by defining all relevant processes related to liquid packaging board container production. Life cycle inventory data for liquid packaging board container production was found from ecoinvent. It showed the main materials needed for liquid packaging board container production, which were board, aluminium, and plastics. These materials were distributed in proportion of 74% board, 5% aluminium, and 21% plastics.

Acquired liquid packaging board container process defined also other processes that were needed for production. Total of ten other processes were needed and nine of them were downloaded from ecoinvent. For liquid packaging board production suitable process was not found. Therefore, it was created manually in SULCA, according to old data from KCL-ECO. According to data, softwood and hardwood pulp, and chips are needed for production.

Majority of wood supply comes from softwood pulp, which accounts 61% of total supply. Chips are responsible of 22%, and hardwood pulp of 17% of the supply.

In addition to wood supply, KCL-ECO data determines also other input flows that are needed for liquid packaging board production. These processes are downloaded from ecoinvent and included to the model. As a result, total of 16 processes are implemented regarding the liquid packaging board container production. Now all processes that are needed for production of liquid packaging board container are defined. Processes are divided into four categories; carton production, energy supply, liquid packaging board container production and wood supply, to ease interpretation of results. Ready life cycle model is illustrated in Figure 5, which shows all used processes and categories.

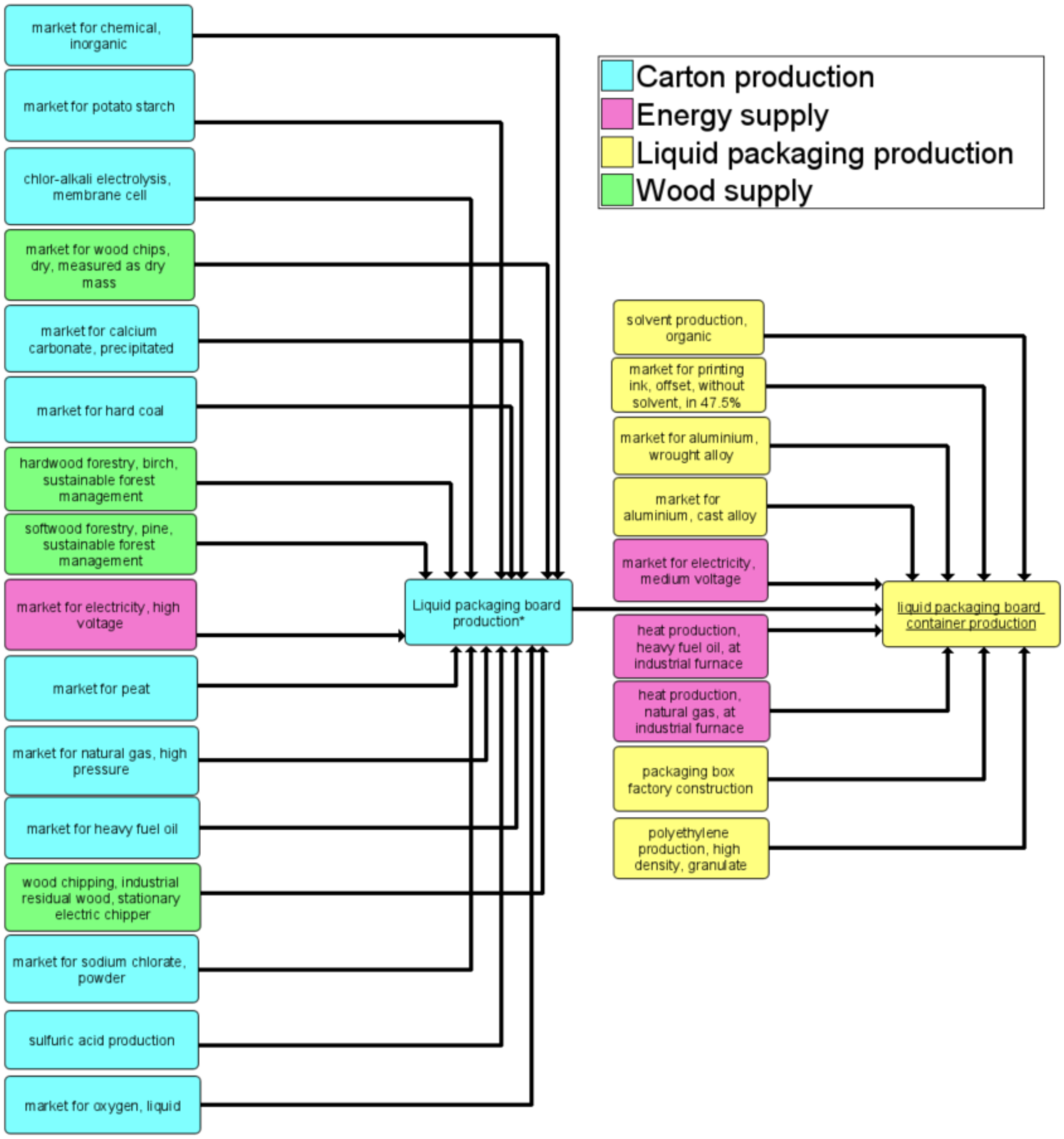

Figure 5. Sulca model for Finland and Sweden.

Figure 5 presents ready Sulca model, which was used for Finland and Sweden. In case of Uruguay *hardwood forestry, birch, sustainable forest management* is replaced with *hardwood forestry, eucalyptus ssp., planted forest management*, because softwood is assumed to originate from eucalyptus plantation. Otherwise, model for Uruguay is fully similar than the one presented for Finland and Sweden.

Wide range of processes are included into the model, which are described more precisely in Appendix 2. Different processes contain various number of assumptions, which can be seen from the name of the processes. The most suitable processes are strived to select, so model would describe situation as realistically as possible. Each process is assumed to be in certain geographical location, which affects to underlying assumptions of the process, and provides certain product as output. Location of selected processes varies due to lack of data. All processes are not provided for each country, and in some cases only global or European data was available.

When model was ready, LCI results were calculated. Results were provided according to land use types presented in ecoinvent. These results were sorted according to land use impact category, and the most influential land use types were recognized. Because terminology in ecoinvent differs significantly from terminology presented for HANPP approach in Taelman et al., land use types did not match one-to-one. Thus, ten most influential land use types were matched with the most suitable options from Taelman et al. and therefore CFs for these land use types can be implemented into the model. Assumed correspondences are presented in Table 2.

Table 2. Terminology connections between ecoinvent and Taelman et al.

Ecoinvent terminology	**Taelman et al. terminology**		
	Finland	**Sweden**	**Uruguay**
Occupation, forest, intensive	Forest, with agricultural activities	Forest, with agricultural activities	Forest, with agricultural activities
Occupation, traffic area, rail/road embankment	Urban land	Urban land	Urban land
Occupation, forest, extensive	Forest, virgin	Forest, virgin	Forest, virgin*
Occupation, annual crop	Rainfed crops (Subsistence/Commercial)	Rainfed crops (Subsistence/Commercial)	Crops and mod. intensive livestock density
Occupation, annual crop, non-irrigated, intensive	Rainfed crops (Subsistence/Commercial)	Rainfed crops (Subsistence/Commercial)	Rainfed crops (Subsistence/Commercial)
Occupation, dump site	Urban land	Urban land	Urban land
Occupation, industrial area	Urban land	Urban land	Urban land
Occupation, lake, artificial	Open water, unmanaged	Open water, unmanaged	Open water, protected
Occupation, mineral extraction site	No data	No data	No data*
Occupation, traffic area, road network	Urban land	Urban land	Urban land

* Data from Argentina

CFs were acquired for selected countries: Finland, Sweden, and Uruguay, and were selected because Stora Enso has forest operations in each of them. In addition, characteristics and therefore also CFs of these forests are differing from each other. For example, in Uruguay forests are assumed to be plantations, when in Finland and Sweden those are sustainable managed forests, which brings naturally differences between these countries. Number of land use types presented in Taelman et al. is different depending on the country, which complicated the linkage of terminologies. For Finland and Sweden exactly the same terminology was found and selected. In case of Uruguay terminology differed in few land use types. *Crops and moderately intensive livestock density* was selected to correspond with *occupation, annual crop* because it was assumed that in Uruguay presumption is that crops are irrigated, unlike in Finland and Sweden. Also, *Open water, protected* was matched with *Occupation, lake, artificial* since the land use type used with Finland and Sweden was not presented for Uruguay. In addition, land use types *Forest, virgin* and *No data* were not presented for Uruguay, so CFs for equivalent terms for Argentina were used. Argentina was selected since it locates near Uruguay, and therefore has similar climatic conditions, and likely matches quite well with Uruguay.

Taelman et al. paper also includes naturalness approach, for which CFs need to be defined separately. Naturalness CFs are calculated for the same three countries as in case of HANPP approach. Average potential NPP for each country is presented in Alvarenga et al. paper's (2013) supporting information, which provides following values: Finland 22 MJ_{ex}/m^2*a, Sweden 22 MJ_{ex}/m^2*a and Uruguay 31,7 MJ_{ex}/m^2*a. Final CFs are calculated by multiplying average potential NPP with NDP, which is presented in Taelman et al. supplementary data. Terminology used in NDPs matches fully with ten most influential land use types, so CFs can be easily connected with ecoinvent terminology. Acquired CFs for both HANPP and naturalness approaches are presented in Table 3.

Table 3. Characterization factors for HANPP and naturalness approaches.

	HANPP [MJ_{ex}/m^2*a]			**Naturalness [MJ_{ex}/m^2*a]**		
	Finland	**Sweden**	**Uruguay**	**Finland**	**Sweden**	**Uruguay**
Occupation, forest, intensive	5,64	4,77	7,37	8,8	8,8	12,68
Occupation, traffic area, rail/road embankment	6,92	7,94	9,12	19,8	19,8	28,53
Occupation, forest, extensive	3,4	3,44	3,38	6,6	6,6	9,51
Occupation, annual crop	6,58	8,16	7,48	16,5	16,5	23,78
Occupation, annual crop, non-irrigated, intensive	6,58	8,16	8,03	16,5	16,5	23,78
Occupation, industrial area	6,92	7,94	9,12	20,9	20,9	30,12
Occupation, dump site	6,92	7,94	9,12	19,8	19,8	28,53
Occupation, lake, artificial	5,29	4,02	5,1	18,7	18,7	26,95
Occupation, mineral extraction site	1,34	4,52	1,38	19,8	19,8	28,53
Occupation, traffic area, road network	6,92	7,94	9,12	19,8	19,8	28,53

In case of HANPP, the CFs differ between countries in each land use type, but variation is relatively small. Countries have the same CFs for some land use types, which is due to land use selection presented in Table 2. The highest and lowest CF alternates between countries depending on the land use type, and overall CFs are quite close to each other. For naturalness approach CFs are higher compared to HANPP approach. CFs for Finland and Sweden are exactly the same, since presented average potential NPPs were the same for both countries. For Uruguay the value was higher, which led also to higher CFs.

CFs were used a bit differently between the countries. For Finland and Sweden, the whole supply chain was assumed to be in the country in question. Therefore, Finland's CFs were used in each process of the model, just like for Sweden. In case of Uruguay, supply chain was assumed to be in Sweden except eucalyptus process, which was assumed to be only process located in Uruguay. So, Uruguay scenario used Sweden's CFs for all other processes excluding eucalyptus process, which was the only process that implemented Uruguay's CFs.

5.3 Results

Ready Sulca model provides results, which can be inspected separately for each country, land use type and process. Software calculates the land area that is demanded annually by different land use types. These values are LCI results and create the basis for result calculation for both HANPP and Naturalness approaches, and to which country- and land use specific CFs are implemented. Land area demand for each land use type in Finland, Sweden and Uruguay is presented in Table 4.

Table 4. Calculated country and land use specific land area demand.

Land use type	Finland [m^2*a]	Sweden [m^2*a]	Uruguay [m^2*a]
Occupation, forest, intensive	3,808	3,808	3,492
Occupation, traffic area, rail/road embankment	0,018	0,018	0,016
Occupation, annual crop	0,016	0,016	0,016
Occupation, dump site	0,014	0,014	0,014
Occupation, forest, extensive	0,005	0,005	0,005
Occupation, annual crop, non-irrigated, intensive	0,004	0,004	0,004
Occupation, lake, artificial	0,006	0,006	0,006
Occupation, industrial area	0,003	0,003	0,003
Occupation, traffic area, road network	0,002	0,002	0,002
Occupation, mineral extraction site	0,001	0,001	0,001

Values for Finland and Sweden are fully equal. This is a consequence of used Sulca model, which is precisely similar for both countries. In case of Uruguay, softwood is assumed to be eucalyptus instead of birch, which leads to differing values. Despite differing model, differences are quite small in most of the land use types. *Occupation, forest, intensive* makes an exception, and difference compared to Sweden and Finland is clear. It is also significantly the most impactful land use type. Land area demand is over 200 times higher compared to the second highest land use type, and therefore causes majority of the impacts.

When demand for land area was calculated, CFs were implemented to the model, and the software calculated the indicator results. The results were calculated similarly for both approaches, but results were achieved separately for both approaches in each country. Next chapters present achieved results for HANPP and naturalness approach individually.

5.3.1 HANPP approach

Results for HANPP approach are calculated according to CFs presented in Table 3. CFs are in unit of MJ_{ex}/m^2*a and describe a loss of NPP due to land use. When CFs are multiplied with annual land area demand, results are achieved in unit of MJ_{ex}. The results present how much exergy is needed to produce the same amount of biomass that is lost during the process. The higher the value is, the more the biotic production is decreased. In proportion, if value would be negative, biotic production would be enhanced. Table 5 presents land use and country specific indicator results per functional unit.

Table 5. HANPP results for ten most influential land use types.

	Finland		**Sweden**		**Uruguay**	
Land use type	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
Occupation, forest, intensive	21,48	98,14	18,17	97,51	16,95	97,41
Occupation, traffic area, rail/road embankment	0,12	0,57	0,14	0,77	0,13	0,75
Occupation, annual crop	0,10	0,47	0,13	0,69	0,13	0,73
Occupation, forest, extensive	0,05	0,22	0,05	0,26	0,05	0,28
Occupation, dump site	0,03	0,15	0,04	0,21	0,04	0,22
Occupation, annual crop, non-irrigated, intensive	0,03	0,12	0,03	0,18	0,03	0,20
Occupation, lake, artificial	0,03	0,16	0,03	0,14	0,03	0,15
Occupation, industrial area	0,02	0,10	0,03	0,14	0,03	0,15
Occupation, traffic area, road network	0,01	0,06	0,02	0,08	0,02	0,09
Occupation, mineral extraction site	0,00	0,01	0,01	0,03	0,01	0,03
Total	21,89		18,63		17,40	

As it can be seen, *Occupation, forest, intensive* is the most influential land use type, and causes over 97% of the impacts in each country. That is due to land area demand, which was significantly the highest for this land use type. CFs presented in Table 3 do not have immense differentiation between land use types, so magnitude of results remains parallel to land use demand results. Therefore, significance of other land use types remains void for the whole model.

When country-specific results are viewed, some differences can be noticed. Differences are not so relevant in land use types demanding less area, and the major of the impacts are caused due to *Occupation, forest, intensive*. Impacts to biotic production are the highest for Finland, followed by Sweden and then Uruguay. Since Finland and Sweden had exactly the same land area demand, difference between countries originates from differing CFs. In case of Uruguay land area demand was smaller which led also to lower indicator results. To see more clearly what causes differing results, processes impacting to *Occupation, forest, intensive* are presented in Table 6.

Table 6. Most influential processes that affect to Occupation, forest, intensive for HANPP.

	Finland		**Sweden**		**Uruguay**	
Occupation, forest, intensive	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
softwood forestry, pine, sustainable forest management	17,29	80,50	14,62	80,50	14,62	86,44
hardwood forestry, birch, sustainable forest management	2,41	11,23	2,04	11,23		
hardwood forestry, eucalyptus ssp., planted forest management					0,82	4,85
market for wood chips, dry, measured as dry mass	1,54	7,16	1,30	7,16	1,30	7,69
market for electricity, high voltage	0,10	0,48	0,09	0,48	0,09	0,52
market for aluminium, wrought alloy	0,04	0,18	0,03	0,18	0,03	0,19
polyethylene production, high density, granulate	0,03	0,14	0,03	0,14	0,03	0,16

Several processes have impact to *Occupation, forest, intensive*, but only processes contributing more than 0,1% of the total results are included to this table. It clearly illustrates difference between the models, since Uruguay do not have impacts from birch, and is only country that uses eucalyptus as raw material. Model was exactly the same for Finland and Sweden, so also percentage shares of different processes are equal, but total values differ due to country-specific CFs. For Uruguay model and CFs are mainly identical as for Sweden, which leads to identical values in most of the processes. Difference arises from eucalyptus process, which demands less area to produce the same amount of hardwood than birch. Due to that also caused impact is smaller, and wood chips production process is the second most impactful process for Uruguay.

Results can be also divided according to categories, which were presented in figure 5. Processes are categorized into four categories based on their function in the model: Wood supply, carton production, liquid packaging production and energy supply. When results are looked from this point of view the most influential categories can be acknowledged. Categorized results are presented in Table 7.

Table 7. Category results for HANPP.

	Finland		**Sweden**		**Uruguay**	
Category	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
Wood supply	21,40	97,76	18,14	97,36	16,90	97,18
Carton production	0,28	1,29	0,28	1,51	0,28	1,62
Liquid packaging production	0,21	0,95	0,21	1,12	0,21	1,20
Energy supply	0,001	0,00	0,001	0,00	0,001	0,00

Wood raw materials is the most significant category of impacts and causes over 97% of impacts in each country. Carton production and liquid packaging production affect to total results slightly, but energy’s share is trivial. Overall impacts are the highest for Finland, followed by Sweden and then Uruguay, which was already seen from Table 5, but in case of less significant categories results are similar between the countries. To illustrate from where impacts to biotic production are caused in case of wood raw materials, processes contributing to that category are listed in Table 8.

Table 8. Impacts to HANPP from wood supply.

	Finland		Sweden		Uruguay	
Wood supply	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
softwood forestry, pine, sustainable forest management	17,38	81,21	14,72	81,16	14,72	87,08
hardwood forestry, birch, sustainable forest management	2,43	11,33	2,05	11,33		
hardwood forestry, eucalyptus ssp., planted forest management					0,82	4,86
market for wood chips, dry, measured as dry mass	1,60	7,45	1,36	7,51	1,36	8,06
wood chipping, industrial residual wood, stationary electric chipper	0,00004	0,00	0,00004	0,00	0,00004	0,00

Results are very much alike the ones presented in Table 6, and processes and countries causing the most impacts remain the same. Values are slightly higher than in Table 6 because impacts from all land use types are considered. Because of that, also processes share of total impacts varies slightly. *Wood chipping* process is also included into the table, because it is part of the wood supply. However, its impacts are insignificant for the whole.

Overall, majority of impacts are from wood raw materials, of which softwood, hardwood, and wood chips cause over 97%. Softwood supply is the most influential one since the usage of it is the highest. Significance of order of other wood resources varies depending on the country. When the results are observed from country perspective, structure of impacts are mostly alike, and major impacts originate from same processes, excluding Uruguay scenario, on which eucalyptus production leads to slightly different results. Overall impacts are the highest for Finland due to highest CF in most influential land use type *Occupation, forest, intensive*. Uruguay's CF for *Occupation, forest, intensive* is the highest of these three countries, but usage of eucalyptus instead of birch results as the lowest indicator results before Sweden.

5.3.2 Naturalness approach

Indicator results for naturalness approach were calculated the same way as in case of HANPP approach. Land area demand of each land use type was multiplied with CFs presented in Table 3. Even if calculation is performed the same way as in HANPP approach, and units are the same, the results are interpreted differently. Naturalness approach results describe how far away current situation is from PNV.

Results were achieved in unit of MJ_{ex}, which describes how much exergy is needed for vegetation to reach its natural state. Naturalness approach measures how vegetation have changed compared to natural situation, and the more exergy is needed, the further current vegetation is from natural vegetation. Table 9 presents how results are divided between different land use types per functional unit.

Table 9. Naturalness results for ten most influential land use types.

	Finland		**Sweden**		**Uruguay**	
Land use type	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
Occupation, forest, intensive	33,51	96,77	33,51	96,77	31,16	96,62
Occupation, traffic area, rail/road embankment	0,36	1,03	0,36	1,03	0,32	1,00
Occupation, annual crop	0,26	0,75	0,26	0,75	0,26	0,80
Occupation, forest, extensive	0,09	0,27	0,09	0,27	0,09	0,29
Occupation, dump site	0,10	0,28	0,10	0,28	0,10	0,30
Occupation, annual crop, non-irrigated, intensive	0,07	0,20	0,07	0,20	0,07	0,21
Occupation, lake, artificial	0,12	0,35	0,12	0,35	0,12	0,38
Occupation, industrial area	0,07	0,19	0,07	0,19	0,07	0,21
Occupation, traffic area, road network	0,04	0,11	0,04	0,11	0,04	0,12
Occupation, mineral extraction site	0,02	0,07	0,02	0,07	0,02	0,07
Total	34,64		34,64		32,25	

Since CFs for Finland and Sweden are the same, just like the Sulca model as well, the results for both countries are fully similar. In Uruguay CFs are differing, which leads to differing values. Even if Uruguay has the highest CF for *Occupation, forest, intensive,* the impact is smaller due to smaller land area demand. Just like in HANPP approach, also naturalness approach has the highest impacts from *Occupation, forest, intensive*, because same inventory results are used. It is so dominant that significance of other land use types remains insignificantly small. Deeper insight of processes affecting the most to *Occupation, forest, intensive* is presented in Table 10.

Table 10. Most influential processes that affect to Occupation, forest, intensive for naturalness.

	Finland		**Sweden**		**Uruguay**	
Occupation, forest, intensive	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
softwood forestry, pine, sustainable forest management	26,98	80,50	26,98	80,50	26,98	86,73
hardwood forestry, birch, sustainable forest management	3,77	11,23	3,77	11,23		
hardwood forestry, eucalyptus ssp., planted forest management					1,41	4,54
market for wood chips, dry, measured as dry mass	2,40	7,16	2,40	7,16	2,40	7,72
market for electricity, high voltage	0,16	0,48	0,16	0,48	0,16	0,52
market for aluminium, wrought alloy	0,06	0,18	0,06	0,18	0,06	0,19
polyethylene production, high density, granulate	0,05	0,14	0,05	0,14	0,05	0,16

Total of 25 processes had impact to *Occupation, forest, intensive*, but only the ones with impact of more than 0,1% of the total are included to table. Nevertheless, three most influential processes are responsible of over 97% of impacts. CFs for Sweden and Finland are the same, and these CFs are used also for Uruguay’s model, excluding eucalyptus process. Therefore, values for each country are fully similar, except in case of processes for hardwood. Because eucalyptus needs less area to produce the same amount of wood compared to birch, the impact for Uruguay is a bit lower than for Finland and Sweden. Due to that also significance order of processes differs, and eucalyptus production process causes less impacts than wood chips.

When category results are inspected, the most influential categories of the model can be noticed. Processes are divided into the same four categories than in case of HANPP approach, and results are presented in Table 11.

Table 11. Category results for naturalness.

	Finland		Sweden		Uruguay	
Category	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
Wood supply	33,56	96,89	33,56	96,89	31,17	96,66
Carton production	0,57	1,66	0,57	1,66	0,57	1,78
Liquid packaging production	0,50	1,45	0,50	1,45	0,50	1,56
Energy supply	0,001	0,00	0,001	0,00	0,001	0,00

Wood raw materials cause most of the impacts also in case of naturalness approach. Almost 97% of impacts originates from wood raw materials and share of other categories remains low. Similarities of the model can be seen on less influential categories, which have fully equal values for each country. Difference in Uruguay model can be seen in wood raw materials category. It is the only part to which differing model affects and leads to lower value. Deeper insight on wood supply category is provided in Table 12.

Table 12. Impacts to naturalness from wood supply.

	Finland		Sweden		Uruguay	
Wood supply	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]	[MJ_{ex}]	[%]
softwood forestry, pine, sustainable forest management	27,22	81,12	27,22	81,12	27,22	87,32
hardwood forestry, birch, sustainable forest management	3,80	11,32	3,80	11,32		
hardwood forestry, eucalyptus ssp., planted forest management					1,42	4,54
market for wood chips, dry, measured as dry mass	2,54	7,56	2,54	7,56	2,54	8,14
wood chipping, industrial residual wood, stationary electric chipper	0,00007	0,00	0,00007	0,00	0,00007	0,00

More specific results for wood supply presents that the results are fully similar for all processes, excluding hardwood forestry. It is the only difference in the model between the countries, and therefore only distinctive factor for differing results. Significance order remains the same for each country as in Table 10, and values are slightly higher since all land use types are considered.

As a whole, naturalness results are a lot parallel as in HANPP, and significance order of processes is similar. Clearly the most impactful land use type is *Occupation, forest, intensive,* while rest of the processes cause only fraction of total impacts. The most significant process is softwood forestry, which is responsible of 80% of total impacts. The biggest difference between these two approaches is that values for naturalness approach are higher. Results for naturalness are largely fully similar due to the CFs, of which most part are fully similar for each country. Hardwood process is different for Uruguay, which is also only process using different CFs. Therefore, it is exclusively responsible of differing results.

6 Results and analyzing

Case study evaluated how liquid packaging board container production affects to biotic production in different countries, when impacts are assessed according to Taelman et al. During the modelling process observations of applicability of the impact assessment model was made, and how do they affect to usage comfort and achieved results. Results are also interpreted more deeply, and recommendations for improvement possibilities are also scouted out from formation of results. This chapter presents key findings of case study considering applicability and result interpretation.

6.1 Applicability

Applicability is an important aspect when impact assessment models are considered. In the model presented in Taelman et al. applicability varied between two approaches. Terminology used in naturalness approach matched with terminology presented in ecoinvent, at least in case of ten most influential land use types. Therefore, it was easy to apply into the model, and it can be assured that used NDPs match with desired land use types.

In case of HANPP approach the situation was quite the opposite. Land use types in Taelman et al. are defined according to Land Degradation Assessment Analysis (LADA), of which none matches with terminology in ecoinvent. That is significant drawback, because these two terminologies need to be matched to be able to complete the impact assessment. Due to that, selection of correspondences is left for the modeler. Terminology in Taelman et al. is not strictly defined, so interpretation and connection of terms is dependent of the modeler. If two people model the same case, it is possible that differing results are achieved. Principally, LCA studies should be as similar as possible, and not open for interpretations.

Other issue that caused difficulties in the modelling process was country specific terminology. Depending on the country, various number of land use specific CFs were defined. For example, for Belgium only seven land use types are defined, when the same number for Argentina is 36. That is natural because actual number of land use types differentiates between the countries. However, it created challenges during the modelling, since the ten most influential land use types were challenging to connect with country specific land use types. For example, land use type *No data* was not defined for Uruguay, which is the reason why CF for the same land use type from Argentina was selected. If country with only seven land use types would have been modelled, the issue would have been even more complicated.

Naturalness approach can be said to be applicable for LCA framework. Its terminology matches with ecoinvent terminology and is therefore easy to apply into the study, but the same cannot be said about HANPP approach. It was difficult to implement due to differing terminology, which demanded various assumptions from modeler. This is an issue that was already pointed out by Taelman et al., and they were aware that CFs are not directly applicable for LCA. Taelman et al. have defined land use types in an accuracy, which is not available yet in land use impact assessment framework. It is good that land use types are defined in a specific manner, so there are preconditions for more precise results. Therefore, development should be pursued also in land use impact assessment framework.

The same terminology issue applies also when land use types in Taelman et al. are compared to PEF framework and applied to both approaches. PEF is underlying framework in ORIENTING project, to which indicator should be applicable. Terminology in PEF is quite similar compared to ecoinvent, but some of the land use types are different. This did not cause additional actions to the modelling process, because terminology was already matched with ecoinvent, but therefore results were not achieved according to land use types presented in PEF framework. Since PEF is desired framework for the indicator, these terminologies should be matched also with PEF framework.

When these issues are reflected with Stora Enso interview, it is clear that especially HANPP approach does not promote the ease of use, which was one of the key points brought up. If impact assessment model is too complicated, it will not be applied, and practitioners will not get value out of it. In that case, it does not meet its purpose. Major developments are needed for applicability, which can happen either via development of land use assessment framework and databases or indicator provided by Taelman et al. To be applicable for LCA studies, and easy to implement, terminology should be uniform during whole modelling process.

6.2 Case study results

Case study provides results from two perspectives: HANPP approach measures how much NPP is lost due to land use, and naturalness approach how far away land’s vegetation is from natural state after land use. Both approaches are exergy based and calculation is performed in a similar way. Difference between results originates from CFs, which are calculated by Taelman et al., and defined differently for both approaches.

HANPP approach provided results, which are presented more precisely in chapter 5.3.1. According to the results, liquid packaging board container production in Finland has the highest impact on biotic production. Production in Sweden causes a little less impacts, while production in Uruguay has the lowest impacts to biotic production. The most important land use type is *Occupation, forest, intensive,* which is responsible for most of the impacts in each country. Therefore, final results are formed according to CFs of these land use types. Uruguay makes an exception, because wood supply differs slightly compared to Finland and Sweden. Despite having the highest CF, Uruguay has the lowest impact to biotic production, because eucalyptus demands approximately four times less land area, to grow the same amount of biomass than birch.

Specific results for naturalness approach are presented in chapter 5.3.2. Magnitude of the results are clearly higher than in case of HANPP approach, because naturalness measures how natural current vegetation is compared to PNV. Country specific results are quite close to each other, and values for Finland and Sweden are exactly the same due to fully similar CFs. Because LCI results are similar for both approaches, significance order of land use types and processes remains the same as in HANPP approach. According to results, the vegetation in the full system remains closest to the natural state in the case where eucalyptus from Uruguay is used. Because less area is needed to produce the same amount of biomass, bigger part of vegetation remains untouched, and therefore land is closer to its natural state compared to Finland and Sweden. Therefore, density and growth rate of the forest are key aspects that affect to biotic production.

Case study provides an unambiguous result, which ranks countries according to their impacts to biotic production. Results are formed from multiplication of land area demand and CF, so these affect clearly and directly to results. However, several other aspects are affecting to results indirectly on the background. For example, CFs are calculated according to certain data and created Sulca model comprises wide scale of processes, which both have their own underlying assumptions. These kinds of matters need to be considered to know how results should be interpreted, and to notice what aspects the model is not including. This way deeper analysis and understanding of results can be achieved.

As all studies, also this case study includes several uncertainties. They accumulate during the modelling process from selection of processes, used data and assumptions made. In addition to these, significant factor of uncertainty is related to the HANPP terminology, which was already pointed out in applicability section. When modeler has the freedom to select the best alternative in their opinion, reality may be totally different, and lead to significantly incorrect estimations. Uncertainty is essential and inevitable part of each study, but as accurate results as possible should be pursued. Therefore, it is not ideal that impact assessment method increases uncertainty even further. In case of naturalness approach similar problem do not exist since terminology matches one to one between Taelman et al. and ecoinvent terminology.

In Stora Enso interview it was wondered whether some other indicators could be implemented into biotic production indicator, or at least assessed alongside it. That way it could assess overall sustainability better. It is extremely important to notice that as such, the indicator evaluates particularly biotic production of certain area, and do not consider any other aspects of sustainability. When indicator is developed further, it needs to be decided whether it is wanted to consider a wider sustainability perspective or to focus just on biotic production. If a wider sustainability perspective is selected also other indicators could be included. Otherwise, it meets its purpose in this regard as such.

Taelman et al. present CFs only for occupation, which means that impacts from transformation cannot be evaluated, and therefore are totally excluded from the study. It means that only use, and recovery phases of land use are noticed, but final impact to land quality is not taken into account. For example, Nordic forests may have been used as commercial forest for hundreds of years and have existed even longer. Plantations on their part are set up later and are not natural vegetation. Therefore, extent of transformation varies depending on the location and exclusion may have significant influence on achieved results.

In case of sustainably managed forests quality change can often be considered as 0, and it is reasonable that transformation data is excluded. However, all forests do not fit to this category, and therefore transformation should not be neglected. For example, in situation, where rainforest is transformed into plantation, it is sure that area’s biotic production increases. However, change in land’s quality, not to mention other effects, could have significant impacts to final outcome. Therefore, excluding transformation totally from assessment, may falsify results substantially.

From Finland and Sweden wood supply comes from sustainably managed forests, while from Uruguay wood comes from plantations. Due to that, transformation should be taken into account in the model for Uruguay, but it is not possible, because transformation CFs are not provided. Consequently, Finland and Sweden are in unfair position compared to Uruguay, because all impacts from Uruguay cannot be included. Uruguay has the lowest impacts on biotic production on both HANPP and naturalness approach, despite having the highest CFs. The results could be different, if also transformation could be included.

In Stora Enso interview also significance of positive impacts was discussed, which emphasizes in forest industry, because biotic production is mainly enhanced. Naturalness approach cannot measure positive impacts, because it is qualitative indicator and measures naturalness of land. Therefore, also enhanced biotic production leads to less natural vegetation. HANPP approach on its part can provide results that are positive. It is included into CFs, which are negative in that case. When land area demand is multiplied with negative CF, also results are negative, which indicates that NPP is enhanced.

However, just a few of presented occupation CFs for forests are negative, and for example for Finland and Sweden CFs for all forest types are positive. As stated in chapter 3.3, carbon content of sustainably managed forests remains the same during rotation period, which leads also to approximately same biotic production. In addition, as discussed with Stora Enso, in Nordic forests biotic production is mainly enhanced. However, these aspects cannot be seen in CFs. That supports Stora Enso's concern that land use is seen as too negative and harmful thing. It is important that indicator can measure also positive impacts, but it does not help if CFs do not reflect with reality.

So, from this point of view the indicator is contradictory for forest industry. It is good that positive impacts can be noticed, but it does not meet its purpose, if those do not end up into CFs comprehensively. CFs presented by Taelman et al. are made according to HANPP map of the year 2000. It is comparatively old, due to which calculation process of CFs could be inspected and possibly updated. It is important that CFs describe reality as accurately as possible, so all sectors, including forest sector are

Case study provides results in unit of MJ_{ex} which reflect to the exergy content of lost or gained biomass production. Exergy is used as a proxy, to evaluate caused impacts of land use. It is good unit for assessment, because all sorts of resources can be expressed in their exergy content. This means that caused impacts from all these resources can be compared with each other. However, it caused troubles during result interpretation, because meaning and magnitude of the results were hard to understand. Therefore, this model demands expertise to this particular topic in order to give valid recommendations to support decision making.

7 Conclusions

Biotic production is key indicator for forest industry since the whole business is based on the biomass production. Various forest types exist with differing properties and conditions, which set the basis for the indicator. Several indicators for biotic production have been presented, but even the ones evaluated to be the most promising have their shortages and are not optimal for forest industry. Therefore, development is certainly needed.

For indicator to be fully applicable and to provide accurate results, two major objectives for future development exists. Research is needed related to land transformation, and CFs for its impacts on biotic production should be developed. This way it could be included into LCA models, and more realistic results could be achieved. Other significant development target is terminology, which varies between database, impact assessment framework and the indicator. To be applicable and easy to use, terminology should be similar in each of these. However, it is noteworthy that Taelman et al. have defined land use types in an accurate manner, which provides possibility for more accurate results. Therefore, development should be pursued also in databases and frameworks, so accuracy of Taelman et al. could be exploited.

Case study was limited to consider only one indicator and in the modelling process just one database, LCA software and impact assessment framework were used and assessed. Therefore, development targets were found only from these particular elements. Since inconsistency in terminology between just these is so significant, there could be need for wider assessment, where also other databases, LCA software and impact assessment frameworks would be evaluated. When the whole modelling process and used terminology is alike regardless of used framework or software, also results are similar and comparability between studies is enhanced.

Developed and more uniform impact assessment of biotic production would have positive impacts also for other sectors than just for forest industries. Wood raw materials are widely used for example as construction material or as fuel for energy production. Therefore, also other sectors may carry out LCA studies considering biotic production. When an indicator is easy to apply and accurate results are achieved in an understandable form, additional value can be achieved even without expertise to this particular topic. To make this possible, the indicator should present and illustrate magnitude and meaning of the results clearly, for instance with the help of examples.

Consequentially developed indicator could lead to deeper understanding of forest resources as a whole. When productivity for certain piece of forest land, and human appropriation to it, can be defined accurately, effects can be realized in more concrete way. Due to that, consequences can be understood, and resources can be used in a more reasonable and efficient way from productivity point of view regardless of the sector. However, it is important to remember that productivity is only one of the aspects that need to be considered. When sustainable resource usage is pursued, also other sustainability indicators should be evaluated comprehensively.

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Appendix 1. Question presented for Stora Enso

1. How important do you consider having such an indicator as biotic production? Why?
2. Have you used some indicator for biotic production so far? Have you found it useful? Has it brought you some additional value in your LCA studies?
3. What are the biggest development targets/problems in biotic production assessment in your opinion?
4. Are there some positive aspects in the LANCA model that should be implemented in the future biotic production assessment model as well?
5. HANPP model is proposed for biotic production assessment. What are your thoughts on its applicability to forest industry?
6. Biotic production itself is not a sufficient indicator when overall sustainability of the land use is assessed. What are the most important aspects that should be considered alongside biotic production? (For example, pesticide, nutrients, or water usage affect to sustainability as well)
7. Biotic production is indicator not only for timber, but also for other biotic products. Do you use/are you planning to use biotic production assessment only to timber products or to other products as well (For example bioplastics or bioenergy)?
8. Are there some other comments/issues/points that you would like to bring up?

Appendix 2. Processes used in Sulca modelling

Process description	**Reference product**	**Location**
Carton production		
chlor-alkali electrolysis, membrane cell	sodium hydroxide, without water, in 50% solution state [kg]	Europe
hardwood forestry, birch, sustainable forest management	pulpwood, hardwood, measured as solid wood under bark [m3]	Sweden
hardwood forestry, eucalyptus ssp., planted forest management	cleft timber, measured as dry mass [kg]	Rest of world
market for calcium carbonate, precipitated	calcium carbonate, precipitated [kg]	Europe
market for chemical, inorganic	chemical, inorganic [kg]	Global
market for electricity, high voltage	electricity, high voltage [kWh]	Finland
market for hard coal	hard coal [kg]	Europe, without Russia and Turkey
market for heavy fuel oil	heavy fuel oil [kg]	Europe without Switzerland
market for natural gas, high pressure	natural gas, high pressure [m3]	Finland
market for oxygen, liquid	oxygen, liquid [kg]	Europe
market for peat	peat [kg]	Europe
market for potato starch	potato starch [kg]	Global
market for sodium chlorate, powder	sodium chlorate, powder [kg]	Europe
market for wood chips, dry, measured as dry mass	wood chips, dry, measured as dry mass [kg]	Europe
softwood forestry, pine, sustainable forest management	pulpwood, softwood, measured as solid wood under bark [m3]	Sweden
sulfuric acid production	sulfuric acid [kg]	Europe

wood chipping, industrial residual wood, stationary electric chipper	wood chipping, industrial residual wood, stationary electric chipper [kg]	Europe
Liquid packaging board container production		
heat production, heavy fuel oil, at industrial furnace 1MW	heat, district or industrial, other than natural gas [MJ]	Europe without Switzerland
heat production, natural gas, at industrial furnace >100kW	heat, district or industrial, natural gas [MJ]	Europe without Switzerland
market for aluminium, cast alloy	aluminium, cast alloy [kg]	Global
market for aluminium, wrought alloy	aluminium, wrought alloy [kg]	Global
market for electricity, medium voltage	electricity, medium voltage [kWh]	Finland
market for printing ink, offset, without solvent, in 47.5% solution state	printing ink, offset, without solvent, in 47.5% solution state [kg]	Europe
packaging box factory construction	packaging box factory [unit]	Europe
polyethylene production, high density, granulate	polyethylene, high density, granulate [kg]	Europe
solvent production, organic	solvent, organic [kg]	Global