MASTER’S THESIS

VALUE-ADDED BIOPRODUCTS OR RENEWABLE ENERGY DERIVED FROM LIGNIN? – COMPARATIVE REGIONAL ECONOMIC AND ENVIRONMENTAL IMPACT ASSESSMENT

Case Metsä Group’s Bioproduct mill in Äänekoski

Anna Rannisto

University of Jyväskylä
School of Business and Management
Corporate Environmental Management
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JYVÄSKYLÄN YLIOPISTON
KAUPPAKORKEAKOULU
JYVÄSKYLÄ UNIVERSITY SCHOOL OF
BUSINESS AND ECONOMICS

ABSTRACT

Author
Anna Rannisto

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Abstract

Metsä Group's next-generation bioproduct mill in Äänekoski will be operational within Q3/2017 and it will have significant regional economic impact on Central Finland. The mill will operate applying principles of circular economy, and thus utilize all possible side streams from pulp production. Lignin is one of the side streams that has huge potential to be refined, as sustainable products and by creating new value added. Conventionally, lignin is combusted with black liquor to generate energy in pulp mills. This thesis compares this conventional situation to refining lignin into biocomposite products made from 100% renewable resources with regard to regional economic and environmental impacts.

Production impact, employment impact and income effects are estimated using input-output analysis (IOA) in order to estimate regional economic impact. Global warming potential and acidification potential are assessed applying the IO and EEIO methodology to estimate environmental impacts of the two cases. The key data was collected from the latest Finnish national input-output tables (2012) and Finnish national emission tables by industry (2012). Crucial information was also gathered from Metsä Group and the Department of Chemistry at University of Jyväskylä.

The results of the study indicate that refining lignin has 9 to 14 times higher production impact, employment impact and income effects compared to combusting the same amount of lignin. The global warming and acidification potentials were also higher with refinement, but only 1.6 to 3 times. One of the key outcomes of the thesis is that the environmental impact cannot be assessed only by the applied method, but also e.g. carbon sequestration and possible product substitution must be taken into account in the assessment.

For the region of Central Finland, refining lignin is interesting option compared to combusting lignin, for it would create significantly more jobs, value added, municipal taxes and multiplier effects. The refinement is aligned with Central Finland´s Strategy 2040, and it would increase the innovation capital and export potential of the region. The intriguing environmental features of the biocomposite products are also interesting for the whole nation.

Keywords
lignin, biocomposite, pulp production, input-output analysis, environmentally extended input-output analysis, Bioproduct mill, pulp mill, Metsä Group, Central Finland, circular economy, bioeconomy

Location
Jyväskylä University School of Business and Economics

Author's address
Anna Rannisto
Corporate Environmental Management
School of Business and Economics
University of Jyväskylä
anna.rannisto@gmail.com

Supervisors
Tiina Onkila, Ph.D.
Corporate Environmental Management
School of Business and Economics
University of Jyväskylä

Timo Tohmo, Ph.D.
Economics
School of Business and Economics
University of Jyväskylä

Esa Storhammar, Ph.D.
Management and Leadership
School of Business and Economics
University of Jyväskylä

Reviewers
Timo Tohmo
Tiina Onkila

LIST OF KEY TERMS

BIOCOMPOSITE	is a composite material composed of a matrix (resin) and a reinforcement of natural fibers.
BIOECONOMY	”comprises those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisms – to produce food, materials and energy.”[1]
BIOPRODUCT	is comprised of materials, chemicals or energy derived from renewable biological resources.
BIOPRODUCT MILL	is the name of Metsä Group’s new pulp mill that aims to utilize its side streams for producing bioproducts. The mill in currently under construction and the start-up of it is expected to take place within Q3/2017.
BIOREFINERY	is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. The Bioproduct mill will be a biorefinery.
BLACK LIQUOR	in industrial chemistry, is the waste product from the kraft pulping process when pulpwood is digested into paper pulp removing lignin, hemicelluloses and other extractives from the wood to free the cellulose fibers.
CIRCULAR ECONOMY	is restorative and regenerative industrial economy by design, and it aims to keep products, components, and materials at their highest utility and value at all times. The concept distinguishes between technical and biological cycles.[2] Compared to open-ended conventional economic system, circular economy system is circular but seldom completely closed. This is due to basic physical laws and missed opportunities. All waste streams can’t always be re-used.[3]
LIGNIN	is a polyfenol and the second most common biopolymer on Earth for 20-30% of wood is lignin.[4]
PERSON-YEAR	is a unit of measurement especially in economics and accountancy, which means one year of work of one person consisting of a standard number of person-days.
THERMOPLASTIC	is a plastic material, a polymer, that becomes pliable or moldable above a specific temperature and solidifies upon cooling.

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[1] (European Commission, 2016a)
[2] (Ellen MacArthur Foundation, 2016)
[3] (Andersen, 2007)
[4] (Novaes et al., 2010)

LIST OF ABBREVIATIONS

AP	acidification potential
AR4	Fourth Assessment Report of Intergovernmental Panel on Climate Change
EEIO	environmentally extended input-output
EEIOA	environmentally extended input-output analysis
EHIA	environmental health impact analysis
EIA	environmental impact assessment
EIO-LCA	environmental input-output hybrid life cycle analysis
ENVIMAT	model for assessing the environmental impact of material flows of the Finnish economy
EXIOPOL	environmental accounting framework using externality data and input-output tools for policy analysis (project funded by the EU)
FU	functional unit
GIS	geographic information systems, GIS overlay analysis
GWP	global warming potential
HD(PE)	high-density polyethylene (plastic)
IAIA	Association for Impact Assessment
IO	input-output
IO-LCA	input-output hybrid life cycle assessment
IOA	input-output analysis
IOA-LCA	input-output hybrid life cycle assessment
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle assessment
LCC	life cycle cost
LCE	life cycle engineering
LCI	life cycle inventory
LCIA	life cycle impact assessment
LCSA	life cycle sustainability assessment
LD(PE)	low-density polyethylene (plastic)
LLD	linear low-density polyethylene (plastic)
LQ	location quotient (method)
MCA	multiple criteria approach
MCDA	multiple criteria decision analysis
MRIO	multi-region input-output
NAMAE	National Accounting Matrix with Environmental Accounts
P-Y	person-year
PE	polyethylene (plastic)
PLA	polylactic acid
PP	polypropylene (plastic)
PS	polystyrene (plastic)
RIA	regulatory impact assessment
SA	sustainability assessment
SAR	Second Assessment Report of Intergovernmental Panel on Climate Change
SDA	structural decomposition analysis

SEA	strategic environmental assessment
SIA	social impact assessment
SIC	standard industry classification
STAT	Statistics Finland
TBL	triple bottom line
TPI	total production impact
WIOD	World Input-Output Database

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1 INTRODUCTION

1.1 Background and motivation for the research

As climate change is ever more inevitable, European Union acts exemplary and takes international responsibility by setting regulations for the member countries in order to reduce greenhouse gases. EU has set as its goal to reduce its greenhouse gas emissions, increase the share of renewable energy and save energy (European Commission, 2015a). In long term, the goal is to reduce greenhouse gas emissions by 89-95% by 2050 compared to 1990 levels (European Commission, 2015b). The Paris Agreement within United Nations Framework Convention on Climate Change (UNFCCC) will speed up the race to avoid dangerous global warming by limiting global warming to well below 2°C. Consequently, the targets and the restrictions set by EU will have an effect on Finland.

Acting on the premises described above, as well as on other premises, Finnish-based Metsä Group corporation made the decision to invest in a huge new biorefinery, a "Bioproduct mill", to be situated in Äänekoski, Finland. As part of the planning phase, Metsä Group identified several novel technologies that would either improve the energy efficiency and/or increase the production of renewable energy of the new mill, compared to the state-of-the-art. Implementing the new technologies would have meant an increased risk level and decreased return on investment. Thus, to mitigate these drawbacks and to support the introduction of new energy-related technology, the Finnish Ministry of Employment and the Economy decided to grant a EUR 32,120,000 subsidy to Metsä Group. The construction of the new mill begun in April 2015 and the start-up of it is expected to take place within Q3/2017. The mill will operate energy efficiently applying circular economy principles, exploiting residues for added value products. It will not require fossil fuels in order to function. The mill will have a significant economic impact on Central Finland. Together with my assignor Regional Council of Central Finland, we are interested in this impact. (TEM, 2015.)

In addition to the impacts of the mill, a major source of motivation for the research is to study the possibilities of circular economy. Circular economy has gained increasing amount of attention among researchers, companies and governments. For instance, China and European Commission have set circular economy strategies (Matthews & Tan, 2011; European Commission, 2016b). The basic operational principle is to promote resource minimisation. Recycling, refurbishing and re-using are in the core of circular economy. Since circular economy is most probably going to take root in the future as well, it is interesting to investigate its effects in practice. The thesis will study two different kinds of micro circular economy cases and their effect on Central Finland. In particular, the thesis will assess two different applications of lignin, which are real options for the Bioproduct mill, but with some liberties taken by the researcher. [5]

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[5] In pulp-producing mills lignin is, today, typically incinerated to generate energy in various forms. However, a few mills have already started to separate lignin to be used as a starting point for new bioproducts. Examples include Domtar in the USA, Stora Enso in Finland and West Fraser in Canada.

1.1.1 Next-generation Bioproduct mill in Äänekoski

Metsä Group will build a next-generation Bioproduct mill in Äänekoski, Central Finland. It will be operational in Q3/2017. The 1.2-billion-euro investment is the most expensive single investment in the history of the Finnish forest industry. The mill will have significant financial impacts on Finland; annual income effect on the Finnish economy is estimated to be 0.5 billion euro/a, during construction the employment impact will be approximately 6,000 person-years and at operational phase there will be more than 2,500 jobs compared to the current 1,000. As most of the product will be exported it has also been estimated that the impact in export will be approximately 0.5 billion euro/a (Metsä, 2015a.)

The mill will produce pulp and other bio-products. The main difference compared to conventional pulp mills is that the mill will utilize both the bioeconomy as well as the circular economy principles on a completely new level. The side streams stemming from the production of pulp, such as lignin, bark, waste gases and tall oil will be reused and refined 100 per cent so that they can be further processed as bioproducts and bioenergy. The mill will use only renewable energy sources and it will generate electricity more than twice it own use. (Metsä, 2015a.)

In 2016 it was announced that Aqvacomp Oy invests in facility that produces biocomposites. Starting from 2017, a new biocomposite mill is built in Rauma, next to Metsä Group's other mill. Aqvacomp Oy investigates the possibility to invest in larger facility to Äänekoski. This aspect increases the credibility of the two thesis cases, because they are otherwise only hypothetical. Other newly announced and studied facilities to Äänekoski are a biogas facility to be operational in 2017, and a textile fibre facility, which is still at a research stage. (Metsä, 2016a.)

1.2 Aim of the research

The main aim of the research is to find out the two lignin applications' regional economic and environmental impacts and to compare them. The aim is first to study the regional economic impacts of both cases on Central Finland, then the environmental impacts and finally to compare both impacts between the cases. The goal is to find out which option is better for (1) the region of Central Finland with regard to economical aspects and (2) the environment. The cases (lignin applications) are presented in chapter 2.2. Case selection.

The results from the thesis will provide insight to the regional economic and environmental aspects of the lignin applications. The results can give insight for example for developing the region of Central Finland – the thesis cases differ with regard to employment impact, production impact, income effect and global warming potential and acidification potential. These issues affect the region with regard to economic, social and ecologically sustainable wellbeing. Additionally, the information could be useful for the management of Metsä Fibre and other interested stakeholders.

1.3 Research task and questions

Neither the regional economic nor the environmental impacts of the two options have been studied in this context before. The research strives to answer the following research questions:

Preliminary question:

1. What are the regional economic and environmental impact differences between the two different lignin application cases of the Metsä Group's Bioproduct mill?

Sub-questions:

1. What are the regional economic and environmental impacts of combusting lignin for energy generation? (Case 1)
2. What are the regional economic and environmental impacts of refining lignin into biocomposite product? (Case 2)

2 METHODOLOGY

2.1 Research design

The design of the thesis follows the characteristics of a comparative case study. Typically, a case study provides detailed, intensive information about a single case or a small set of cases that are related with each other. In the thesis two related lignin applications are studied, which fits the case study description. Simons (2009) highlights that case study is required for studying the uniqueness of a single case but reflecting it to other possible cases. At the same time Gillham (2010) sees that case study can investigate individual, group, institution, community or multiple cases to answer specific research questions.

Other features of a common case study according to Hirsjärvi et al. (2012) are concentration on processes, studying the case's connection to the surrounding environment and collection of data using various methods. These features are suitable to the thesis characteristics since technological processes of applying lignin are gone through in detail for compiling representative regional economic and environmental impact results. Additionally, studying the case's connection to the surrounding environment is in the core of the thesis' preliminary question. The data was also to be collected by various means like enquiries, reports, articles and databases. (Hirsjärvi, Remes, & Sajavaara, 2012.)

Eriksson and Koistinen (2005) define a case study essentially about a research strategy and an approach how to conduct the specific research. Simons (2009) points out that in the literature case study is referred as a method, a strategy, an approach and often not consistently. She prefers 'approach' for emphasizing the nature of overarching research intent and methodological purpose. A case study possesses both qualitative and quantitative research preferences, which demonstrates its diversity. In the thesis emphasis was mainly put on quantitative research, which involves counting and measuring. Qualitative characteristics in the thesis process was conducted largely by investigating and discussions with experts in the field of chemistry and pulp production. However, the findings resulting from the discussions were analyzed with quantitative manner.

Eriksson and Koistinen (2005) see that case study process doesn't usually proceed straightforwardly and the researcher will encounter many phases, return back and specifying, comparing data against another, developing the dialogue between theory and findings and so forth. Consequently, the researcher needs to endure uncertainty and adjustments. Looking back at the thesis process it can be said that the researcher sure did encounter setbacks and change of plans with regard to research strategy, choices of data and specifying the scope and research questions. (Eriksson & Koistinen, 2005.)

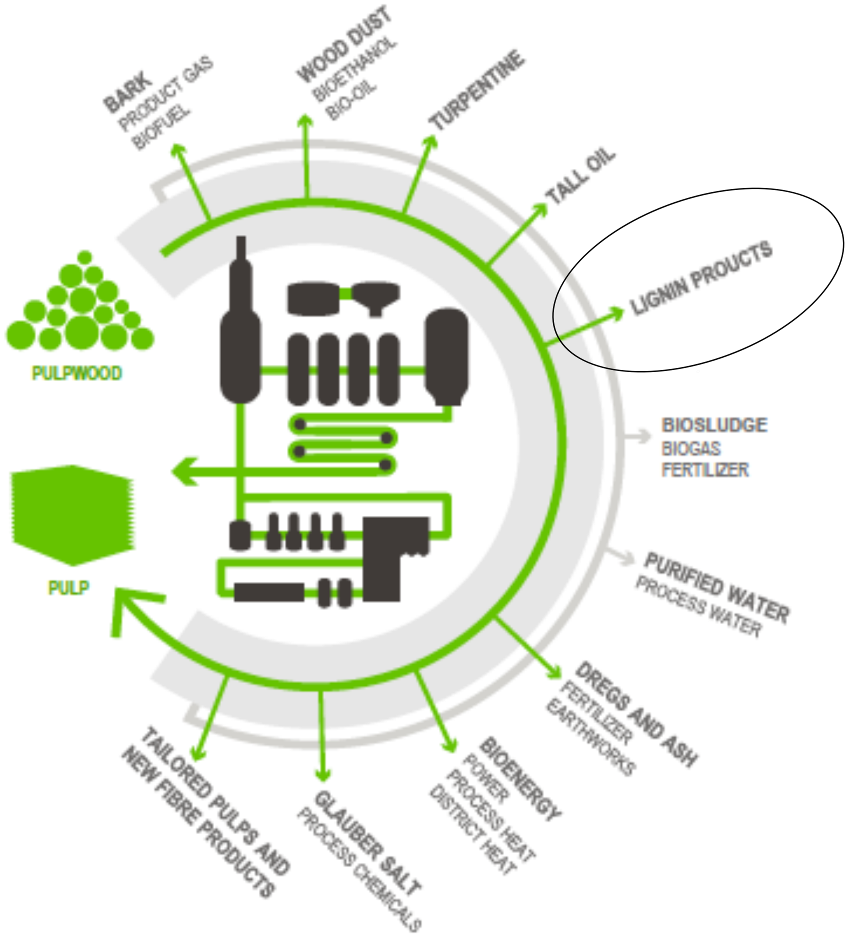
Although a case study can be a manifold and a complex spell, Eriksson and Koistinen (2005) have still defined some central working stages as designing the research questions, analyzing the research composition, defining and choosing cases, defining theoretical concepts and viewpoints, figuring out the logic between the data and research questions, deciding data analysis methods and finally deciding how to report the research. The researcher goes along with these statements and working stages, although the sequence between stages varied a lot while working with the thesis for a long period of time - the next stage after five could be actually one instead of six. Gillham (2010) also underlines that one should not start before prior theoretical notions, because most suitable theories can't be decided until getting a hold of data and the context. (Eriksson & Koistinen, 2005.)

As a method for comparing the two cases, applied environmentally extended input-output (EEIO) analysis is chosen. It is an environmental extension to an economic input-output analysis method. EEIO is presented and explained later in chapters 3.3.1 and 3.3.2.

2.2 Case selection

Two different cases of lignin application are assessed in the thesis. (1) Case 1 follows the option zero in the environmental impact assessment (EIA) of the Bioproduct mill conducted by Metsä Group subsidiary Metsä Fibre, where lignin is combusted for producing steam and electricity that are used by the mill and surplus energy is sold to the market and distributed (Metsä, 2015b). (2) Case 2 follows the option 1 in EIA, where part of lignin is separated from kraft black liquor. An addition to EIA, in case 2, lignin is sold first to hypothetical refiner A located in Äänekoski close to the mill, which refines lignin into biocomposite material and resells the biocomposite material to another hypothetical refiner B located in Äänekoski, which further refines it to a biocomposite product and sells it to the market.

These two cases have been selected because of the researcher's interest in refining lignin and its applicability to substitute fossil based plastic products. Regional Council of Central Finland, assignor of the thesis, has also special interest on the possible regional economic impacts of the Bioproduct mill and its by-products on Central Finland. The topic is current, since Metsä Fibre is interested to refine lignin into biocomposites (Metsä, 2015c; Metsä, 2016a). The goal is to attain a better picture of the two options and their relevance with regard to regional economic and environmental aspects. Picture 1 illustrates the bigger picture at the Bioproduct mill and its planned by-products in pulp production. Lignin is only one of the by-products but it is chosen for a review in order to gain a reasonable scope for the thesis. As mentioned, lignin has also special potential in substituting fossil based plastic products compared to other by-products at the Bioproduct mill.



PICTURE 1. Potential bioproducts at Metsä Group's Bioproduct mill.

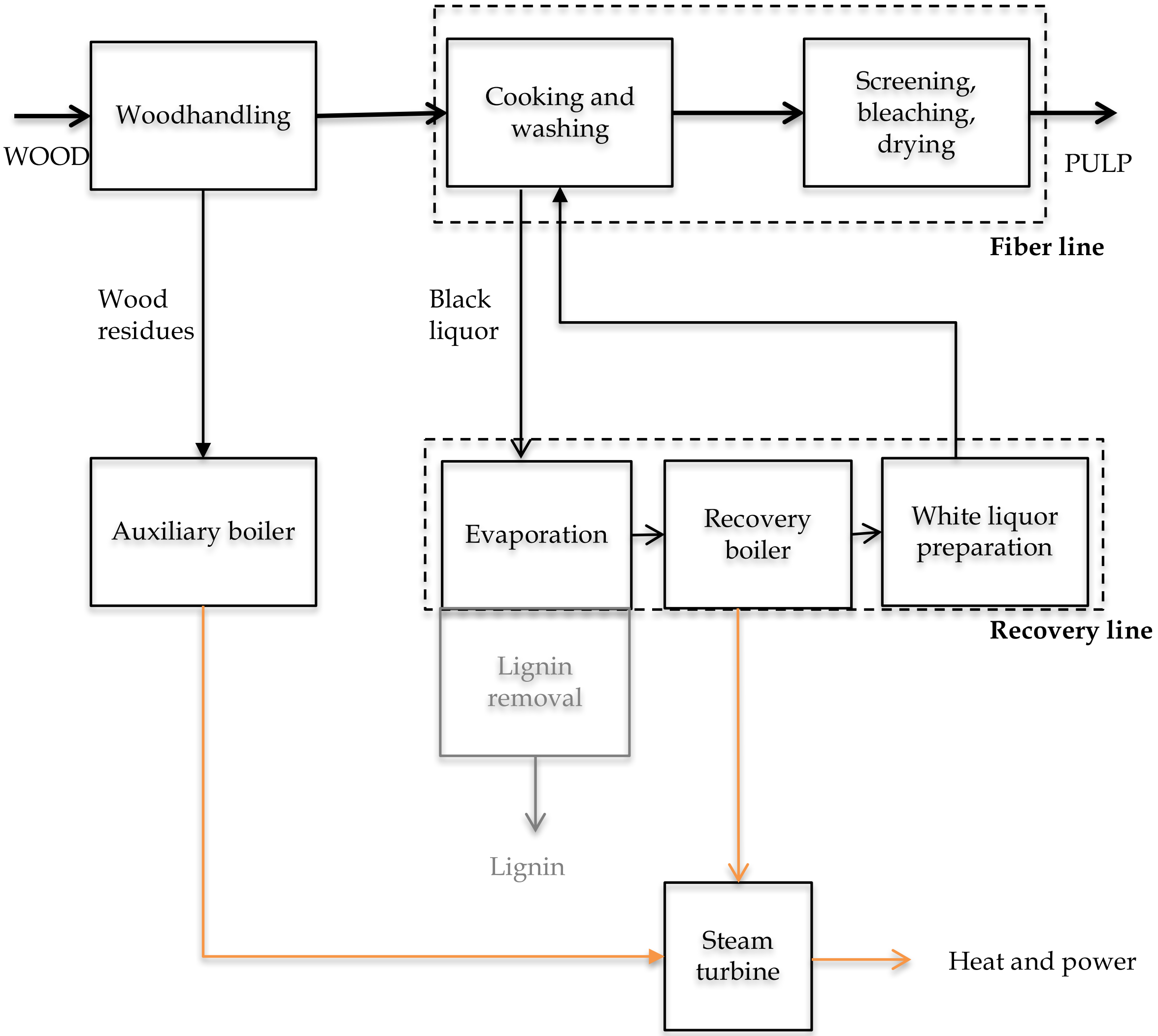


FIGURE 1. Conventional kraft pulp production process with lignin removal (figure applied from Hamaguchi et al., 2012).

The central production phases of the two cases are represented in the figure 1 and the scope of the analysis is represented in the figure 2, which is continuation of figure 1. The production of pulp begins from the forest, where it's logged. Wood is then transported to woodhandlig and other processes at the mill illustrated in the figure 1. As for the thesis scope, it starts from kraft black liquor evaporation, see box "Evaporation" in figure 1. In case 1, lignin is part of black liquor that is evaporated and then combusted in recovery boiler for energy generation through steam turbine. The scope of case 1 is limited to selling the surplus energy generated. In case 2, lignin is separated from black liquor in the evaporation phase. Separated lignin is then refined to biocomposite product and finally sold to the market. More detailed process descriptions are presented in chapter 4.

Production phases prior to evaporation are not taken into account, for they are similar in both cases and the aim of the research is to **compare** the two cases. There is no comparison in similar processes and raw-materials. For comparability purposes only the monetary value of lignin is observed and assessed in the analysis. Therefore, production phases after evaporation are related to lignin and its value creation. The amount of the observation unit of lignin is 60,000 tons. The reasoning behind the observation unit is explained in chapter 4.2.3. It is interesting to see the development of monetary value of the same amount of the same raw-material in two different processes.

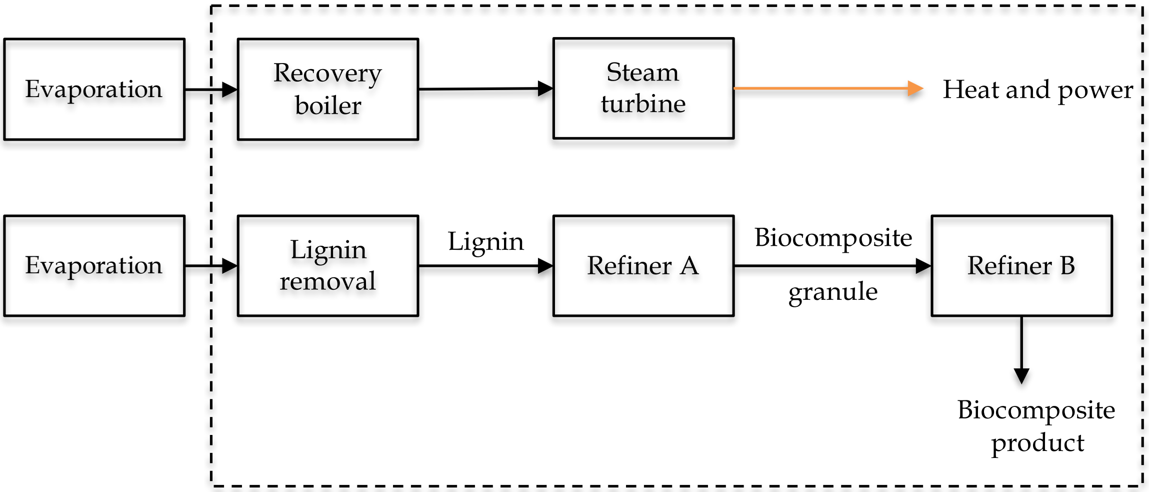


FIGURE 2. Case selection and scope.

2.3 Data and literature collection

Data for the applied environmentally extended input-output analysis is collected from Finland's national input-output tables and national greenhouse gas emission tables from Statistics Finland. Data in the tables is from 2012 and is the most recent available. Data for assessing the income effects are also from 2012 for consistency. Technical process data is collected from environmental impact assessment (EIA) report of Metsä Group's Bioproduct mill (Metsä, 2015b). Information was required for choosing an apt biocomposite, which was then gained from VTT Technical Research Centre of Finland Ltd. Some crucial chemical knowledge and information was gained from the faculty of chemistry in the University of Jyväskylä. The key sources for choosing the method applied in the thesis were Paloviita (2004) and Mattila (2013). Other information is collected from databases, books and journals, websites and other contacts. The key sources of the thesis are collected in table 1.

Farquhar (2012) makes a division between primary and secondary data sources for qualitative and quantitative case study research. According to her, primary data is new data collected directly by the researcher from original sources and specifically for the research project. Secondary data is collected from external data sources such as governmental information or privately generated market data from companies, or it can be from the case itself, such as websites. Qualitative primary data sources are for example interviews, focus groups, participant observation, diaries, whereas qualitative secondary data include meetings, internal reports, consultancy reports, market research reports and government and EU data. Quantitative primary data sources according to Farquhar (2012) are survey, observation and experiment. Quantitative secondary data sources include for example spreadsheets, graphs, annual reports, external statistics, panel data and EU data. According to this division, the thesis' analysis is based entirely on secondary quantitative and qualitative data.

Data	Source/reference
Finnish national input-output tables (2012)	Statistics Finland
Finnish national emission tables by industry (2012)	Stat, 2016a
Environmental Impact Assessment (EIA) of the Bioproduct mill	Metsä, 2015b
Introduction to the Bioproduct mill, pulp production issues, processes and chemical background. Some specifications to the EIA	Niklas von Weymarn, Metsä Group
Insight to opt an apt biocomposite material	Antti Ojala, VTT
Insight to the chemistry of pulp production, related issues and refinery	Raimo Alén, Jarmo Louhelainen, Joni Lehto Department of Chemistry, University of Jyväskylä
Matrix sustainability: Applying Input-Output Analysis to Environmental and Economic Sustainability Indicators – Case: Finnish Forest Sector (Academic dissertion)	Paloviita, 2004
Input-output analysis of the networks of production, consumption and environmental destruction in Finland (Doctoral dissertion)	Mattila, 2013
Support for the chapters: introduction, methodology, theory, analysis and results	Journals, books, articles, websites, thesis supervisors and assignor

TABLE 1. The key sources of the thesis.

2.4 Data analysis

The data is analyzed with input-output analysis and applied environmentally extended input-output analysis (EEIOA). EEIOA has its base on economics and input-output analysis, but more recent applications are also from the field of ecology and environmental sciences (e.g. EIO-LCA). According to Farquhar (2012) the analysis of quantitative data is judged on how it contributes to the overall research question and together with other data sets that supplement the research strategy. After literature review, hybrid-LCA was reviewed as the best option for obtaining the most realistic results for the preliminary question. However, due to the inadequate data availability and data assessment methods, more generalizing method EEIOA was chosen as the next best option. The most notable differences compared to hybrid-LCA are the environmental impact results, which do not portray the actual impacts accurate enough. The economic impacts are conducted in the same way in both assessment methods. Therefore, the analysis of quantitative data lacks with regard to environmental impacts. Anyway, the researcher saw that the application of EEIOA can still give insight for comparing the two cases. In addition, other research is presented and collated to the results for assessing especially the reliability of environmental impact results. Description of EEIO is presented in chapter 3.3.2 and overview of hybrid-LCA is presented in chapter 3.3.1.2.

As mentioned by notably cited Keeney and Raiffa (1993), suitable indicators or methods should reflect the criteria and goals of the decision maker. In this thesis the goal is to compare economic and environmental impacts of the two cases. Cases vary with regard to their outcome's characteristics – in the other case there will be a concrete end-product (biocomposite product refined from lignin) and in the other case renewable energy (lignin is combusted), which is a commodity as well. However, renewable energy can be seen also as an input rather than output. In the thesis this energy is considered as an outcome and a commodity. Both of the case commodities have market prices. Chosen economic impacts are regional economic impacts (production impacts, employment impacts and income effects), since they describe the economic extent between the cases but also in relation with other options of production. Chosen environmental impacts or indicators are global warming potential and acidification potential. Reasons for the environmental indicator choices are explained in chapter 4.4. The goal is to compare these impacts and indicators between the two cases. Therefore, the suitable method should fit the goal.

Data collected from Statistics Finland and analyzed in IOA and applied EEIOA was aggregated to 30 industries from the original 64 in all calculations. This was due to achieving consistent and comparable data sets and consequently results. The data sets were two different tables collected from Statistics Finland, which both had different amount of industries. Aggregation was obligatory for congruent calculations. The aggregated 30 industries are listed in appendix 1. More detailed data analysis choices are discussed and presented in chapters 4 and 5.

3 THEORY

Case study is a complex process and it usually requires using various theories and methods. This thesis will be no exception. Ultimately, the goal was to find the most suitable method to answer the preliminary question of "what are the regional economic and environmental impacts of two different lignin applications of the Metsä Group's Bioproduct mill to be". Environmentally extended input-output (EEIO) analysis is presented and discussed as the best applicable option.

This chapter will go through the main theoretical concepts and methods related to the framework in outline. The aim is to present EEIO analysis and provide a general sense about the surrounding theoretical framework. First regional economic impact assessment method input-output analysis (IOA) is explained in outline. Secondly the framework of environmental impact assessment is discussed and some central methods are presented. Then the framework of combining environmental and economic impact assessment methods is discussed and central theories and methods are presented. Special emphasis is put on alternative methods for explaining the relationship between the best (hybrid-LCA) and the second best (EEIO) assessment methods evaluated for the thesis. Finally, the selected method of applied environmentally extended input-output analysis (EEIOA) is presented.

3.1 Regional economic impact assessment

Economic impact assessment in general pursues to uncover what are the impacts of a certain stimulus. A stimulus can be triggered because of e.g. demand. In this paper there are two comparable stimuli: a) Metsä Fibre combust lignin for energy generation and b) Metsä Fibre separates lignin, sells it to refiner and so forth. The stimuli b is an extra investment, whereas the first one is part of the mill's integral functions in any case when the mill is operational – therefore the word "stimulus" doesn't represent the case well. Economic impacts under investigation are regional income per capita, number of employed regionally, regional output and other issues concerning cross-regional social and economic problems. The objective is to understand how regional differences arise and what is the nature of these differences. (Armstrong & Taylor, 2000.)

According to Pleeter (1980) regional economy models that produce impact estimates can be categorized into *economic base*, *econometric* and *input-output models*. These models cover various advanced and suitable applications. *Economic base models* separate economic activities into local service industries and export service industries - simply, to local economy and others. The model is a simplified equilibrium of a local economy and its' activities, where prices, wages and technology are assumed constant, supply perfectly elastic and changes are not allowed for distribution of income or resources. The model is useful in understanding the interdependencies of an economy. (Pleeter, 1980.)

Multiple-equation systems represent *econometric models*. These systems portray economic structure of a local economy and attempt to predict aggregate variables such as income and employment. There are models e.g. from 16 to 228 equations, so the sophistication varies a lot. Compared to economic base models, econometric models apply time-series data, whereas economic base models' timeframe is typically a single period. (Pleeter, 1980.)

Time-series data, with the time span of several years, requires available data from several years. However, according to Armstrong and Taylor (2000), *Input-Output Analysis (IOA)* is designed so that it takes a "detailed snapshot of the input-output linkages that exist within a region". This feature enables IOA to analyse regional economic scenarios that have not been observed for sequential years (Armstrong & Taylor, 2000). With the help of input-output analysis, the impact of an exogenous stimulus on aggregate demand is observed. These economic impacts on aggregate demand can be direct and indirect. *Direct economic impacts* are exogenous, which means that they are originating externally and can not be influenced within the system. *Indirect economic impacts* are generated from multiplier effect, which means a situation where an injection of extra income or investment leads to more spending, which creates more income, and so on. The multiplier effect refers to the increase in final income arising from any new injection of spending. Input-output analysis is a common and a good way to assess indirect economic impacts. (Pleeter, 1980.)

Modelling regional economic impact, the most used estimates for the effects of exogenous changes are according to Miller & Blair (2009) "(a) outputs of the sectors in the economy, (b) income earned by households in each sector because of new outputs, (c) employment (jobs, in physical terms) that is expected to be generated in each sector because of the new outputs and (d) the value added that is created by each sector in the economy because of the new outputs". The thesis will deal with all the estimates above. The regional economic impact assessment framework of the thesis described above is illustrated in figure 3.

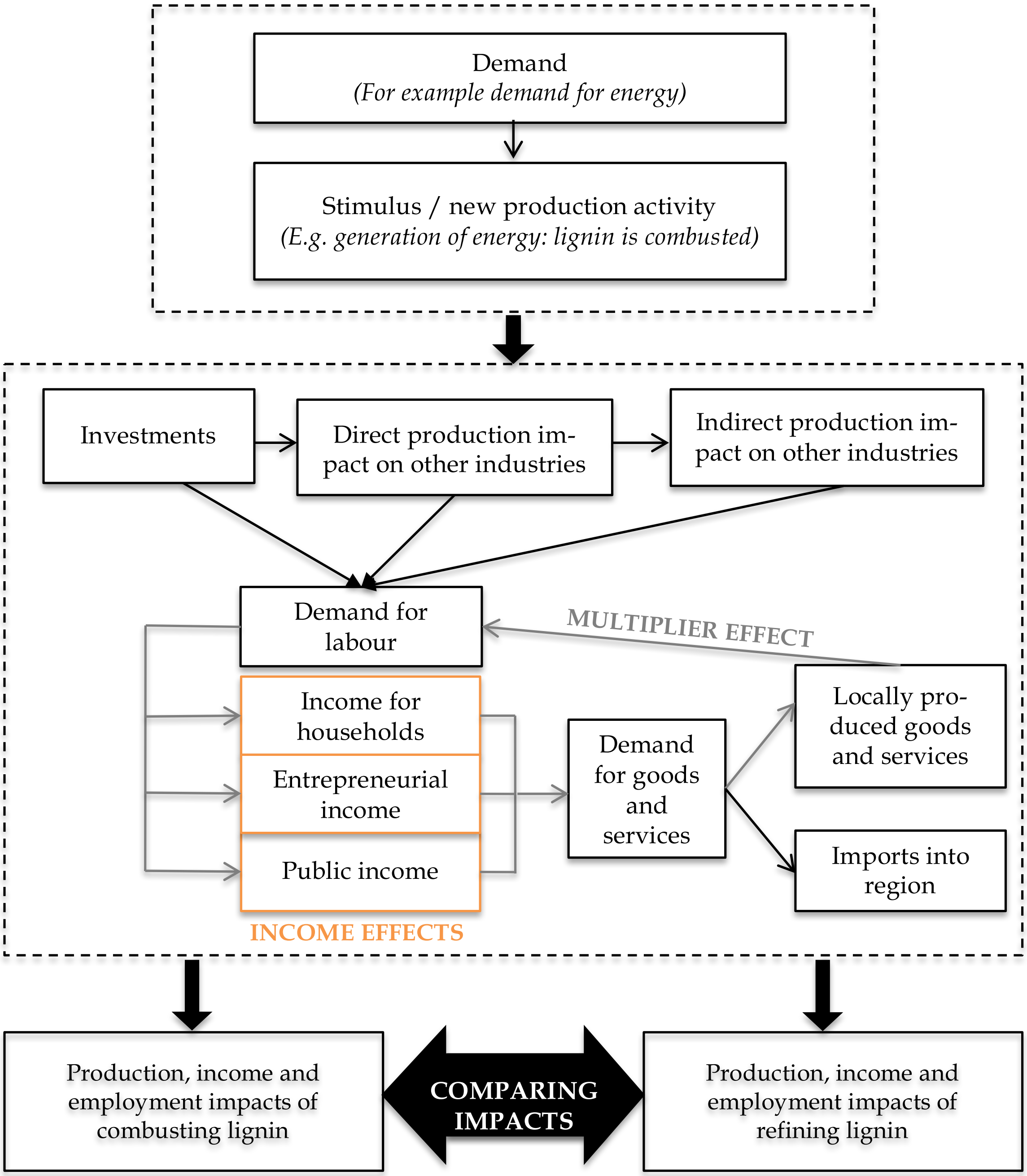


FIGURE 3. Regional economic impact assessment framework of the thesis. Orange colour presents income effects and grey colour presents multiplier effect. (Applied from Armstrong and Taylor, 2000.)

3.1.1 Input-output analysis

The Input-Output Analysis (IOA) was developed first by Wassily W. Leontief during 1930s. The simple but fundamental notion of the input-output model is that the production of output requires input (Armstrong & Taylor, 2000). A simple example is a chair as an output, which is made out of e.g. steel, wood, paint and rubber. Following the principle, input-output model reflects the structure of our technology.

In the analysis economy is divided into sectors or industries, and the flow of goods and services among the sectors indicates the dependencies between them. These dependencies are called *input-output relations*. They specify the sector's needed inputs in order to produce one unit of output (Yan, 1969). IOA supplements partial analysis of economics comprehensively by taking the fundamental structure of an economy into account (Suh, 2003).

Input-output tables or *transaction tables* are used for analysing these interdependencies and relations. For analysing economics problems, input-output tables in monetary units are especially useful. For ecological studies, physical units (tonnes etc.) can be used – in principle, it is possible to make an analysis of the biological metabolism of living beings. For social studies, time units might serve as a data base. A comprehensive analysis of sustainability requires an integrated analysis of all three types of input-output tables. (EUROSTAT, 2008.)

3.1.1.1 Transaction table

Most countries compile *transaction tables* on regular basis (Suh, 2003). The amount of industries can vary from aggregated 15 industry transaction tables to for example 98-industry model for the Scottish economy (Scottish Government, 2016). The table illustrates where a sector's inputs come from and where its output goes to, and it converts use and supply tables into one input-output table (Armstrong & Taylor, 2000; Onat et.al., 2014).

Transaction table contains the basic information on which the input-output model is based on. The table's rows illustrate how a producer's output is distributed throughout the economy. The columns illustrate what is the composition of inputs required by an industry to produce its output. (Miller & Blair, 2009.) The information of a transaction table extends a certain period of time, but usually one year (Armstrong & Taylor, 2000). Additionally, transaction tables are published always some years later, so if trends and technology have been changed, tables can't exactly portray the current situation.

Industries presented in transaction tables have their own specific sales structure and therefore similar product mix. Therefore, whether each industry and company within each selected industry would manufacture completely different products and services, they are standardized - transaction table is based on industry sales assumptions (Onat et.al., 2014).

The basic principles of a transaction table are illustrated in table 2. The table presents a three-industry economy. Presented industries are agriculture, manufacturing and service. It describes the input-output relations between these three industries and similarly between industries and households, government and residents in other regions. Industries require inputs also outside the industries in order to produce outputs: household services offer labour, government provides several services and other regions offer goods and services (imports). There is demand for the outputs outside the industries within households, government and other regions (exports). These relations are illustrated in the table, too. Finally, gross inputs and gross outputs are compiled. Although input-output table is a tool for examining the regional economy, the table illustrates the economy's reliance on other economies by imports and exports. (Miller & Blair, 2009; Armstrong & Taylor, 2000.)

	Inputs to			Final demand sector			Gross output
	Sector 1: Agriculture	Sector 2: Manufacture	Sector 3: Services	Households	Government	Exports	
Outputs from:							
Sector 1: Agriculture	20	40	0	20	0	20	100
Sector 2: Manufacture	20	20	10	80	10	60	200
Sector 3: Services	0	40	10	25	20	5	100
Payments for:							
Household services	40	45	70	5	0	0	160
Government services	10	15	5	0	0	0	30
Imports into regions	10	40	5	0	0	0	55
Gross inputs	100	200	100	130	30	85	645

TABLE 2. Transaction table applied from Armstrong & Taylor, 2000.

Taking a closer look to the table, we see that agriculture requires €20 worth of agricultural inputs and €20 of manufacturing inputs in order to produce €100 of agricultural output. The €100 of agricultural output is shown at the far right column "Gross output". Other inputs for the agricultural sector are shown in the payments sector at the lower left side of the table. It purchases labour from household services (€40), governmental services (€10) and services and goods imported from other regions (€10). Additionally, we see from the first row that agriculture sells its output to itself (€20), manufacturing sector (€40) and final demanders as households (€20) and residents in other regions (exports €20). Gross input equals exactly gross output since the transaction matrix is based on the principle of double-entry bookkeeping. (Armstrong & Taylor, 2000.)

Although this method of constructing an input-output transaction table is most commonly used, it is important to know that it is not the only one. For this thesis a 30-industry table is constructed that is aggregated and applied from 64-industry Finnish national tables. In addition to industries, various other figures are included. These figures are comparable to "payments for" and "final demand sector" sections in table 2. "Payments for" stands for an industry's payments, which in addition to other figures is summarized as the use of domestic goods, use of imports, Finnish households' purchases abroad, foreigner households' purchases in Finland, product and production taxes, compensation of employees, the number of employed, intermediate consumption, value added, fixed capital (investments) and gross input. As for the "final demand sector", the following figures summarized are included in the studied transaction table: expenditures of households and societies, fixed capital (investments), exports and gross output. If a transaction table would be constructed from a country's whole economy, gross input and gross output figures (645 in table 2) are comparable to gross national product, which states the total of productive activity (Leontief, 1966).

3.1.1.2 Production model

Production model is the mathematics behind input-output anlaysis and therefore also behind environmentally extended input-output analysis. Here the Leontief inverse matrix is solved.

Row equation for transaction table

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \qquad (i = 1, \dots, n) \tag{1}$$

Where x_i denotes the gross output of industry *j*. x_{ij} denotes the flow of output from industry *i* to industry *j* (i is a row, j is a column). y_i is the end product.

Input coefficient a_{ij} denotes how much industry j requires industry i's production in order to produce one unit of output.

$$a_{ij} = \frac{x_{ij}}{x_j} \tag{2}$$

From equation (2) intermediate product's demand can be solved, which can then be substituted in the balance sheet equation.

$$x_{ij} = a_{ij}\, x_j \tag{3}$$

When substituted in the row equation, we'll get

$$x_{ij} = \sum_{j=1}^{n} a_{ij}\, x_j + y_i \qquad (i = 1, \dots, n) \tag{4}$$

In matrix form:

$$x \ = Ax \ + y, \text{where x } = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

Leontief inverse matrix is formed from the matrix A. Leontief inverse matrix represents the dependency between industries' total production and demand of end products. By solving the following equation (5) inverse matrix is formed

$$(I - A)x = y \tag{5}$$

Same in general formula:

$$x = (I - A)^{-1} y \tag{6}$$

or

$$x_i = \sum_{i=1}^{n} b_{ij} y_j \qquad (i = 1, \dots, n) \tag{7}$$

when

$$(I - A)^{-1} = \left[b_{ij}\right] \tag{8}$$

Leontief inverse matrix $(I - A)^{-1}$ denotes the dependency between industries' total production and demand of end products. Cell $\left[b_{ij}\right]$ illustrates how much production is required from industry i in order industry j to produce one unit of end product or output. (Miller & Blair, 2009; Armstrong & Taylor, 2000; Leontief, 1966)

3.1.1.3 Total effects

Observed data from a defined region is required for constructing an IO model (Miller & Blair, 2009). Statistics base is also more comprehensive in IOA.

The total effects caused by exogenous changes can be divided into different subclasses depending on if the input-output model is open with respect to households. If households are taken into account, total effects are divided into **direct effects** and **indirect effects**, which are called also simple multipliers. If households are not taken into account, total effects are divided to direct, indirect and **induced effects**, which are called also total multipliers. (Miller & Blair, 2009.) Direct and indirect effect can be estimated on both local and national level (Storhammar & Mukkala, 2011).

Direct, indirect and induced effects can be demonstrated with an example from the bio-product mill. *Direct effects* are effects caused by inputs required in the production and acquired from the same or other industries (Storhammar & Mukkala, 2011). For example, if the demand of pulp increases, the mill will react and produce more pulp to meet the demand. This is the direct effect, which generates local income and employment. *Indirect effects* occur in the supply chain. As there is more production in the mill, the demand for chemicals and other inputs from suppliers increases and creates indirect effects. *Induced effects* occur via the mill's employees by spending some of their increased income locally on goods and services. (Armstrong & Taylor, 2000.)

Although the input-output analysis can point out the dependencies of products and services between industries, and track the needed inputs for producing outputs, IOA has several limitations. Paloviita (2004) points out the following limitations: uncertainty of source data, imports assumption uncertainty, estimation uncertainty of capital flow, proportionality assumption uncertainty, aggregation uncertainty, allocation uncertainty and gate-to-grave truncation error. The most relevant limitations and uncertainties for the chosen applied method (EEIO) are presented in chapter 3.3.2.

3.2 Environmental impact assessment

In recent decade there has been increasing interest in environmental issues and sustainable development in general. Environmental aspects have been incorporated to households' and companies' way of thinking and daily activities. With increasing interest, the amount of regulation and legislation nationally and globally has increased. Calculating one's impact gives a good overview about the actual impact on the surrounding environment, which can then be compared to other impacts. Comparability gives insight, which impacts are really significant and which especially needs measures. The purpose of environmental impact assessment (EIA) is an aid to decision-making and the formulation of development actions, a vehicle for stakeholder consultation and participation and an instrument for sustainable development (Glasson et al., 2012).

According to Glasson et al. (2012) definitions of environmental impact assessment varies from "broad definition of Munn [1979], which refers to the need 'to identify and predict the impact on the environment and on man's health and well-being of legislative proposals, policies, programmes, projects and operational procedures, and to interpret and communicate information about the impacts' to the narrow and early UK DoE [1989] operational definition: The term ‘environmental assessment’ describes a technique and a process by which information about the environmental effects of a project is collected, both by the developer and from other sources, and taken into account by the planning authority in forming their judgements on whether the development should go ahead.” The International Association for Impact Assessment (IAIA) defines environmental impact assessment rather similarly as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (Fridian & Halley, 2009).

There is no one and only method for assessing environmental impacts (Seppälä et al., 2009). As environmental impact assessment (EIA) is an instrument for sustainable development, its theoretical framework has been extended to other parts of sustainability. EIA has been expanded since 1970’s with social impact assessment (SIA), environmental health impact analysis (EHIA) and strategic environmental assessment (SEA). Other types of impact assessment that have recently merged include regulatory impact assessment (RIA), human rights impact assessment, cultural impact assessment, post-disaster impact assessment and climate change impact assessment. Different methods have arisen alongside current issues. (Wathern, 2013; Morgan, 2012.)

Gasson et al. (2012) identify three components in assessing environmental impacts within environmental impact assessment framework: “1) appropriate information necessary for a particular decision to be taken must be identified and, possibly, collected, 2) changes in environmental parameters resulting from implementation must be determined and compared with the situation likely to accumulated without the proposal and 3) actual change must be recorded and analysed.” EIA can be thought of as a data management process from a technical point of view. (Glasson et al., 2012.)

Anjaneyulu & Manickam (2007) sort environmental impact assessment methods to ad hoc methods, checklist methods, matrices methods, networks methods, overlays methods, environmental index for using factor analysis, cost/benefit analysis and predictive or simulation methods. Former study of Canter (1999) categorized EIA methods for ad hoc methods (case studies), checklist methods (decision-focused checklists), matrices methods, networks methods (impact trees and chains), overlays methods (overlay mapping), scenarios and trend extrapolation methods (similar to predictive or simulation methods of Anjaneyulu & Manickam) as well as additional categories as expert opinions and expert systems, literature reviews, monitoring, and risk assessment. The main difference between these two categorizations is Canter’s risk assessment category and Anjaneyulu & Manickam’s cost/benefit analysis, since expert opinions and systems, literature reviews and monitoring are usually integrated in other methods. Also Anjaneyulu & Manickam’s environmental index for using factor analysis is relevant. Summarized, environmental impact assessment methods are collected in the following list:

- Ad hoc methods (case studies)
- Checklist methods (scaling, rating, ranking: weighting)
- Matrices methods (simple, stepped, scoring)
- Networks methods (impact trees and chains)

- Overlays methods (e.g. GIS)
- Predictive or simulation methods (scenarios, trends)
- Environmental index for using factor analysis
- Cost/benefit analysis
- Risk assessment

Suitable method varies with regard to the assessment object. There is no universal method that can be applied to all project types, since the need of technical information and subjective judgement varies (Canter, 1999). For example, costs and environmental impacts for its entire life cycle are to be considered for a product. Thus, life cycle approaches have emerged such as Life Cycle Cost (LCC, for economic costs), Life Cycle Assessment (LCA, for environmental impacts) and also Life Cycle Engineering (LCE). The latter takes the technical performance of a product into account with its economic and environmental viability (Fridian & Halley, 2009). Methods don't provide complete answers to all questions related to the environmental impacts. They need to be selected based on professional judgement and appropriate evaluation with relation to data availability, analysis and interpretation of results (Canter, 1999).

3.2.1 Diverse environmental impacts

Environmental impacts are diverse and can be linked e.g. to hydrology, water and air quality, land use, biodiversity or biocapacity, climate change, terrestrial and aquatic ecology, noise and vibration, landscape, historic environment, recreation and amenity, toxicity, geology and soils, interrelated and cumulative impacts (Glasson et al., 2012; Mattila, 2013). In order to connect environmental impacts to, for example, monetary measures, these environmental categories can be expressed as indicators. For example, indicator for land use of beef can be expressed as m^2 land used per €1 produced output (beef, Kg). With regard to land use, forestry and agriculture industries would have high land use rate. Since there are various environmental aspects to consider, it can be difficult to choose relevant indicators for describing environmental impacts.

In practice the availability of environmental information varies a lot. The availability should not have too high effect on choosing the indicators. Decision analysis theory implies that indicators should reflect the criteria and goals of the decision maker. A widely used method for environmental decision making is multiple criteria decision analysis (MCDA). It typically consists of mapping the value system of the decision maker into a value tree, which connects the overall objective to criteria, subcriteria and finally attributes used to measure those subcriteria. (Mattila, 2013.)

Yet, can you give environment a price tag? Decision makers have subjective opinions on what is important, valued and valuable. This chain of reasoning does not always go hand in hand with natural laws. In addition, it can be seen that environmental goods such as fresh air have intrinsic value regardless of the one who is valuing the good. In spite of this debate, environmental goods have been given an estimated value through various means. The variety of approaches is caused mainly by the fact that different researchers ask different questions (Schaltegger & Burritt, 2000). In environmental economics and natural sciences different methods for valuing environment have been developed. Figure 4 illustrates central environmental impact valuation methods. The methods are not explained in detail since they are not central to the research questions. However, they provide a general framework to measuring environmental impact.

The selected environmental indicators for the thesis are described in chapter 4.4.

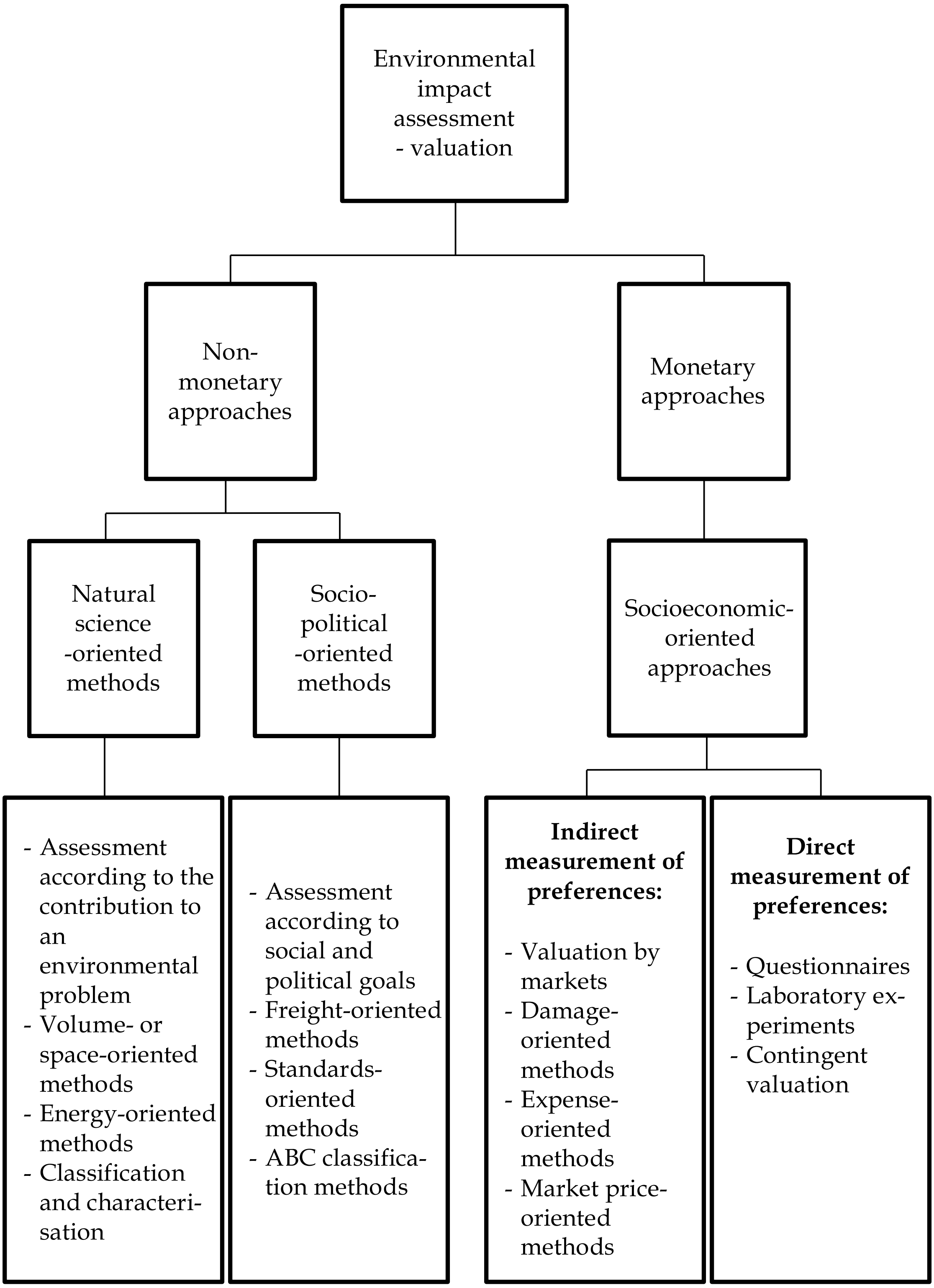


FIGURE 4. Environmental impact assessment approaches (Schaltegger & Burrit, 2000).

3.3 Combining economic and environmental methods

The background of recent combinations of economic and environmental impact theories and methods is rather manifold. Multiple branches of science are involved and interlinked: economics, accounting and environmental science. When speaking of sustainability in general, social sciences are also involved. In the field of economics, with regard to environmental issues, there is a division into environmental and ecological economics. Environmental economics use neoclassical analytical approach with "narrow" sustainability focus while ecological economics criticize this reductionist approach and tries to have a more diversified socio-economic approach with "wider" sustainability focus (Venkatachalam, 2007).

The field of accounting with regard to environmental issues can also be divided into environmental accounting and ecological accounting (or according to Wackernagel et al. (1999), natural capital accounting), although ecological accounting can be seen as a subcategory of environmental accounting. Ecological accounting searches for quantified information, usually in physical terms, as kilogram of CO_2 emissions. Life Cycle Analysis (LCA) is one of the most known and used methods in ecological accounting. General environmental accounting pursues monetary information of environmentally induced impacts. (Schaltegger & Burritt, 2000.)

Current methods of combining environmental and economic information have been developed both individually and jointly within all of these branches – economics, accounting (,social) and environmental sciences. Environmental economics originated from resource economics, which is a branch of economics (Venkatachalam, 2007). Ecological economics emerged alongside with environmental scientists and ecology and then to a part of economics. The background of economic and ecological accounting is similar.

There are not many methods that combine regional economic and environmental impacts. Based on the literature review, *Environmentally Extended Input-Output Analysis (EEIOA)* appears to be the most suitable one that can be applied in the thesis. For broad strategic analysis, aggregate analysis of trends and broad scenarios are sufficient. If a specific policy measure's or decision's environmental effects are analysed, the model or method should indicate the causal relation between the policy measure and the effect. Consequently, the required level of detail varies with the policy measures considered and implemented. EEIO models are suitable with a detailed sector resolution as it supports more detailed and specific policies or decisions. Although with more detailed requirement of information, EEIO is not sufficient and usually is covered by LCA (Tukker et al., 2006). In the following chapter (3.3.1) EEIO and other related assessment methods are presented and discussed.

3.3.1 Environmentally extended input-output (EEIO) analysis – background and other methods

Since late 1960's, Leontief and other economists have applied input-output analysis also for environmental issues and problems. As the name implies, previously presented monetary (or physical) input-output accounting framework (see chapter 3.1.1) is extended with environmental data. This framework is called environmentally extended input-output analysis. Leontief initially presented extended environmental data in physical units. (Paloviita, 2004; Turner et al., 2007.)

Many environmental-economic models are based on input-output analysis within economics and environmental sciences. For example, LCA applies environmental input-output models. Additionally, LCA has many other linkages and overlaps with EEIO and sustainability assessment. (Paloviita, 2004; Turner et al., 2007.) Currently, EEIOA still continues to grow in popularity for evaluating the relationship between economic activities and downstream environmental impacts (Kitzes, 2013).

EEIO connects economic consumption activities and environmental impacts by evaluating the upstream, consumption-based drivers of downstream environmental impacts, such as emission of pollutants. EEIOA can track the total indirect effects to environmental aspects throughout the supply chain (Mattila, 2013). Among other applications, EEIO models have been used for assessing global carbon, nitrogen, water, ecological, and biodiversity/wildlife footprints. (Kitzes, 2013.)

3.3.1.1 Other methods

There are no prevalent and accepted categorization of methods related to EEIOA. Categorization has been done, for example, with regard to measurement practices, scientific background, measurement object or other. Hoekstra (2010) divided EEIO methods for general EEIO models, imputation methods (multipliers), structural decomposition analysis (SDA) and others that include e.g. key sector analysis and structural path analysis. He has done the division by methodology. Miller & Blair (2009) had three more general basic categories of environmental input-output models: 1) generalized input-output models (similar to general EEIO models of Hoekstra), 2) economic-ecological models and 3) commodity-by-industry models.

Generalized input-output models include technical coefficients matrix or satellite accounts, which reflect the production and decrease of for example pollution. For a pollutant type, direct impact coefficient is calculated, which means in this case pollution amount per € value of one unit of output; for example, 1 Kg CO_2 per €100 of output. Different indicators, such as land use and CO_2 emissions are included in this model. In *economic-ecological models* additional "ecosystem sectors" are added, where flows between economy and ecosystem sectors can be tracked. Fully integrated and limited economic-ecologic models are included in this category. In *commodity-by-industry models* environmental factors are considered as commodities in a commodity-by-industry input-output table. (Miller & Blair, 2009.)

In addition to these environmental extended input-output models there are various competing methods. These are previously mentioned life cycle analysis and its further developed models (hybrid-LCA, life cycle sustainability assessment LCSA, economic input-output LCA or IOA-LCA), economy-wide material flow analysis, environmentally weighted material consumption and other extensions of input-output analysis such as enterprise input-output, physical input-output, input-output accounting and global input-output. (Paloviita, 2004; Matthews & Small, 2008; Cicas et al., 2007; Tukker et al., 2006; Onat et al., 2014.)

More recently division between single-region and multiple region models have been done, due to the development of EEIO models (Hoekstra, 2010). For a longer time, economic input-analysis has been approached from single-region and many-regional points of view. More specifically, many-regional models include interregional and multiregional approaches (Miller & Blair, 2009). On account of developing global-scale input-output database, these models can be utilized in EEIO applications. This research is named in general as multi-region input-output (MRIO) (Wilting et al., 2011). Multi-region input-output tables and databases have been developed, such as EXIOBASE[6], EORA[6] and the World Input-Output Database (WIOD[6]) (International Input-Output Association, 2016; Kitzes, 2013). Development towards comprehensive global EEIO tables and databases is essential due to the global nature of environmental impacts.

Another interesting, and method-based, way of studying the framework is with regard to interlinked methods of input-output analysis, sustainability analysis (SA) and life cycle analysis (LCA), as Mattila (2013) has done. In the study Mattila linked LCA and the broader scope of SA and measuring development with multiple criteria approach (MCA). MCA's purpose is to evaluate the overall environmental consequences of an alternative, taking into account multiple criteria and their relative weights. MCA has been used with LCA and environmental performance indicators to develop a tool to measure the overall environmental impacts of business (Hermann et al., 2006). LCA is also suitable for diversifying the scope of input-output analysis, which is originally rather focused on selected, few environmental indicators such as CO_2 emissions. As economic input-output analysis observes the interactions between industries, life cycle assessment looks at the total environmental impacts in the supply chain from cradle-to-grave (form raw material acquisition to manufacturing, use and recycling). (Mattila, 2013.)

3.3.1.2 EEIO and LCA

Life cycle assessment is a common methodology for quantifying the environmental impacts of products or processes throughout its life cycle from cradle-to-grave including material extraction and processing, transportation, use and and end-of-life phases (Finnveden et al., 2009). End-of-life phases include disposal and recycling and the term 'product' includes both products and services. LCA considers all aspects of natural environment, human health and resources (ISO, 2006). LCA was not developed for systematic analysis until early 1990s. Its roots in research are related to energy requirements in the 1960s and pollution prevention in the 1970s (Rebitzer et al., 2004). Since 1990s development and harmonization have resulted an international standard (Finnveden et al., 2009). The main components of LCA are goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation (Onat et al., 2014). The components or steps are illustrated in figure 5.

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[6] For more information about multi-regional input-output models, go to http://www.environmentalfootprints.org/mriohome

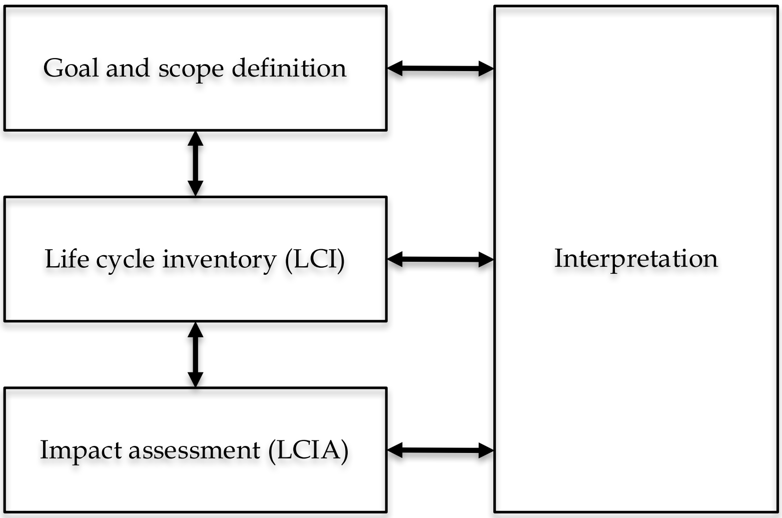

FIGURE 5. The four stages of life cycle assessment (ISO, 2006).

The goal and scope definition includes the reasons for carrying out the study and the intended application and audience. The system boundaries and the functional unit (FU) are also to be defined and described. FU is a quantitative measure of the functions that the goods or service provide. In the life cycle inventory (LCI) all the inputs (resources) and outputs (emissions) are associated with each stage of the life cycle and in relation to the functional unit. The magnitude and significance of the effects of the estimated inventory are studied with the impact assessment (LCIA) by characterizing and ranking the expected effects. Finally, in the interpretation, the results from the previous steps are evaluated in relation to the goal and scope. Conclusions and recommendations result from this final step. (Finnveden et al., 2009; Matthews & Small, 2008.)

EEIO or IO-LCA has emerged from a sparsely used tool into an important part of LCA research. IO and hybrid-LCA methods have been applied in applications as waste input-output (Kondo & Nakamura, 2004), hybrid Life Cycle Cost (LCC) (Nakamura & Kondo, 2006), transportation (Facanha & Horvath, 2006), socio-economic impacts (Hondo et al., 2006) and regional IO-LCA (Yi et al., 2007; Cicas et al., 2007). (Suh & Nakamura, 2007).

Wang et al. (2012) categorized LCA studies into process-based, IO-based and hybrid-LCA, which is an integration from the first two. Matthews & Small (2008) have a different point of view, as they categorize LCA developments to full or exhaustive, streamlined and economic input-output LCA (EIO-LCA or IOA-LCA). Huppes & Suh (2002) incorporate IOA-LCA into three types of hybrid-LCA methods: tiered hybrid, input-output hybrid and integrated hybrid (Paloviita, 2004). Onat, Kucukvar & Tatari (2014) added triple bottom line (TBL)-based LCA in addition to previous categories, which takes sustainability in general into account. IOA-LCA or EIO-LCA and EEIO are same methods, but the abbreviations IOA-LCA or EIO-LCA are used within environmental sciences and EEIO more often within economics (Wang, et al., 2012).

LCA is seen as a "bottom-up" approach while EEIO is seen as "top-down" approach. LCA begins with describing e.g. product's material inputs and environmentally significant outputs whereas EEIO begins with pre-calculated national figures and then aggregated economic and environmental impacts, which are then allocated to certain products. Process-based LCA method describes accurately material inputs and outputs and their environmental significance in the supply chain within the defined scope. However, it lacks data outside its' scope. EEIO gives a more holistic view, which is based on national and regional sectoral data and nothing is excluded. Despite the holistic view, the main weaknesses of EEIO or IO-LCA compared to process-based LCA are "(1) the low level of detail (or coarse sector resolution), (2) data age, (3) use of a monetary unit, and (4) neglecting (or not explicitly considering) the use and EoL [End-of-Life] phases" (Suh & Nakamura, 2007). The low level of detail of data is an issue since compiling input-output tables for an entire economy takes several years. The first three points are often made among the LCA community and the fourth point among the IO community. Another issue is international trade. IO tables covers detailed national data when exports and imports are presented in general figures. This is an issue since international trade is increasingly an integral part of the global economy. Addressing global challenges based on national IOA is therefore limited. In the end, environmental impacts are global and interpreting them with IOA provides only a restricted view. (Suh & Nakamura, 2007.)

Hybrid-LCA reduces these two errors by combining bottom-up and top-down methods. Based on Huppes & Suh's research (2002), Paloviita (2004) separates hybrid-LCA even further to tiered hybrid-LCA and integrated hybrid-LCA. In tiered hybrid-LCA, process-based LCA and input-output-based LCA are analysed separately whereas in integrated hybrid-LCA process-based and input-output-based LCAs are first developed independently but then merged into one system (Wang, et al. 2012; Matthws & Small, 2008.).

Combination of LCA and EEIO methods (hybrid-LCA, EIO-LCA, IOA-LCA) are suitable for reaching the goals of the thesis. The thesis cases are micro-level cases, because they have detailed information of the production processes. Consequently, a method that applies detailed information would represent the cases best. EEIO methods are suitable, for example, for studying nationwide or global economies and processes, since they require high level of aggregation. High level aggregation of detailed production processes of the two cases presented in the thesis may not reflect the actual process and information. However, combination of LCA and EEIO methods would complement the shortage of both methods. The high level of detail of LCA methods would compensate the lack of detailed information in EEIO methods. That is to say, for example, actual emitted greenhouse gas emissions of the two cases could be included in e.g. the hybrid-LCA calculations. In the general EEIO analysis greenhouse gas emissions are aggregated from the national estimates and therefore do not represent precisely the detailed production process. On the other hand, LCA does nott provide any economic information. As individual methods, EEIOA is superior to LCA in taking both the economic and the environmental aspects into account. Tukker et al. (2006) recommend hybrid-LCA for assessing the impacts of individual products. More generally, Tukker & Jansen (2006) finds EEIO superior because they see it inherently more complete, consistent, and systematic in allocating environmental impacts to final output categories. Additionally, once the model is constructed, it can be updated relatively easily with new emission data and economic data (when available).

Environmentally extended input-output analysis is the chosen applied method for this thesis. According to literature review, it seems that hybrid-LCA would have been the most suitable method for comparing the economic and environmental impacts of these the two cases. Unfortunately, hybrid-LCA requires detailed data that was not available despite my best efforts, and therefore the second best method (EEIO, according to the literature review) was chosen.

3.3.2 Environmentally extended input-output (EEIO) analysis – the method

Input-output analysis has been proposed to be a good framework for sustainability assessment (Murray & Wood, 2010; Duchin, 2004). Indeed, it can track the total indirect effects to economic, social and environmental aspects throughout the global supply chain, but is not based upon the assumption of growth and maximization of profits and consumption. Readily available statistics (gross domestic product, employment, greenhouse gas emissions) can be used to make a "triple bottom line" assessment for any company, region or country (Wiedmann et al., 2007; Duchin, 2004).

Environmentally extended input-output analysis (EEIO) is one of the fastest growing fields in input-output analysis. Hoekstra (2010) reviewed 360 papers in the refereed literature between 1969 and 2009. Although the review is still available only as a conference paper, it is the richest literature review in the field of EEIO. He noticed that the field of EEIO has experienced rapid growth since the mid-1990s: just 50 (out of 360) papers were published before 1995. Papers published between 1970s and 1990s focused mainly on energy consumption. Since 1990s, EEIO literature adapted and diversified. Nearly 50% of the articles in 2005-2009 dealt with global warming. However, other environmental topics emerged, such as land issues (e.g. ecological footprint analysis), acidification and water use. In addition, after 1995 the amount of studies that investigated simultaneously multiple environmental pressures increased instead of single type of environmental pressure. Geographically, before 1995 most of the papers were published in the United States. More recently, most applications are published in Europe and Asia. (Hoekstra, 2010.)

The 360 articles reviewed by Hoekstra (2010) were published mainly (75 %) in four journals: Ecological Economics (87), Energy Policy (62), Economic Systems Research (47), Journal of Industrial Ecology (22) and Structural Change and Economic Dynamics (15).

Previously in the paper EEIO models were categorized to generalized input-output models, economic-ecological models and commodity-by-industry models (Miller & Blair, 2009). Generalized input-output models are the most traditional and common ones and also used in this thesis. Miller and Blair (2009) present two variations of the model, one aimed at analysis of impacts and another aimed at planning applications. In this thesis, impact analysis method is applied. As the name implies, EEIO is an extension of the input-output analysis that was presented in chapter 3.1.1. In the analysis environmental emissions or processes are incorporated to the national economic tables - or in this case, regional economic tables (Mattila et al., 2011).

EEIO - Mathematics

If the emissions of industries are known, input-output analysis can be extended to EEIO by matrix multiplication:

$$g = B(I - A)^{-1}f \tag{9}$$

where g presents the overall emissions caused by the final demand, B is a matrix of emissions intensities (emissions type by industrial sector), f the final demand of products and $(I - A)^{-1}$ is known as the Leontief inverse. Emission intensities can be calculated from reported annual emissions by dividing each column with the production output of the corresponding industry sector. Emission intensities can be allocated to regional level by first narrowing the production outputs down to regional production outputs. f can be replaced with a diagonal matrix with the values of a f at the diagonal in order to yield a matrix of emissions caused by production of final demand products and services. (Mattila et al., 2011.) Finally, the calculated emissions per monetary unit (for example €1) of output can be illustrated as satellite accounts.

The equation 9 describes the emissions or other impacts caused throughout the supply chain of producing the final demand products or services. If the final demand vector is replaced by a unit matrix (or left out completely), equation 9 will give the total emissions caused in meeting a unit of demand. The manifold interactions of production are completely captured with the analysis and there are no processes left out, which is a limitation of process-based life cycle assessment. (Mattila et al., 2011.)

EEIO – Strengths and weaknesses

The model is unique in the sense that it combines economic input-output analysis, which is able to cover the whole global economy and its interdependencies at its best, but at the same time the model can be narrowed by different applications, such as LCA, which results e.g. hybrid-LCA. The variety of restrictions and applications enables the framework's flexibility for instance to assess sustainability. As said, EEIO is well suited for analysing different scenario prospects for sustainable development (Duchin, 2004; Mattila, 2013). Upstream environmental impacts related to downstream economic consumption can be traced and evaluated. According to Kitzes (2013), EEIO is able to trace "product trees" back for infinite times, utilize publicly available input-output tables to deduce production recipes, avoid double counting in environmental impacts between industry sectors, capture trade in secondary processed products and capture trade in services if a monetary transaction table is used. Environmentally extended input-output analysis has shown to suit well to assess forest industry's both "economic goods and environmental bads" in connection with the rest of the economy, too (Mattila et al., 2011). This statement supports the decision to choose an applied EEIO method for solving the preliminary question of the thesis.

Although EEIO seems fit for solving the preliminary question of the thesis and a suitable method for combined economic and environmental impact assessment, it has some shortcomings that are listed below.

- Input-output tables have to be aggregated and it often takes years to process the data before the tables are published (Suh & Nakamura, 2007; Kitzes, 2013). Technology changes rapidly so the data can be outdated.
- Input-output tables are not available in every country (Kitzes, 2013).
- The level of aggregation affects the results. Results obtained from EEIO analysis between a 27-industry and a 117-industry model differ significantly. This is due to very different trade developments and energy intensities of industry sectors (Wiedmann et al., 2007). Yamakawa & Peters (2009) support the claim by prompting the data providers and users to grasp at understanding the extent of variations in the data in order to them to understand the uncertainties. Piñero et al. (2015) point out that especially for Finland, particularly problematic is the aggregation of forestry activities with other biomass extractive sectors. Worldwide, aggregation bias is highest for agricultural products, mining and quarrying products (Koning et al., 2015). ENVIMAT model has been developed in Finland and it's fit for preventing the aggregation bias. Additionally bottom-up approaches, such as LCA, supplement the analysis and prevent aggregation bias (Piñero et al., 2015).
    - Aggregation bias in greenhouse gas emissions is found to be lower than bias with materials (Piñero et al., 2015).
- One of the main assumptions of EEIO is homogeneity, that is the assumption that each industry sector produces homogeneous goods or services. In detail, it is assumed that fixed proportion of inputs produce an industry's output (Kitzes, 2013).
- Many indicators that are relevant for the overall objective, are not available. For example, water scarcity and species loss methods are still under development (Mattila, 2013).
- Kitzes (2013) finds assessing environmental impacts accurately is often difficult, too. Inventories of environmental impacts are usually a mix of empirically measured data and modeled estimates, which can be biased. Onat et al. (2014) highlight the nature of pollutant emissions. The ultimate effect of pollutant emissions on a region is depended on the manner in which that pollutant is discharged into the environment. Technical, climatic and geographic factors have their own effect on the dispersion of emissions. Additionally, outlining territorial emissions is problematic.
- The conventional single-region EEIO lacks international scope. Production factors can extend to many upstream levels, but the model does not include those levels. Multi-region input-output (MRIO) is developed for this purpose. (Wiedmann et al., 2007.)
- Input-output tables or transaction tables may exclude some activities in the economy, unpaid work for instance (Kitzes, 2013).
- EEIO is problematic model for analysing detailed environmental impacts for a single product. Tukker et al. (2006) find this because they see it is not possible to build a transaction table and EEIO model with sufficient resolution to analyse life cycle impacts of a single product. Although they agree that with help of hybrid-LCA this is possible.

- Finally, limited access to data is a significant limitation to EEIO. There is a major gap between theoretical and practical application of the methodology in the literature. Data gathering and processing can be extremely complex. (University of Singapore, 2016.)

The extension and importance of these limitations depend upon the input-output database used for environmentally extended input-output analysis and the original goal of the study. For example, the required level of data is different for environmental problem analysis and broad strategic analysis (Kitzes, 2013; EUROSTAT, 2008).

EEIO literature is still held by lack of data and most of the studies are case studies of a single environmental pressure for a singly (rich) country for a single year. However, the renewed interest towards EEIO (e.g. new EU projects such as EXIOPOL and WIOD) will have positive impact on data availability and coverage. According to Hoekstra's (2010) extensive literature review and future research should invest in time series, input-output data for developing countries, multiregional datasets, broaden the scope to sustainability and connect the model to other satellite accounting systems. (Hoekstra, 2010.)

4 BACKGROUND INFORMATION AND ANALYSIS

The case study is a unique one and consequently input-output method is adapted. Before the applied EEIO can be conducted, the monetary value of lignin in both cases need to be solved. For comparability, the observed amount of lignin (t) has to be the same in both cases. This chapter will go through the two case processes in detail and provide background information that is needed for the applied environmentally extended input-output analysis. Figure 6 presents the two cases and their connection to standard industry classification (SIC) and thus the connection to the input-output analysis. Figure 6 is continuation to the figure 1 that is presented in chapter 2. The cases, case processes and relevant background information are discussed in more detail in chapters 4.1. and 4.2. It should be noted that all the calculations in both cases' steps are linked to lignin.

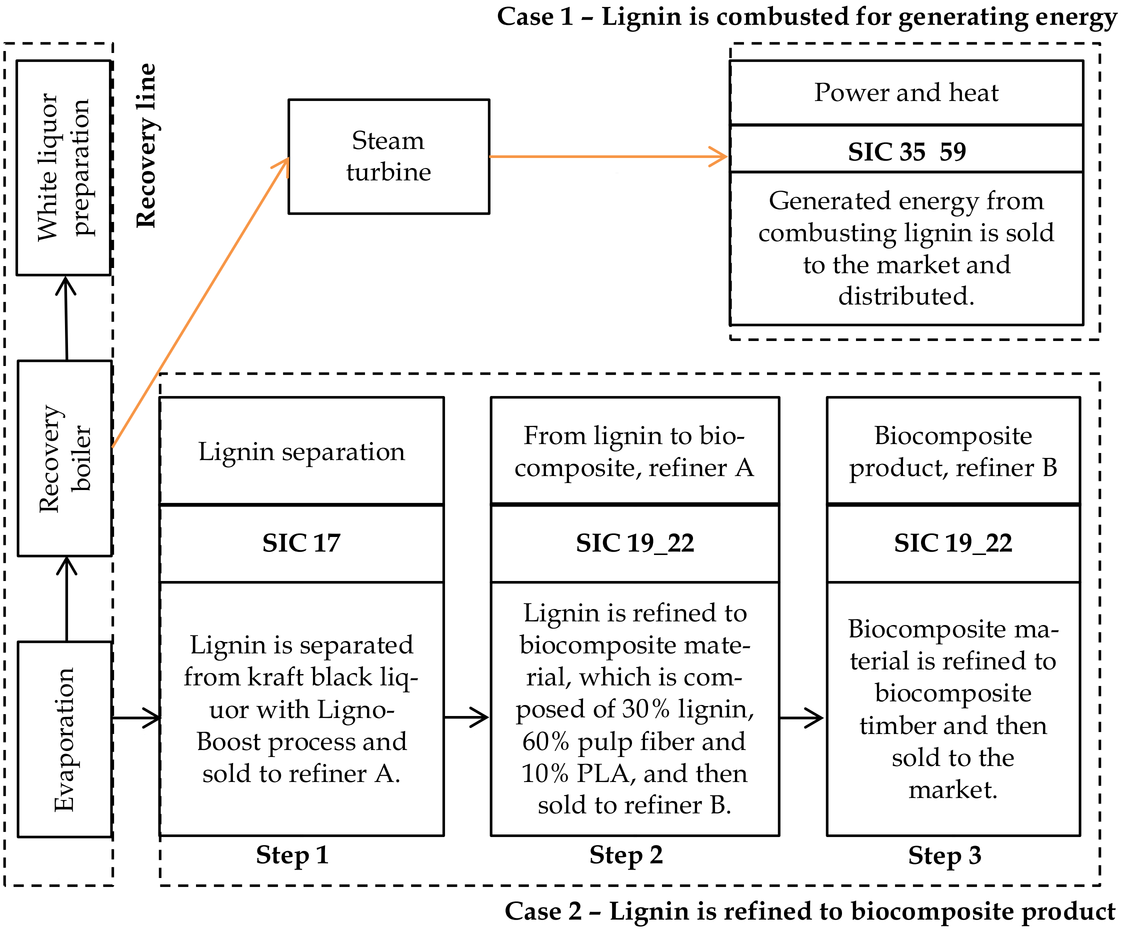

FIGURE 6. Processes of case 1 and 2 including applied Standard Industry Classifications (SIC) . The figure is continuation to the figure 1 in chapter 2.

4.1 Case 1 - Lignin is combusted for energy generation

4.1.1 Process

In the case 1, Metsä Fibre will not separate lignin, but incinerate it with kraft black liquor. This is a typical procedure at kraft pulp mills. Combustion generates energy in addition to recovering the cooking chemicals. The current Metsä Fibre's pulp mill in Äänekoski (to be closed when the new one starts) is, for example, already almost energy self-sufficient. and some of the energy surplus is thus sold to the energy market. In case 1, the Bioproduct mill will truly be self-sufficient and even greater amounts of energy can be sold to the market. Generation and sales of energy are included in the aggregated standard industry classification 35_39; energy management, water and waste management.

As the figures 1 and 6 illustrate, black liquor is processed to white liquor at the recovery line as a part of pulping process. After black liquor is separated from the fiber line, it is evaporated and then combusted in a recovery boiler to recover cooking chemicals and to generate energy in the form of electricity and steam. Kraft black liquor is the most important by-product of kraft pulp production, because it contains the key chemicals for cooking and it is a significant source of energy. Lignin has the highest heat value among kraft black liquor constituents and consequently, is a significant factor in the black liquor and energy generation. However, the recovery boiler can sometimes be a bottleneck of the pulping process. Partial removal of lignin can in such cases be used to unburden the overload and thus, increase production of main product pulp. (Ragauskas, 2014.)

4.1.2 Background information for the analysis

According to EIA of the Bioproduct mill, approximately 600 Kg lignin is formed per produced pulp ton. As the Bioproduct mill will produce 1.3 million pulp ton per year, approximately 780,000 t/a lignin is formed (Metsä, 2015b). According to the Research Director of Metsä Fibre, from the 780,000 t/a lignin 100,000 t/a can be separated. In the thesis the observed amount of lignin to be combusted is 60,000 t per year. The amount of 60,000 t per year is due to the same studied number in case 2. Same quantities in both cases are required for comparability that is the aim of the thesis. Rationale behind selected 60,000 t per year is explained in chapter 4.2.3.

4.1.3 Analysis

The monetary value of lignin is key to the input-output analysis and thereby to the environmental analysis in both cases. Assessing the monetary value of lignin in combustion is a bit tricky, because the value is not created in the market. Many aspects affect to the value creation, for example, if the recovery boiler is the bottleneck of the mill, if there is demand for the surplus heat energy in the near-by area or if the turbines are effective enough. The value in combustion is also dependent on lignin's features for producing heat value in the recovery boiler. Separating lignin reduces the amount of organic matter and thus the heat value in the recovery boiler. As the heat value is lower, the recovery boiler doesn't produce steam and electricity as before, so less energy can be sold to the energy market. According to Raimo Alén (2015), separating 60,000 t lignin per year corresponds to the loss of a generated 0.2 TWh (200,000 MWh) of energy (Alén, 2015). When the market price of electricity is approximately €50/MWh (Energiavirasto, 2016), the value of 60,000 t lignin is 10 MEUR (€50/MWh times 200,000 MWh). It is acknowledged that the mill produces also steam energy, which has lower market price. The lower steam price is taken into account by diminishing the electricity price to €50/MWh. However, the value of lignin used in the calculations is 9,313,494 €. This is due to the input-output analysis method – to avoid excessive value added. Here original lignin value 10,000,000 is multiplied by corresponding inverse matrix estimate 1.074 (Chemicals indusry). These numbers are used in production and employment impact, income effects and environmental impact analysis. 60,000,000 Kg lignin is a functional unit.

Material	To combustion, Kg/a	Corresponding electricity value, MWh	Electricity price, €/MWh
Lignin	60 000 000	200 000	50

TABLE 3. Amount of lignin to combustion and corresponding electricity value and price as a base for the case 1 calculations.

4.2 Case 2 - Lignin is refined into biocomposite product

It is well-known phrase among chemical scientists that you can make almost anything out of lignin apart from money. As said, lignin is often used as a fuel on wood pulping site, but it also has applications in the field of biomaterials. Various processed lignin applications have been studied and manufactured, but often producing these applications at large scale has not been cost-effective. Some exemplary applications are solid and liquid fuels, carbon fibers, activated carbon and resins in the plastic industry. Overall lignin can replace many petroleum-based chemicals and can be used as a bio-based additive to polymers. In this study lignin is a by-product in pulp production, and if it is to be applied, it has to be separated from black liquor. The most known lignin separation method is called "LignoBoost", technology provided by Valmet. (Ragauskas, 2014; Bernier et al., 2013; Volama, 2012.)

Tecnaro GmbH has verifiably produced biocomposite materials and products that are from renewable resources and contain lignin (Hu, 2002; Tecnaro, 2016). One of them is ARBOFORM© and it is applied in the thesis.

4.2.1 Process

In the case 2 lignin is first separated from black liquor, sold to refiner A, which merges lignin, cellulose fiber and PLA for producing ARBOFORM©-like biocomposite material. Refiner A then resells biocomposite material to refiner B, which further-upgrades this material to biocomposite product, timber. These three steps (see figure 6) and their technical and chemical background are explained in more detail in this chapter in connection with standard industry classification (SIC). The assessment of monetary value of lignin is explained in chapter 4.2.4.

It is hypothetically presumed that the refiners would be situated in Äänekoski, next to the new Bioproduct mill for e.g. cost-effectiveness (Alén, 2015). If the refiners would be situated further, costs of transportation would increase and affect lignin price. Additionally, according to Niklas von Weymarn, the Research Director of Metsä Fibre, biocomposite materials cannot be effortlessly transported long distances until the material is processed into granule form. In the thesis, refiner A will refine lignin (cakes) into biocomposite granules. Therefore, especially refiner A is to be situated close to the Bioproduct mill. More detailed analysis of the final placement of refiners has not been conducted for the paper.

Case 2 diverges from case 1 in the evaporation phase (see figure 6). In the case 1, after evaporation, lignin is still part of black liquor and thus incinerated. In the case 2 lignin is separated in the evaporation phase by LignoBoost methodology. In this process lignin is recovered by carbonation, dewatering, conditioning, acidification and washing resulting pure lignin cakes (Valmet, 2016). Lignin cakes are then sold to refiner A. This step 1 (see figure 6) functions under the standard industry classification 17 (paper industry).

In step 2 (see figure 6) lignin is transported to the refiner A close by and refined into biocomposite. Refiner A manufactures ARBOFORM©-like biocomposite material that is made from 30% lignin, 60% cellulose fiber and 10% polylactic acid (PLA). Lignin and cellulose fiber are supplied from the Bioproduct mill, since this would maximize the utilization of the mill and circular economy principle. PLA is purchased from another supplier since it is mainly produced from corn starch (Södra, 2016). Biocomposite production method is applied from Tecnaro GmbH that owns the trademark ARBOFORM©. According to the developers of ARBOFORM©, it is a formulation of 30% lignosulfonates, 60% wood pulp fibers and 10% additives (Hu, 2002). These various additives are derived from renewable raw-materials. Owing for analysis simplification, only one additive, PLA, is chosen for the studied material. Polylactic acid is biodegradable aliphatic polyester fermented from 100% renewable resources, such as corn or potatoes. PLA's weaknesses are high production cost, brittleness, and low thermal stability. However, adding cellulose derivatives optimizes cost-performance balance and improves the mechanical and thermal behaviours of PLA (Frone et al., 2013).

Lignin, cellulose fiber and PLA are merged to granules by special extrusion method of Tecnaro GmbH, which differs from more conventional extrusion by allowing biocomposite's preparation without inducing heat stress to the natural components. This is important because "any thermal stress will lead to the decomposition of the natural fibers and a significant decrease in their reinforcing abilities" (Hu, 2002). Finally, the finished granules are sold and transported to refiner B close by. Processes in step 2 are part of standard industry classification 222 'Plastic product production', which is integrated to industry classification 19_22.

In step 3, biocomposite is refined to biocomposite product, terrace timber, which consists of 50% biocomposite and 50% less costly material (wood). Now biocomposite is in granule form and it is injection moulded like other thermoplastics and carried out on standard injection moulding machines. For injection moulding technical details, see Nägele et al. (2002). As the name implies, injection moulding moulds the material right in the form that is pursued. In this case biocomposite granules are moulded into timber form. Finally, biocomposite timber is sold on the open market. Processes in step 3 are part of standard industry classification 222 'Plastic product production', which is integrated to industry classification 19_22.

There are additional ways of manufacturing alternative biocomposite timber or other similar products. However, these alternative manners of production can be applied similarly to EEIO analysis presented in the thesis if their production processes are applicable to the steps 1, 2 and 3 and relative standard industry classifications in that order. The added value of lignin increases in steps 2 and 3. Therefore, if other production methods are applied with regard to these steps, all the three steps and SIC's need to be included.

4.2.2 ARBOFORM ® and the biocomposite product

The purpose of this chapter is to explain why biocomposite timber was chosen as the end product, and why it is composed of ARBOFORM®-like material.

Production and disposal of fossil fuel based products have multiple detrimental effects on the environment and ecosystems. New sustainable solutions need to be developed and studied before choosing the products of the future. The author wanted to choose a pro-environmental material that can be manufactured from 100% renewable resources and is suitable for replacing petroleum-based materials for plastic products. As the case company was Metsä Group and studied case processes were of the Bioproduct mill, materials derived from wood were an obvious choice. A key idea of the new-generation Bioproduct mill is to utilize bioeconomy and circular economy principles, residues of production, in order to produce added value products, so the case selection fits the mill's core functions.

After consultancy of the Research Team Leader Antti Ojala from Technical Research Centre of Finland VTT and additional research, ARBOFORM® produced by Tecnaro GmbH was chosen as an appropriate material to further research because of its suitable characteristics with regard to the requirements of a suitable material listed above. It is thermoplastic material, which combines the attributes of natural wood and the processability of a thermoplastic. As said above, it is a formulation of 30% lignosulfonates, 60% wood pulp fibers and 10% additives. ARBOFORM®-made materials are easily produced by the injection molding or pressing technology and can be further processed by mill cutting and circular sawing. It is applied for many products and industries. It has been used for automotive industry and interior parts, civil engineering, electronics (loudspeakers, keyboards, mouse), commodities industries (knives, plates, glasses), musical instruments (flute, harmonica), gardening products and so on (Tecnaro, 2016). By varying the composition of ARBOFORM® both in terms of quality and quantity, it suits specific product requirements.[7] (Hu, 2002.)

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[7] For more details, see Hu (2002) and Tecnaro (2016).

Biocomposite terrace timber was chosen as the end product for its applicability. It has a steady demand and a good amount of lignin could be assimilated. Price of terrace timber (€7/Kg) is reasonable and follows the prudence principle. This enables the competitiveness with petroleum-based plastics. It is assumed that with this price there would be an actual market for lignin. Naturally, if lignin or biocomposite material would be applied to products with higher value added, the price and consequently production impacts would increase. There are many interesting application possibilities for the chosen biocomposite material. For all the reasons listed above, other lignin-based biocomposite materials are also applicable in the analysis, which is explained in the Conclusions.

4.2.3 Analysis and data

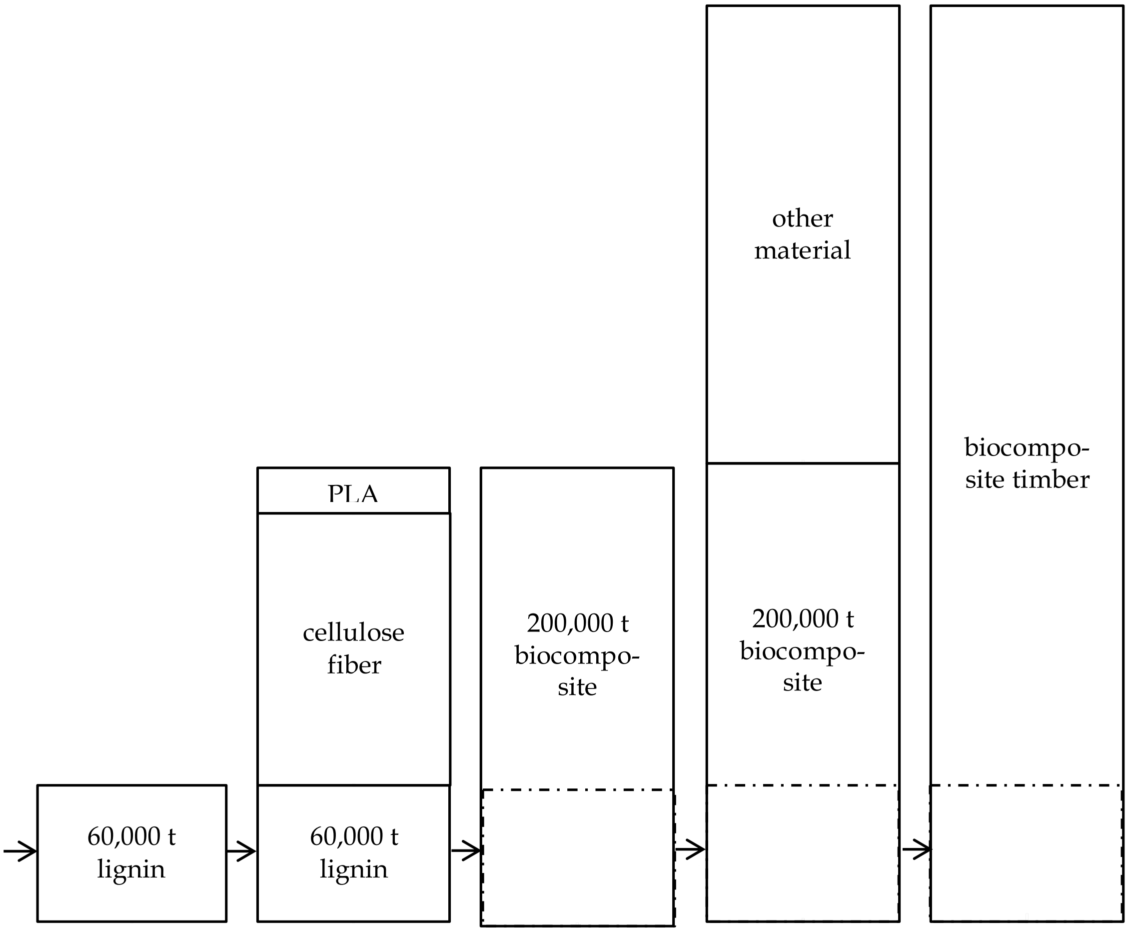

FIGURE 7. Proportion of lignin and other components in the biocomposite timber production process.

It is not feasible to separate all lignin from black liquor. Organic matter (lignin) is required for successful combustion. Additionally, less lignin in combustion decreases the heat value and consequently the amount of generated energy. Roughly 20-30 % of all lignin in kraft black liquor can be separated rather easily without comprising the combustion. In the analysis, approximately 10% of all the lignin in recovery boiler is separated. It is estimated in EIA that if lignin is not separated, electricity production is 1.7 TWh/a, and if 50,000 – 70,000 t/a lignin is separated, 1.5 TWh electricity is produced per year. Based on these estimates and discussion with the Research Director of Metsä Fibre, 60,000 t of lignin was chosen to be hypothetically separated in the thesis. According to Alén (2015), 60,000 t lignin is approximately 10% of all dissolved lignin in black liquor and extraction of 10% lignin is equivalent to less than 5% decrease in heat value of remaining black liquor. Therefore, separating 60,000 t lignin follows prudence principle. (Alén, 2015; Metsä, 2015b.)

Price estimates for lignin, biocomposite material and biocomposite terrace timber are required for the applied EEIO analysis. Price estimates for PLA and cellulose fibers give support for estimating biocomposite material price. Price ranges and derived price estimates per kilogram are presented in table 4. Price range from €2.50 to €5 per kilogram for biocomposite material ARBOFORM® is based on its price, which starts at €2.50 per kilogram (Eco-innovation Observatory, 2016). The chosen price estimate is however €3.50/Kg (average is €3.75/Kg) in order to be more competitive with petroleum-based plastic product prices. Biocomposite product price €7/Kg is based on the price of biocomposite material (€3.50/Kg) for pursuing a price that could enable profitable business. According to Tecnaro GmbH, substitutive petroleum-based plastic materials are e.g. PE (LD, HD, LLD), PP and PS. The price range of these regular plastics vary between €1 and €5 per kilogram (Eco-innovation Observatory, 2016) and thus the price cannot be much higher.

Material	Price, €/Kg	Price estimate, €/Kg
Lignin	0.5 – 1	0.75
Cellulose fiber	0.4 – 0.7	0.55
PLA	2 - 4	3
Biocomposite material (granules)	2.5 - 5	3.5
Biocomposite product (timber)	7	7

TABLE 4. Price estimates for biocomposite product and its components.

As 60,000 t lignin is the functional unit in the analysis, consequently 200,000 t biocomposite material is produced (it contains 30% lignin: 60,000 divided by 0.3), which is presented in figure 7. In the analysis, biocomposite material and biocomposite product price estimates are first multiplied by the amount of biocomposite (200,000 t) in order to solve the market value, which is then multiplied by the share of lignin (0.3) for calculating market value and its production impacts (and consequently employment effect and environmental impacts) for 60,000 t lignin. For example, the value of lignin in the biocomposite material is €210,000,000 as seen in table 5. However, the "share of lignin" (table 5) at the first phase is 37,676,448 due to the input-output analysis method – to avoid excessive value added. Here original lignin value 45,000,000 is multiplied by corresponding inverse matrix estimate 1.194 (Paper indusry).

Material/product	Amount to be sold, Kg	Value, €	Share of lignin, €
Lignin	60,000,000	45,000,000	37,676,448
Biocomposite material	200,000,000	700,000,000	210,000,000
Biocomposite product	200,000,000	1,400,000,000	420,000,000

TABLE 5. The value creation of lignin at different production phases.

4.3 Environmental impacts

Chosen indicators for environmental impacts for the thesis are greenhouse gases: carbon dioxide CO_2, carbon monoxide (CO), methane CH_4 and nitrous oxide N_2O collectively **Global Warming Potential (GWP),** and also sulfur dioxide SO_2 and nitrogen oxides NO_x collectively **Acidification Potential (AP)**. Global warming and acidification are important environmental impacts to consider and are commonly used environmental impact categories (European Commission, 2010; Standdorf et al., 2005; De Bruijn et al., 2002). However, the two indicators present only limited outlook of environmental impacts, and leave for example biodiversity aspects from consideration. GWP and AP are chosen because of the availability and comparability of data, and for reaching a reasonable scope for the thesis. National Finnish data for emissions by industry (SIC) was available only for emissions CO_2, CO, CH_4, N_2O, SO_2 and NO_x, which all are included in the analysis. Emissions data by standard industry classification (SIC) was required for comparability to input-output analysis, which applies also SIC. Data for the applied EEIOA was collected from Statistics Finland's (Stat) data base. (Stat, 2016a.)

Global warming potential is a common standardizing tool for comparing greenhouse gases that facilitates in processing complex issues. Therefore, GWP is a good tool in policy making and statistics. GWP-coefficients convert emissions to carbon dioxide equivalents (CO_2e). This is done because of practical matters – CO_2e is a good tool for comparing different emissions with various environmental impacts with regard to greenhouse effect. The coefficient for carbon dioxide is always 1. Other emissions are compared to carbon dioxide. For example, the coefficient for methane is 25, which means that its global warming potential is 25 times higher compared to carbon dioxide. The bigger the coefficient is, the more times the emission mass unit has an effect on global warming compared to carbon dioxide mass unit. Ordinarily the coefficients are calculated for a mass unit of emission, for example for one kilogram of CO_2. Time horizon of GWP varies but most commonly used time horizon is 100 years, which is applied in the thesis. For the common GWP-coefficients involves great uncertainty, about 35%. This is due to the requisite calculation hypothesis and partly natural scientific uncertainty (IPCC, 1995). IPCC develops GWP's. (Lindroos, Ekholm & Savolainen, 2012.)

GWP is a standard practice for comparing emitted greenhouse gas emissions of, for example, different technologies (Edwards & Trancik, 2014). Intergovernmental Panel on Climate Change (IPCC) has declared GWP-coefficients that have evolved over the years. IPCC's GWP-coefficients from Second Assessment Report (SAR) in 1995 have been used at Kyoto Protocol's first commitment period 2008-2012. At the second commitment period (2013-2020), GWP-coefficient from IPCC's Fourth Assessment Report (AR4) in 2007 have been used. Compared to SAR, coefficient for methane and nitrous oxide changed in AR4. Methane coefficient increased from 21 to 25 and nitrous oxide coefficient decreased from 310 to 298. Renewed AR4 coefficients are applied in the thesis (see table 6). In addition to GWP-coefficients developed by IPCC, there are multiple alternative coefficients for calculating greenhouse gases. Edwards & Trancik (2014) argue that GWP with fixed time horizon doesn't reflect the climate change mitigation targets and the changing environment. They also propose a new class of metrics with regard to CH_4 emissions. Alike Edwards & Trancik (2014), Shine et al. (2005) propose an alternative metrics for GWP, called the Global Temperature Change Potential. (Lindroos, Ekholm & Savolainen, 2012; United Nations, 2016; IPCC, 2016.)

Acidification potential is also a common standardizing tool for comparing acidification impact of different emissions. AP-coefficients convert emissions to sulfur dioxide equivalents (SO_2e), thus AP indicates SO_2 discharge on soil and into water (Acar & Dincer, 2014). The coefficient for sulfur dioxide is always 1. Other emissions are compared to sulfur dioxide. In addition to sulfur dioxide, only nitrogen oxides are included in the thesis' analysis, which is due to the data availability explained earlier in this chapter. Nitrogen oxides' AP-coefficient is 0,7 (Heijungs et al., 1992; Paloviita, 2004). Consequently, NO_x have smaller acidifying impacts (or release less hydrogen ions in the environment) on the environment than SO_2. AP-coefficients are calculated for a mass unit of emissions, normally one kilogram. In general, the primary contributors for acidification are oxides of sulfur (SO_x), nitrogen oxides (NO_x) and ammonia (NH_3) (Stranddorf, Hoffmann & Schmidt, 2005). The calculation of methods is more reliable with GWP than with AP, as GWP is highly reliable and AP quite reliable (GHK, 2006). Similar superiority ratio between the coefficients are with regard to confidence in the inventory data (GHK, 2006).

Emission	**CO_2**	**CO**[8]	**CH_4**	**N_2O**	**SO_2**	**NO_x**
GWP-coefficient	1	1.9	25	298	-	-
AP-coefficient	-	-	-	-	1	0.7

TABLE 6. Global warming potential and acidification potential coefficients (Heijungs et al., 1992; IPCC, 2016; Lindroos, Ekholm & Savolainen, 2012; Paloviita, 2004).

GWP and AP emission types listed in table 6 also have an effect on each other. For example, SO_2 emissions have an effect on global warming. However,

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[8] Carbon monoxide has only indirect greenhouse effect (Ilmastosivut, 2016).

categorized emissions in table 6 have the most significant effect on their corresponding coefficients. Furthermore, apart from carbon dioxide (CO), this categorization has been applied in previous literature (Paloviita, 2004).

5 ANALYSIS, RESULTS AND CASE COMPARISON

In this chapter regional economic and environmental impacts are presented and analyzed. Production impacts, employment impacts and income effects are presented in chapter 5.1. Refining lignin generates almost 7 times more employee compensation and other income effects, almost 10 times higher total production impact and over 11 times higher employment impact than combusting lignin. Government and municipalities in Central Finland collect more taxes from refining lignin as well. Global warming potential and acidification potential results are presented in chapter 5.2. Compared to economic impacts, the differences between the two cases with regard to environmental impacts are not that flagrant. Refining lignin has approximately 1.25 times higher global warming potential compared to combustion, whereas acidification potential is almost 2 times higher. It should be noted once again that the production costs are not taken into consideration in the analysis.

The results of case 1 are based on the value of 60,000 t lignin, which is 9,313,494 € (see chapter 4.1.3). The results of case 2 are based on the value of 60,000 t lignin, which is 37,676,448 € (see table 5 in chapter 4.2.3).

5.1 Regional economic impacts

Regional economic impacts include production impacts, employment impacts, income effects (including municipal taxes paid in Central Finland) in this chapter.

5.1.1 Production impacts

Refining and combusting lignin causes total production impacts, direct production impacts and indirect production impacts. Total production impacts and direct production impacts are illustrated in chart 1 and table 7. **Direct impacts** are calculated by multiplying the value of lignin with the intermediate inputs matrix A of Central Finland. The matrix A is estimated with location quotients (LQ) method from national contribution factor matrix, which is in turn estimated from national input-output table. National input-output tables are aggregated from 64 to 30 industries in order to link two different tables (for more thorough explanation see chapter 2.4).

The refining process in case 2 is divided in three phases: (1) lignin is separated from black liquor and sold for a refiner A nearby, (2) lignin is refined to biocomposite material and sold to refiner B nearby and (3) biocomposite material is refined to a product (timber) and sold, where first (1) phase is linked to paper industry, second (2) phase is linked to chemicals industry and third (3) phase is as well linked to chemicals industry (SIC). All the phases combined have an approximate 121.2 MEUR direct production impact on Central Finland.

In case 1, lignin combustion is linked to industry of energy management; water and waste management (SIC). Combusting lignin for energy has an approximate 11.9 MEUR direct production impact on Central Finland.

Total production impacts are calculated by multiplying the value of lignin with Leontief inverse matrix $(I-A)^{-1}$ of Central Finland (see chapter 3.1.1.2). **Indirect impacts** are calculated by subtracting direct impacts from total impacts. Combusting lignin for energy has altogether 13.2 MEUR total production impact on Central Finland, when refining lignin into biocomposite product has a 127.7 MEUR total production impact on Central Finland. Indirect impact for combusting lignin is approximately 1.3 MEUR, whereas the figure for refining is approximately 6.5 MEUR. Thus, the total production and direct impact are almost 10 times higher compared to combusting lignin.

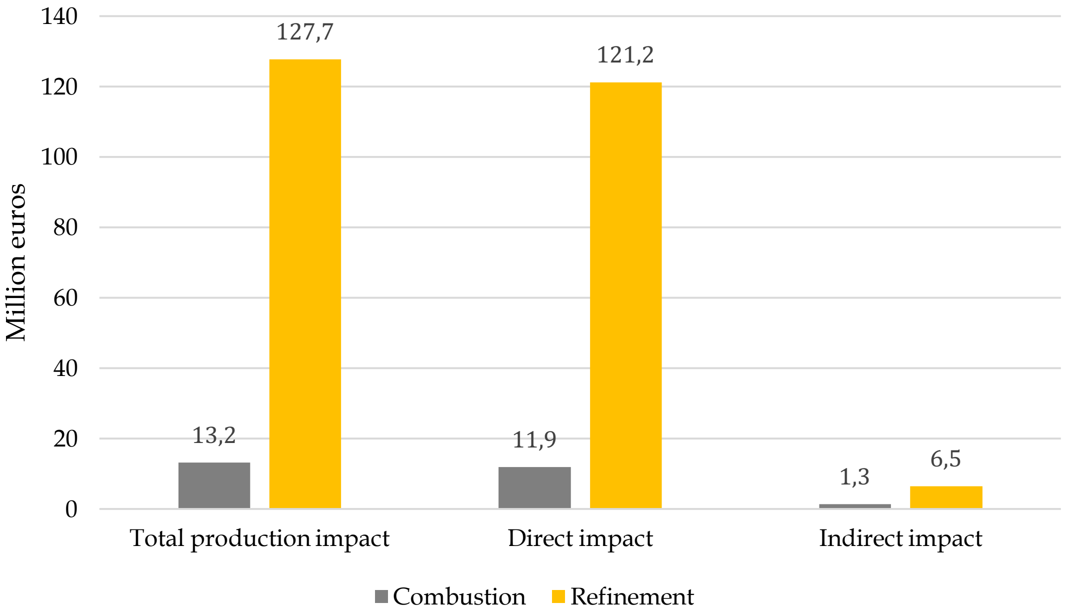

CHART 1. Total, direct and indirect production impact of cases 1 and 2.

The main impact in refining lignin comes from chemicals industry, which incorporates approximately 85% of the whole production impact (109.0 MEUR of 127.7 MEUR). The impact is rather obvious since the refining process includes refining and selling lignin products both to refiner A and B, and finally to end-users, where both A and B operates in chemicals industry. Refiners A and B spend on labour, other raw-materials, machinery and equipment, and so on. For other industries the main total production impacts focus on industries energy management; water and waste management (3.1 MEUR), transportation and storage (2.6 MEUR) and wholesale and retail trade (2.2 MEUR). It should be noted that transportation and storage impacts are relatively high, since the analysis is based on the whole chemicals industry in Central Finland. However, in this case the refiners are located near to the Bioproduct mill, so that much transportation is not required until retailing the final product (timber). Additionally, the scope in both cases excludes extraction of raw-materias, which means that transportation of timber is not included in the scope of the analysis.

In the other case lignin is only sold once (energy market) and it is not refined similarly. The main total production impact in combusting lignin comes from energy management industry, which covers approximately 76 % (10 MEUR of 13.2 MEUR) of the whole production impact. This is also rather evident since lignin is combusted for energy, transmitted to electric stations and then to the end-users – these steps are all included in the energy management industry. For other industries the main total production impacts focus on industries construction (0.4 MEUR), manufacture of furniture; other industrial production; repair, maintenance and installation of machinery and equipment (0.3 MEUR) and mining and quarrying (0.3 MEUR). It should be noted that maintenance and construction of power-distribution networks, as well as repair, are involved in construction industry.

Industry	**Production impact Combustion**		**Production impact Refinement**	
	Direct, 1,000 €	Total, 1,000 €	Direct, 1,000 €	Total, 1,000€
Agriculture and hunting	0	14	23	86
Forestry and fishing	81	170	0	151
Mining and quarrying	234	287	313	484
Food industry	35	60	128	266
Textile, clothing and leather industry	5	7	22	29
Woodworking industry	112	170	50	224
Paper industry	52	85	489	719
Printing industry	2	11	32	96
Chemicals industry	27	50	108,731	108,998
Building material industry	7	25	151	230
Basic metal refining and manufacturing industry (excl. machinery)	19	61	312	512
Electrical and electronics industry	11	22	97	148
Manufacture of other machinery and equipment	110	164	273	490
Manufacture of vehicle	3	10	226	277
Manufacture of furniture; Other industrial production; Repair, maintenance and installation of machinery and equipment	233	294	445	719
Energy management; Water and waste management	9,884	10,000	2,461	3,087
Construction	270	361	724	1,143
Wholesale and retail trade, Repair of motor vehicles and motorcycles	176	278	1,609	2,183
Transportation and storage	125	237	1,876	2,607
Accommodation and food service activities	6	20	22	116

Publishing; Audio-visual activities; Telecommunications; Data processing services	70	129	553	933
Financial and insurance activities	68	94	291	420
Real estate activities	61	107	181	481
Professional, scientific and technical activities	111	193	681	1,114
Administrative and support service activities	133	197	664	1,037
Public administration and defence; compulsory social security	62	96	595	775
Education	4	9	162	198
Human health and social work activities	2	6	5	34
Arts, entertainment and recreation; Other service activities; Housekeeping services	10	22	88	165
Total	**11,913**	**13,179**	**121,204**	**127,722**

TABLE 7. Direct and total production impact per industry.

5.1.2 Employment impacts

Refining and combusting lignin have differing employment impacts that are presented as person-(work)years. Employment impacts for each industry are based on **labor input coefficients**. A coefficient illustrates how much workforce is required in order to produce one unit of output – the bigger the coefficient, the more workforce is required. Labor input coefficients are calculated by dividing each industry's amount of employed by total output of the industry. All the figures are calculated for Central Finland. Person-years for each industry are calculated by multiplying selected industry's labor input coefficient by corresponding total production impact. A person-year is a unit of measurement, which means one year of work of one person consisting of a standard number of person-days. Labor input coefficients for each industry and person-years (employment impact) of refining and combusting lignin for each industry are illustrated in table 8.

Labor input coefficient for producing and selling the final biocomposite product is 3.12 (chemicals industry) and the coefficient for combusting lignin for energy and selling it is 1.77 (energy management; water and waste management). That is, chemicals industry has approximately 1.76 times higher impact on employment than energy, water and waste management industry. Total employment impact of combusting lignin is approximately 43.7 person-years. Total employment impact for refining lignin is approximately 490.5 person-years. Refining lignin has over 11 times higher impact on employment compared to combusting lignin.

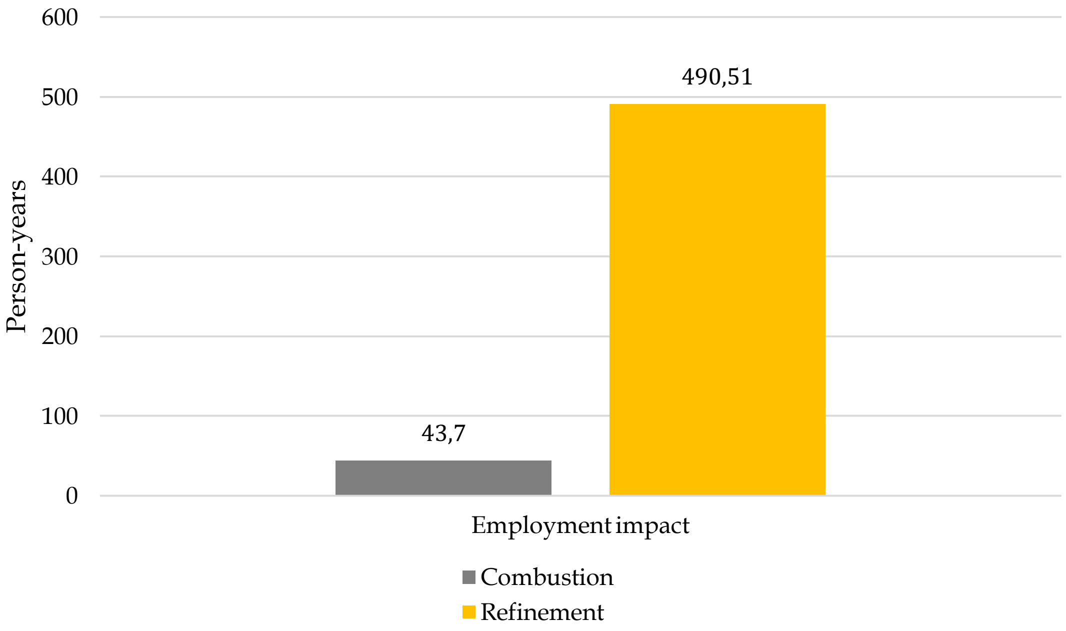

CHART 2. Employment impact of cases 1 and 2.

The main employment impact in refining lignin comes from chemicals industry, which covers approximately 69% of the employment impact (339.8 of 490.5 person-years). Most of these 339.8 person-years comes from biorefineries, refinery A and refinery B. For other industries the main employment impacts focus on wholesale and retail trade (30.7 person-years, 6.2%), transportation and storage (25 person-years, 5.1%), administrative and support service activities (17 person-years, 3.4%) and professional, scientific and technical activities (13.9 person-years, 2.8%). Alike to total production impacts, it should be noted that transportation and storage impacts are relatively high, since the analysis is based on the whole chemicals industry in Central Finland. However, in this case the refiners are located near to the Bioproduct mill, so that much transportation is not required until retailing the final product (timber). Therefore, the estimates do not comprise the assumption that the Bioproduct mill and refiners A and B are all in the same Äänekoski region and might not hold that much transportation compared to the whole industry.

The main employment impact in combusting lignin comes from energy, water and waste management industry, which covers approximately 41% of the employment impact (17.7 of 43.7 person-years). For other industries, the main employment impacts are on wholesale and retail trade (3.9 person-years, 8.9%), administrative and support service activities (3.2 person-years, 7.3%) and construction (2.7 person-years, 6.2%). It should be noted that maintenance and construction of power-distribution networks, as well as their repair are involved in construction industry. Highest labor input coefficients are for agriculture and hunting (26.5), textile, clothing and leather industry (17.37) and administrative and support service activities (16.29). Lowest labor input coefficients are in real estate activities (0.75), paper industry (1.54) and energy management; water and waste management (1.77). Although energy management; water and waste management industry possess low coefficient, it still has a significant employment impact. Altogether, this case's distribution of employment represents the actual distribution well.

Industry	**Person-years, Combustion**	**Labor input coefficient**	**Person-years, Refinement**
Agriculture and hunting	0.4	26.5	2.27
Forestry and fishing	1.0	6.11	0.92
Mining and quarrying	1.2	4.25	2.06
Food industry	0.2	4.1	1.09
Textile, clothing and leather industry	0.1	17.37	0.51
Woodworking industry	0.9	5.32	1.19
Paper industry	0.1	1.54	1.11
Printing industry	0.1	8.88	0.85
Chemicals industry	0.2	3.12	339.84
Building material industry	0.2	7.39	1.70
Basic metal refining and manufacturing industry (excl. machinery)	0.5	7.9	4.05
Electrical and electronics industry	0.1	3.44	0.51
Manufacture of other machinery and equipment	0.7	4.37	2.14
Manufacture of vehicle	0.1	7.28	2.02
Manufacture of furniture; Other industrial production; Repair, maintenance and installation of machinery and equipment	2.5	8.44	6.07
Energy management; Water and waste management	17.7	1.77	5.47
Construction	2.7	7.43	8.50
Wholesale and retail trade, Repair of motor vehicles and motorcycles	3.9	14.05	30.68
Transportation and storage	2.3	9.55	24.90
Accommodation and food service activities	0.2	12.14	1.41
Publishing; Audio-visual activities; Telecommunications; Data processing services	0.9	6.66	6.21
Financial and insurance activities	0.5	5.59	2.35
Real estate activities	0.1	0.75	0.36
Professional, scientific and technical activities	2.4	12.46	13.88
Administrative and support service activities	3.2	16.29	16.89
Public administration and defence; compulsory social security	1.0	10.72	8.31

Education	0.1	11.96	2.36
Human health and social work activities	0.1	15.67	0.53
Arts, entertainment and recreation; Other service activities; Housekeeping services	0.3	14.14	2.33
Total	**43.7**		**490.5**

TABLE 8. Employment impact and labor input coefficients per industry.

5.1.3 Employment impact on Central Finland

98 percent of all workers in Äänekoski lives in Central Finland. The remaining 2 percent commutes from outside Central Finland. Central Finland is divided into six sub-regions; Jyväskylä, Joutsa, Keuruu, Jämsä, Äänekoski and Saarijärvi-Viitasaari sub-regions. Municipalities in these regions are listed in appendix 2. As most of the workers live in Central Finland, most of the employment impact affects sub-regions in Central Finland. If lignin would be combusted to generate energy, the employment impact of Central Finland would be approximately 42.5 person-years, most of which at Äänekoski (33 person-years) and Jyväskylä (8) sub-regions. If lignin would be refined, the impact would be approximately 480 person-years. Äänekoski (373) and Jyväskylä (90) sub-regions would have the highest impact in this case, too. The evaluation and results presented in table 9 are based on commuting statistics - where do the workers of Äänekoski actually live.

Sub-region of Central Finland	**Employment, person-years**	
	Combustion	**Refinement**
Joutsa	0	0
Jyväskylä	8	90
Jämsä	0	0.5
Keuruu	0	0.5
Saarijärvi-Viitasaari	1.5	16
Äänekoski	33	373
Total	42.5	480

TABLE 9. Employment impact to Central Finland.

5.1.4 Income effects

In addition to intermediate inputs, basic inputs are required in order to produce an output. Basic inputs include employee compensation, use of exports and imports, taxes and product subsidies. Employee compensation is significant, since part of the compensation reverts to the economy by causing multiplier impact (chapter 3.1). Table 10 illustrates how the share for spending is composed.

	Combustion, 1,000 €	Refinement, 1,000 €
Employee compensation	1,927	13,253
Employer's social security contribution, 2.12%	- 41	- 281
Earned income after social security contribution	1,886	12,972
National tax, 17.5%	- 330	- 2,270
Municipal tax, 20.04%	- 378	- 2,600
Unemployment insurance contribution, 0.60 %	- 11	- 78
Pension insurance contribution , 5.15%	- 97	- 668
Household's disposable income	1,070	7,356
Savings rate, 0.80%	- 9	- 59
Share for spending	1,061	7,298

TABLE 10. Formation of share for spending per year.

In order to calculate the share for spending, first employer's social security contribution is subtracted, which was 2.12% in 2012 (Vero, 2016a). From the remaining income, national and municipal taxes are subtracted. National tax was 17.5% (Vero, 2016b) and average municipal tax in the Central Finland region was 20.04% (Kunnat, 2016) in 2012. After taxes, unemployment insurance contribution and employment pension collateral contribution are subtracted. In 2012 unemployment insurance contribution was 0.60% (Vero, 2016a) and employment pension collateral contribution 5.15% (Vero, 2016a). Savings rate for 2012 was 0.80% (Stat, 2016b).

By combusting lignin for energy generation, approximately 1.9 MEUR would be distributed in Central Finland as earned income from which 1 MEUR would be shared for spending. Refining lignin would cause approximately 13 MEUR earned income in Central Finland, from which 7.3 MEUR would be shared for spending.

5.1.5 Municipal taxes paid to Central Finland

98 percent of municipal taxes presented in table 10 are dispersed to Central Finland. The remaining 2 percent of municipal taxes are collected outside Central Finland. If lignin would be combusted to generate energy, approximately 400,000 EUR of municipal taxes would be paid to Central Finland, most of which to Äänekoski (300,000 EUR) and Jyväskylä (70,000 EUR) sub-regions. If lignin would be refined, municipal taxes paid would be approximately 2.6 MEUR, from

which most taxes would be paid to Äänekoski (2 MEUR) and Jyväskylä (0.5 MEUR) sub-regions, too. For comparison, municipality of Äänekoski collected total 62.5 MEUR of municipal taxes in 2015 (Äänekoski, 2016). The evaluation and results (table 11) of the distribution of paid municipal taxes in Central Finland are based on commuting statistics - where do the workers of Äänekoski actually live and consequently pay taxes.

Sub-region of Central Finland	**Municipal tax, €**	
	Combustion	**Refinement**
Joutsa	100	800
Jyväskylä	71,000	486,000
Jämsä	300	2,000
Keuruu	400	3,000
Saarijärvi-Viitasaari	13,000	87,000
Äänekoski	294,000	2,022,000
Total	379,000	2,600,000

TABLE 11. Distribution of paid municipal taxes in Central Finland by sub-region.

5.1.6 Summary

Economic impact	**Combustion**	**Refinement**
Total production impact, 1,000 €	**13,179**	**127,722**
Employment impact, person-years	**43.7**	**490.5**
Taxes (national and municipal), 1,000 €	**708**	**4,870**

TABLE 12. Total production impact, employment impact and taxes of cases 1 and 2.

Depending on the economic impact (production impact, employment impact, taxes or, for example, share for spending), refining 60,000 t lignin has 7 to 11 times higher economic impact compared to combusting the same amount of lignin. In case 1, majority of economic impacts focus on energy management; water and waste management industry. In case 2, majority of economic impacts focus on chemicals industry. In both cases production impacts were highly focused on these two industries (76% and 85%), but employment impacts spread wider to other industries compared to the two (41% and 69%). Most (98%) of the impacts are centralized on Central Finland, mainly on Äänekoski (78%) and Jyväskylä sub-regions (19%).

5.2 Environmental impacts

In environmentally extended input-output analysis environmental impacts are allocated to one unit of output, in this case to 60,000 t lignin. This is done to both cases 1 and 2. In order to evaluate both case's environmental global warming potential and acidification potential, following calculations are conducted. Similar method of assessment is conducted in both GWP and AP. In the next chapter calculus is demonstrated only for GWP. Same steps are applied in the assessment of AP.

5.2.1 Global Warming Potential

Statistics Finland reports emission tons (CO_2, CO, CH_4, N_2O, SO_2 and NO_x) per industry. In the analysis these industries are first aggregated similarly to the economic assessment above from 64 to 30 industries. Next emission tons are allocated per 1 MEUR of output per industry. Now GWP (or AP) is calculated for each aggregated industry. Each industry's combined tons of CO_2 emission are multiplied by coefficient 1, N_2O emission tons are multiplied by 298, CH_4 by 25 and CO by 1.9 (see table 6). Finally, these estimates are count up for obtaining GWP-coefficient for the specific industry. Similar calculation principle is applied in AP but with coefficients 1 for SO_2 and 0.7 for NO_x.

Now as GWP and AP coefficients are estimated for each industry, we can evaluate GWP and AP for both thesis cases. For this phase, total production impact of both cases are required to be already calculated. Total production impact of each industry is divided by 1,000,000 (STAT reports emission tons per 1,000,000 million euros) and then multiplied by GWP or AP coefficient of each industry. Now we have global warming potential and acidification potential of the two cases per each industry. Now we know, for example, what the global warming potential of effected transportation or food industry is, if lignin is combusted for energy generation.

By adding up GWPs and APs of each industry we have GWP and AP for the whole case, that is GWP and AP for combusting 60,000 t lignin and for refining 60,000 t lignin. The results are presented in tables 14 and 16.

As mentioned before, GWP is composed of CO_2, N_2O, CO and CH_4 emissions. Table 13 presents all of these discharged emissions for both cases. As a base for the calculations, in case 1 (60,000 t lignin is combusted) approximately 15,072.3 tons fossil-based CO_2 emissions is emitted and 25,576.7 tons in case 2. Bio origin CO_2 emissions are emitted approximately 7,597.6 tons in case 1 and 3,858.7 tons in case 2. 1.2 tons of nitrous oxide is emitted in case 1 and 3.7 tons in case 2. 14.5 tons of carbon monoxide is emitted in case 1 and 19.6 tons is case 2. 76.9 tons of methane is emitted in case 1 and 28.1 tons in case 2. This is due to high concentration of energy management; water and waste management industry, which is the main emittor industry of methane. The emission information is derived from tables of Statistics Finland that are structured similarly as in the NAMEA framework (Moll et al., 2006; Tukker et al., 2006).

Discharged emissions, tons	Combustion	Refinement
Fossil origin carbon dioxide, CO_2	**15,072.3**	**25,576.7**
Bio origin carbon dioxide, CO_2	**7,597**	**3,858.7**
Carbon monoxide, CO	**14.5**	**19.6**
Nitrous oxide, N_2O	**1.2**	**3.7**
Methane, CH_4	**76.9**	**28.1**

TABLE 13. Discharged emissions per combusted or refined 60,000 t lignin.

In table 14 global warming potentials and GWP-coefficients are presented per industry. In case 1 – lignin combustion – by far the highest global warming potential is emitted by energy management; water and waste management industry with 98.3% (24,552.95) of the total GWP (24,981.86). Paper industry has the next highest GWP of 133,39 (0.5%) and transportation and storage GWP of 106.93 (0.5%). In case 2, 66% (20,627.81) of the total GWP (31,264.38) is emitted by chemicals industry. For other industries, 24.2% (7,578.50) of total GWP is emitted by energy management; water and waste management industry, 3.8% (1,715.50) by transportation and storage industry and 3.6% (1,131.24) by paper industry.

Industry	GWP, Combustion	GWP-coefficient, Per 1M€ of output	GWP, Refinement
Agriculture and hunting	22.67	1,587.75	136.21
Forestry and fishing	21.59	126.89	19.11
Mining and quarrying	27.06	94.17	45.56
Food industry	1.29	21.4	5.70
Textile, clothing and leather industry	0.07	10.52	0.31
Woodworking industry	19.73	116.02	26.01
Paper industry	133.39	1,573.83	1,131.24
Printing industry	0.10	9.01	0.86
Chemicals industry	9.50	189.25	20,627.81
Building material industry	12.03	475.17	109.06
Basic metal refining and manufacturing industry (excl. machinery)	20.02	326.15	167.04
Electrical and electronics industry	0.00	0	0.00
Manufacture of other machinery and equipment	0.19	1.18	0.58
Manufacture of vehicle	0.02	2.39	0.66
Manufacture of furniture; Other industrial production; Repair, maintenance and installation of machinery and equipment	0.21	0.73	0.52

Energy management; Water and waste management	24,552.95	2,455.29	7,578.50
Construction	23.24	64.45	73.68
Wholesale and retail trade, Repair of motor vehicles and motorcycles	1.63	5.89	12.85
Transportation and storage	106.93	450.91	1,175.50
Accommodation and food service activities	0.03	1.65	0.19
Publishing; Audio-visual activities; Telecommunications; Data processing services	0.28	2.19	2.04
Financial and insurance activities	2.69	28.69	12.04
Real estate activities	14.10	132.08	63.50
Professional, scientific and technical activities	0.35	1.83	2.04
Administrative and support service activities	7.98	40.47	41.97
Public administration and defence; compulsory social security	3.26	34.09	26.43
Education	0.06	6.87	1.36
Human health and social work activities	0.04	6.96	0.23
Arts, entertainment and recreation; Other service activities; Housekeeping services	0.45	20.48	3.38
Total	**24,981.86**		**31,264.38**

TABLE 14. Global warming potentials and GWP-coefficients.

Highest GWP-coefficients are for energy management; water and waste management industry (2,455.3), agriculture and hunting (1,587.8), paper industry (1,573.8) and building material industry (475.2). Lowest GWP-coefficients are in electrical and electronics industry (0), manufacture of furniture; Other industrial production; Repair, maintenance and installation of machinery and equipment (0.7) and manufacture of other machinery and equipment (1.18).

It should be noted that these estimates do not represent GWP in detail, since the evaluation is mainly based on estimates and characteristics of chemicals and energy management; water and waste management industries, which have altogether from 90.2 (66 plus 24.2) to 98.3 percent share of total GWPs estimated. Compared to conventional chemicals industry, both thesis cases are fully based on renewable resources, which is not yet common within the whole industry, and especially when the data was collected for 2012 statistics. Additionally, energy management; water and waste management industry include all forms of energy generation in addition to renewables. The share of fossil-based CO_2 emissions in evaluating GWP is approximately 15,000 of total 25,000 in case 1, and 26,000 of total 31,000 in case 2. Thus, it is crystal clear that the results are divergent in reality and depended on the true amount of fossil origin CO_2 emissions. The share of bio-based CO_2 emissions of GWPs is approximately 7,600 of 25,000 (30%) in case 1, and 3,900 of 31,000 (13%) in case 2 estimations. However, if Metsä Fibre will have more detailed data about the actual emissions in the future, these pieces of information can be set against to them.

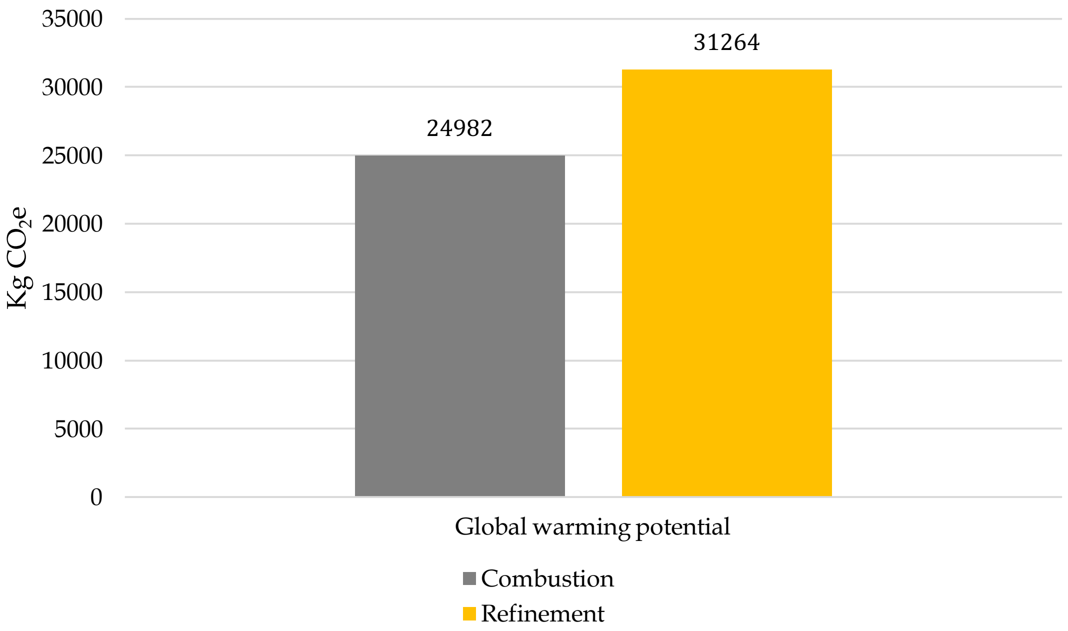

CHART 3. Global warming potential of cases 1 and 2.

Combusting lignin for energy, the global warming potential would be approximately 25,000 Kg CO_2e, whereas refining lignin has an approximate global warming potential of 31,000 Kg CO_2e. Consequently, refining lignin has only 1.25 higher impact on global warming than combusting it to generate energy.

Other key notion for the assessment is the renewable nature of combusting wood or wood residues. Recently there has been debate, especially in European Union, whether it is actually carbon neutral to combust wood for energy generation. Conventionally wood-based energy has been thought as carbon neutral, since trees absorb the same amount of carbon dioxide as they discharge in combustion. However, trees absorb CO_2 emissions only while they grow, so for absorbing all carbon dioxide that is discharged in the end, it takes decades until a tree is fully grown (depending on wood species). Therefore, in the short term CO_2 emissions increase, and in longer term, they can be seen as neutral.

Other research provide insight for the reliability of these results. Bernier et al. (2013) conducted a life cycle assessment of (1 Kg) kraft lignin for polymer applications with *ecoinvent v2.2* database and the IMPACT 2002+ impact assessment method. The researchers excluded harvesting, recausticizing (after recovery boiler), lime kiln, bleaching, drying and the final step of producing pulp from the scope. They included other processes related to recovery boiler and separating lignin: precipitation, filtration, washing and drying. The functional unit and end product was 1 Kg solid lignin. Therefore, the results are applicable for (only) the case 2, refining lignin, where separation of lignin is required. Bernier et al. computed global warming potential of 0.57 Kg CO_2e per 1 Kg untransformed dry kraft lignin powder. This implies global warming potential of 34,000 tons CO_2e for 60,000 t lignin. It should be noted that natural gas was used as a fuel in the evaluation.

The scope of the research of Bernier et al. (2013) fits the scope of case 2 well, because e.g. wood harvesting and final steps of producing pulp is excluded in case 2, too. However, any refining process and related transportation are not taken into consideration in the paper of Bernier et al. (2013). Therefore, this piece of information indicates that case 2 GWP of 31,000 t CO_2e is low.

5.2.2 Acidification Potential

Method of assessing acidification potential is presented in previous chapter. Only results are presented and discussed in this chapter.

Acidification potential (AP) is composed of SO_2 and NO_2 emissions. As a base for the calculations, in case 1 (60,000 t lignin is combusted) approximately 18.7 tons of sulphur dioxide is emitted and 57.2 tons in case 2. An approximate 28.9 tons of nitrogen dioxide is emitted in case 1 and 42.4 tons in case 2. This emission information is derived from tables of Statistics Finland.

Discharged emissions, tons	**Combustion**	**Refinement**
Sulphur dioxide, SO_2	**18.7**	**57.2**
Nitrogen dioxide, NO_2	**28.9**	**42.4**

TABLE 15. Discharged emissions per 60,000 t lignin combusted or refined.

The acidification potential of combusting lignin for energy generation would be approximately 39 Kg SO_2e, whereas refining lignin has approximately acidification potential of 87 Kg SO_2e. Consequently, refining lignin has over twice as big impact on acidification compared to combustion.

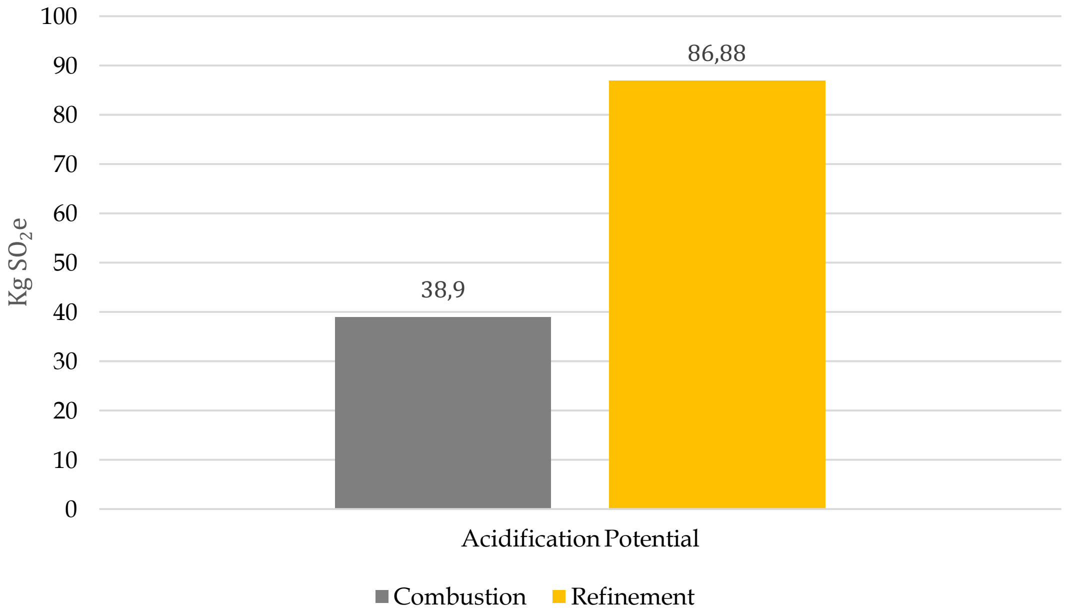

CHART 4. Acifidication potential of cases 1 and 2.

Industry	**AP, Combustion**	**AP-coefficient, Per 1M€ of output**	**AP, Refinement**
Agriculture and hunting	0.02	1.18	0.10
Forestry and fishing	0.11	0.62	0.09
Mining and quarrying	0.05	0.18	0.08
Food industry	0.00	0.08	0.02
Textile, clothing and leather industry	0.00	0.02	0.00
Woodworking industry	0.02	0.12	0.03
Paper industry	0.11	1.28	0.92
Printing industry	0.00	0.04	0.00
Chemicals industry	0.03	0.6	65.16
Building material industry	0.02	0.81	0.19
Basic metal refining and manufacturing industry (excl. machinery)	0.03	0.52	0.26
Electrical and electronics industry	0.00	0	0.00
Manufacture of other machinery and equipment	0.00	0.02	0.01
Manufacture of vehicle	0.00	0.01	0.00
Manufacture of furniture; Other industrial production; Repair, maintenance and installation of machinery and equipment	0.00	0.01	0.01
Energy management; Water and waste management	37.65	3.77	11.62
Construction	0.10	0.28	0.32
Wholesale and retail trade, Repair of motor vehicles and motorcycles	0.00	0.01	0.03
Transportation and storage	0.71	2.98	7.77
Accommodation and food service activities	0.00	0	0.00
Publishing; Audio-visual activities; Telecommunications; Data processing services	0.00	0.01	0.00
Financial and insurance activities	0.01	0.06	0.03
Real estate activities	0.01	0.12	0.06
Professional, scientific and technical activities	0.00	0	0.00
Administrative and support service activities	0.02	0.08	0.09
Public administration and defence; compulsory social security	0.01	0.1	0.08
Education	0.00	0.02	0.00
Human health and social work activities	0.00	0.02	0.00
Arts, entertainment and recreation; Other service activities; Housekeeping services	0.00	0.04	0.01
Total	**38.90**		**86.88**

TABLE 16. Acidification potentials and AP-coefficients by industry.

In table 16, acidification potentials and AP-coefficients are presented per industry. In case 1 – lignin combustion – by far the highest acidification potential is emitted by energy management; water and waste management industry with 96.8% (37.65) of the total AP (38.90). Transportation and storage industry has the next highest AP of 0.71 (1.8%). In case 2, 75% (65.16) of the total AP (86.88) is emitted from chemicals industry. For other industries, 13.4% (11.62) of total AP is emitted from energy management; water and waste management industry and 8.9% (7.77) from transportation and storage industry.

Highest AP-coefficients are for energy management; water and waste management industry (3.77), transportation and storage (2.98), paper industry (1.28) and agriculture and hunting (1.18). Lowest AP-coefficients are in electrical and electronics industry (0), accommodation and food service activities (0) and professional, scientific and technical activities (0).

Bernier et al. (2013) computed aquatic acidification of 0,0053 Kg SO_2e per 1 Kg untransformed dry kraft lignin powder. This implies acidification potential of 318 tons SO_2e for 60,000 t lignin. It should be noted again, that natural gas was used as a fuel in the evaluation and refining processes were not included. This piece of information indicates that the AP of 87 t SO_2e of case 2 is too low.

5.2.3 Summary

Environmental impact	Combustion	Refinement
Global Warming Potential	24,981.86	31,264.38
Acidification Potential	38.90	86.88

TABLE 17. Environmental impacts: global warming potential and acidification potential of case 1 and 2.

Depending on the environmental impact indicator (GWP, AP), refining 60,000 t lignin has approximately 1.25 to over 2 times higher environmental impact compared to combusting the same amount of lignin. In case 1, nearly all of GWP and AP impacts come from energy management; water and waste management industry. In case 2, majority of GWP and AP impacts focus on chemicals industry, but there is more dispersion: 24% of GWP and over 13% of AP come from energy management; water and waste management industry. Transportation and storage industry should be noted to be a significant emitter of acidic emissions as well, with the share of 8.9 percent of all acidic emissions.

5.3 Combined environmental and regional economic impacts

Tables 18, 19 and 20 collate the results of economic and environmental impacts of cases 1 and 2, more specifically, total production impact (TPI), employment impact (person-years, P-Y), global warming potential (GWP) and acidification potential (AP) of each industry concerning the application of 60,000 t lignin. The results are usually presented by satellite accounts in EEIOA, but the researcher decided that the table below is more illustrative with regard to comparison of thesis cases. In table 18 results are presented by industry and in table 19 in aggregate numbers. The bolded numbers in table 18 are used as a base in the calculations and therefore the values are especially significant.

Ind.	C TPI, 1,000 €	R TPI, 1,000 €	C P-Y	R P-Y	C GWP	R GWP	C AP	R AP
1	14	86	0.4	2.27	22.66	136.21	0.02	0.10
02_03	170	151	1.0	0.92	21.59	19.11	0.11	0.09
05_09	287	484	1.2	2.06	27.06	45.56	0.05	0.08
10_12	60	266	0.2	1.09	1.29	5.70	0.00	0.02
13_15	7	29	0.1	0.51	0.07	0.31	0.00	0.00
16	170	224	0.9	1.19	19.73	26.01	0.02	0.03
17	85	719	0.1	1.11	133.39	1,131.24	0.11	0.92
18	11	96	0.1	0.85	0.10	0.86	0.00	0.00
19_22	50	**108,998**	0.2	**339.8**	9.50	**20,627.81**	0.03	**65.16**
23	25	230	0.2	1.70	12.00	109.06	0.02	0.19
24_25	61	512	0.5	4.05	20.02	167.04	0.03	0.26
26_27	22	148	0.1	0.51	0.00	0.00	0.00	0.00
28	164	490	0.7	2.14	0.19	0.58	0.00	0.01
29_30	10	277	0.1	2.02	0.02	0.66	0.00	0.00
31_33	294	719	2.5	6.07	0.21	0.52	0.00	0.01
35_39	**10,000**	3,087	**17.7**	5.47	**24,552.95**	7,578.50	**37.65**	11.62
41_43	361	1,143	2.7	8.50	23.24	73.68	0.10	0.32
45_47	278	2,183	3.9	30.68	1.63	12.85	0.00	0.03
49_53	237	2,607	2.3	24.90	106.93	1,175.50	0.71	7.77
55_56	20	116	0.2	1.41	0.03	0.19	0.00	0.00
58_63	129	933	0.9	6.21	0.28	2.04	0.00	0.00
64_66	94	420	0.5	2.35	2.69	12.04	0.01	0.03
68	107	481	0.1	0.36	14.10	63.50	0.01	0.06
69_75	193	1,114	2.4	13.88	0.35	2.04	0.00	0.00
77_82	197	1,037	3.2	16.89	7.98	41.97	0.02	0.09
84	96	775	1.0	8.31	3.26	26.43	0.01	0.08
85	9	198	0.1	2.36	0.06	1.36	0.00	0.00
86_88	6	34	0.1	0.53	0.04	0.23	0.00	0.00
90_98	22	165	0.3	2.33	0.45	3.38	0.00	0.01
Total	13,179	127,722	**43.7**	490.5	**24,981.86**	31,264.38	**38.90**	86.88

TABLE 18. Total production impact, employment impact, global warming potential and acidification potential of cases 1 and 2 per industry; TPI = total production impact, P-Y = person-year, C = combust, R = refine.

Industries have impacts of different sizes because of their characteristics. First of all, chemicals industry (19_22) and energy management; water and waste management industry (35_39) have the most significant share of total results, since the cases 1 and 2 operate under these industries. Transportation and storage industry (49_53) has relatively high total production and employment impact, and even higher global warming and acidification potential, if lignin is refined. Paper industry (17) on the other hand has small production and employment impacts, but high global warming potential. Agriculture and hunting (1), building material (23) and basic metal refining and manufacturing (24_25) industries have similar features. On the other hand, publishing; audio-visual activities; telecommunications; data processing services industry (58_63) has rather high economic impacts, if lignin is refined, but almost no environmental impacts at all.

There are variations within the industries between the two cases. Refining lignin has almost 2,100 times higher economic and environmental impacts in chemicals industry compared to combustion. The disparities in other industries are not as substantial. Refining lignin has over 20 times higher economic impacts and almost 50 times higher global warming potential than combusting lignin in manufacture of vehicle industry (29_30), 22 times higher economic and environmental impact in education industry (85) and 11 times higher in transportation and storage industry. It is interesting to note the same size impacts of the two cases on forestry and fishing (02_03) and only 1.7 times higher impacts in mining and quarrying (05_09) and 1.3 higher impacts in woodworking industry (16). Energy management; water and waste management industry is the only one with higher economic and environmental impacts when lignin is combusted.

Environmental and economic impacts	Combustion	Refinement
Total production impact, 1,000 €	13,179	127,722
Employment impact, person-years	43.7	490.5
Taxes, 1,000 €	708	4,870
Global Warming Potential	24,981.9	31,264.38
Acidification Potential	38.90	86.88

TABLE 19. Impacts combined: total production impact, employment impact, taxes, global warming potential and acidification potential.

Environmental and economic impacts	Combustion	Refinement
Total production impact	1	9.7
Employment impact	1	11.2
Taxes	1	6.9
Global Warming Potential	1	1.25
Acidification Potential	1	2.2

TABLE 20. The proportion of environmental and economic impacts of refining lignin to combustion of lignin.

In conclusion, refining 60,000 t lignin has significantly higher economic impact on the region of Central Finland compared to lignin combustion. Environmental impact is similarly higher when lignin is refined, but in considerable lower proportion. On the basis of this evaluation and scope, refining lignin is the preferable option with regard to economic impacts, but not recommended with regard to environmental impacts. Depending on how you value environmental (and economic) impacts, the superiority between the cases can be formed within the scope defined in the thesis.

6 DISCUSSION

The aim of the thesis was to present an interesting, potential and sustainable option of lignin application for the new Bioproduct mill and to compare it with the original alternative – combusting lignin, as it was conducted in the previous mill – with regard to regional economic and environmental impacts. The Bioproduct mill will have a notable economic impact on Finland with an approximate 6,000 person-years during construction and at operational phase more than 2,500 jobs compared to the previous 1,000 (Metsä, 2016b). Therefore, the mill has and will have a significant regional economic impact on the region of Central Finland. Environmental impact is not limited to the borders of Central Finland nor Finland, but the results are derived from national averages. This chapter will answer to the sub-questions and finally to the preliminary question of the thesis critically and in the light of relevant issues, prior research and highlighting the limitations of the study.

6.1 Main research findings, limitations and future research

Sub-question:

1. What are the regional economic and environmental impacts of combusting lignin for energy generation? (Case 1)

Based on the analysis, the first alternative (case 1) would have a regional economic impact of 13.2 MEUR of production impact, employment impact of 43.7 person-years (jobs), national taxes of €330,000 and municipal taxes of €378,000, from which €370,000 would be collected in the region of Central Finland. Äänekoski sub-region would have the biggest employment impact with 33 person-years and income effects with €288,000 municipal taxes. For comparison, municipality of Äänekoski collected total 62.5 MEUR of municipal taxes in 2015 (Äänekoski, 2016). The regional economic impact to the sub-region of Jyväskylä would be much lower with the employment impact of 8 person-years and income effect of €69,000 municipal taxes. Based on the same analysis, combusting lignin would have a global warming potential of 25,000 Kg CO_2e and acidification potential of 39 Kg SO_2e.

Production impact, employment impact, income effects, global warming potential and acidification potential results in case 1 are based on the value of lignin, which is derived from the ability of lignin to produce heat value in recovery boiler. The amount of generated energy that corresponds to 60,000 t lignin is multiplied by the price of electricity in order to get the value of 60,000 t lignin. Therefore, these two elements – the ability to produce heat value and the electricity price – are crucial for the end results. In the thesis the estimation of the lignin's ability to produce heat value in the Bioproduct mill is based on assessment of Doctor of Technology, Professor Alén (2015) from the University of Jyväskylä. The lack of a comparative view is a minor limitation to the results although it doesn't mean that the assessment is not correct. The other element (electricity price) is an exogenous variable and dependent on external factors, so the results reflect only a snapshot of the energy market. Moreover, electricity is not the only form of generated energy in the Bioproduct mill. Steam energy is also generated and the price of steam energy is lower than electricity. The price is also more fluctuating. The lower price is taken into account by choosing a lower price of electricity. In addition, to environmental estimation is not robust. Inaccurate estimates are due to the low resolution of applied EEIOA, where the characteristics of applied energy management industry do not correspond to the characteristics of combusting lignin.

Sub-question:

2. What are the regional economic and environmental impacts of refining lignin into biocomposite product? (Case 2)

Based on the analysis, the second alternative (case 2) would have a regional economic impact of 127.7 MEUR of production impact, employment impact of 490.5 person-years (jobs), national taxes of 2.3 MEUR and municipal taxes of 2.6 MEUR, from which 98% would be collected in the region of Central Finland. Äänekoski sub-region would have the biggest employment impact with 373 person-years and income effects with 2 MEUR municipal taxes. For comparison, municipality of Äänekoski collected total 62.5 MEUR of municipal taxes in 2015 (Äänekoski, 2016). The regional economic impact to the sub-region of Jyväskylä would be much lower, but still significant, with the employment impact of 90 person-years and income effect of €486,000 municipal taxes. Based on the same analysis, combusting lignin would have a global warming potential of 31,000 Kg CO_2e and acidification potential of 87 Kg SO_2e.

Production impact, employment impact, income effects, global warming potential and acidification potential results in case 2 are based on the assumption of hypothetical refiners A and B, which would be located close to the Bioproduct mill. Although Aqvacomp Oy investigates the possibility to invest in larger biocomposite facility to Äänekoski, at this point the refineries are only hypothetical. The nature of applied EEIO allows this presumption in the analysis, which means that there is no need for detailed technological information of the two hypothetical refineries because the resolution of the applied EEIOA is low. For example, chemicals industry has a certain structure of inputs and outputs, which the model presumes constant at every refining phase. On the one hand, the low resolution prevents to form an accurate environmental impact assessment, but on the other it allows some missing information in order to perform e.g. hypothetical analyses.

The results of regional economic and environmental impact assessment in case 2 are dependent on the (market) price estimates of lignin, cellulose fiber, PLA, biocomposite material ARBOFORM© (granules) and biocomposite timber per kilogram. All the price estimates other than biocomposite granules and biocomposite timber are averages based on market values, so the foundation for the applied EEIOA is reasonable. The literature and data about ARBOFORM© biocomposite granules are mainly based on the work of same authors that are related to Tecnaro GmbH. This is a limitation to the study because of the possibility of partiality. If the global warming potential and acidification potential results of case 2 are set against to the research of Bernier et al. (2013), the calculated GWP of 31,000 Kg CO_2e and 87 Kg SO_2e are too low. Too low estimates are due to the low resolution of EEIOA, where the characteristics of applied chemistry industry do not correspond to the characteristics of separating and refining lignin.

Preliminary question:

1. What are the regional economic and environmental impact differences between the two different lignin application cases of the Metsä Group's Bioproduct mill?

As said in the previous chapter 5.3, based on the input-output analysis refining lignin generates 7 to 11 times higher regional economic impact compared to combustion. Especially employment impact is higher with over 490 person-years (jobs) compared to nearly 44 person-years. Over 11 times higher employment impact is mainly due to the new refining facilities (refiners A and B) and the required workforce in case 2. Chemicals industry has also higher labor input coefficient (3.12) than energy management industry (1.77), which affirms the magnitude of higher impact. Although the 44 person-years are estimated in the case 1, it should be noted that this estimate is embedded in the person-years of the whole Bioproduct mill, since it would not need any extra workforce in order to function, whereas in case 2 new workers are essential for successful business.

The (negative) environmental impact is also higher in case 2, although not in the same ratio as with regard to regional economic impact. Based on the analysis, global warming potential is 1.25 times higher and acidification potential 2.2 times higher in case 2. The interpretation of the ratio depends on the method of valuing environmental impacts – in this case global warming and acidification. Additionally, commensurate environmental and economic impacts are problematic in many ways. Admitting the fact of discrepancy in setting economic and environmental impacts against each other, and based on the analysis, it can be only stated that refining lignin has higher environmental impact than combustion.

There are plenty of more than meets the eye with regard to the environmental results. The preliminary question or point of view was to compare the environmental impact between the two thesis cases. As discussed in the chapter 3.2.1, there is a wide diversity of environmental impacts, although indicators for only climate change and acidification are included in the analysis. In addition, the observed environmental impact in the thesis excludes the early life cycle phases of both cases (since they are the same in both cases). By excluding wood harvesting from the scope, also e.g. the decreased ability to sequestrate carbon in the short term i.e. the increased amount of released carbon in the short term is excluded from the scope. However, this is justified because the preliminary question of the thesis was to compare the environmental impact of the two cases – not to measure the whole life cycle impact. Still within the scope there are other aspects that are not discussed and compared previously in the analysis.

First of all, the ability to capture or sequestrate carbon should be considered for studying the impact on global warming, because in both cases the raw material is wood. According to Pervaiz and Sain (2002), a value of 325 Kg carbon per metric ton of hemp based composite is estimated which can be stored by the product during its useful life. The estimation has been made with 65% fiber content of 1 ton of composite. Applying the result roughly to the thesis case 2 (60,000 t lignin corresponds to 200,000t composite), this would mean 65,000 Kg carbon stored by the product during its useful life per 200,000 ton of lignin based composite if the composite would be composed of 65% fiber content. In the thesis case 2, the composite is composed of 30% lignin, 60% pulp fiber and 10% PLA, which means that 90% of the composite would be made with fiber content. In the study of Pervaiz and Sain (2002) hemp is used as the fiber – not lignin or pulp fiber – but according to the study, the net carbon sequestration by industrial hemp crop is estimated as 0.67 ton/h/year, which is compatible to all USA urban trees and very close to naturally, regenerated forests. Similarly, lignin and pulp fiber are derived from wood. The biocomposite product would have a proenvironmental impact by sequestrating carbon throughout its life cycle in contrast with combusting lignin, where the carbon is released instantly.

Another point of view is to analyze the environmental impact by looking at the end products as substitutive products. In case 1 the resulting lignin based renewable energy could replace non-renewable energy. On the other hand, in case 2 the resulting refined renewable biocomposite product could replace fossil based plastic products that are harmful to the environment in many ways. In order to measure the scale of these substitutive impacts, for example with regard to GWP and AP, further research is required. The application of the substitutive product is focal. For example, in the study of Pietrini et al. (2007) the life cycle of poly-based composites and conventional petrochemical plastics were calculated and then compared. Two different end products were assessed: a cathode ray tube (CRT) monitor housing and the internal panels of an average car. The global warming potential was lower with poly-based composites compared to conventional petrochemical plastics apart from the GWP (100 years) of applying to materials to internal panels of an average cars. The observed poly-based composite was heavier than the conventional plastics and therefore it consumes more gasoline while driving, which in turn contributes to global warming.

Investing in refineries close to the Bioproduct mill would definitely promote circular economy principle, since 90% of the biocomposite material would be composed of raw materials provided by the mill residues. The value of lignin would increase almost 5 times and when further refined into biocomposite product, the value of lignin would be already 9 times higher compared to the price of pure separated lignin. Although the results are interesting and suggest to invest in refineries close to the Bioproduct mill in Äänekoski, the costs, economic or environmental impacts of the possible investment are not studied in the thesis. The results show only one side of the whole picture within the thesis scope. For a full economic and environmental analysis more detailed analysis is to be conducted in addition to cost analysis and a full life cycle analysis.

6.2 Other limitations

As a method, the applied EEIO is adaptable and it answers to the economic part of the both sub-questions well but weakly to the environmental part, as explained earlier in the theory chapters. There are still some shortcomings also in the economic part. The most recent input-output tables applied in the thesis analysis should represent the current technology but are however from 2012. Aggregation of industries from 64 to 30 industries is problematic since it covers some central information especially in the key industries: chemicals industry (19_22) and energy management; water and waste management industry (35_39). Additionally, industry homogeneity presumes that same kind of homogeneous goods or services are produced (Kitzes, 2013). In the previous chapter 5 some differences between the thesis cases and the industry in general were discussed. In addition to the weaknesses of the method, indirect employment impacts resulting from the employees' share for spending was not taken into consideration in the analysis. This was due to concentrating only to immediate impacts. Therefore, there is room for further study of multiplier impacts. One key limitation is the somewhat outdated data in the IOA and applied EEIOA, which is collected from 2012 tables.

The environmental data behind a EEIO is a mix of empirically measured data and modeled estimates, which can be biased (Kitzes, 2013). The environmental impact estimates of GWP and AP give insight of the magnitude of impact but do not present detailed estimates. Too much weight is given to the industry infrastructure of energy management and chemicals industry, for they do not fully correspond to the two analysed cases in the thesis. On the other hand, at the moment there is no public information that there would be refiners like A and B close to the Bioproduct mill. Therefore, similar refineries should be found, data gathered and the results applied to the analysis. For this detailed thesis case the applied EEIO's estimates are too general especially because of the aggregated industries applied in the analysis. Tukker et al. (2006) finds it not possible to form an EEIO model with sufficient resolution to analyse life cycle impacts of a single product, although the thesis case analyzes do not take the whole life cycle of a biocomposite product or generated energy into account. However, a life cycle analysis of the both cases would be required for a comprehensive and more accurate environmental impact analysis. In addition, GWP and AP don't address the concept of ″environmental impact″comprehensively for they are only one part of environmental impact. This aspect is discussed in more detail in chapters 4.3. and 3.3.2. Moreover, although the emissions are divided into two different categories (GWP, AP) the listed emissions have also effect on each other. For example, SO_2 and NO_2 emissions affect global warming. However, these two methods are fit for measuring global warming and acidification in general. More suitable method for incorporating both economic input-output analysis and life cycle analysis for assessing environmental impacts is for example hybrid-LCA method presented in chapter 3.3.1.2.

7 CONCLUSIONS

The results indicate that utilizing side streams of pulp production, in this case refining lignin, has a significantly greater regional economic impact, especially the employment impact, compared to combusting lignin. On the other side the global warming potential and acidification potential are higher with refinement, although the ratio between the two cases is lower than with regard to regional economic impact. The case 2, refining lignin into biocomposite products, is more attractive option for the region of Central Finland. Employment of 480 person-years and 2.6 MEUR of collected municipal taxes in the region of Central Finland, and over 7 MEUR share for spending would increase the consumption and consequently employment and demand in the region compared to from 7 to 11 times lower figures for the case 1, combusting lignin. The recent debate over the unsustainable nature of combusting wood for energy generation favors the case 2, too.

Bioeconomy is one of the key lines of business in the region of Central Finland stated in the 2040 strategy of Central Finland (Regional Council of Central Finland, 2016). Both thesis cases are aligned with the strategy. The objective is to utilize natural resources smartly in order to strengthen to competitiveness of the region. Especially case 2 fits this objective, for the refinement adds value to lignin 9 times compared to the price of pure separated lignin, whereas the added value of combusted lignin (energy) is 5 times higher than pure lignin. The production of innovative biocomposite products has also an effect to the image and brand of the region of Central Finland. The costs of the hypothetical investment of case 2 should be assessed for more thorough analysis on competitiveness. According to the Research Institute of the Finnish Economy (Etla) the value added for the whole Bioproduct mill is estimated to be almost 12 billion euros for the cumulative period of 2017 to 2047 (Ali-Yrkkö et al., 2016). Together with the standpoints listed above, environmental perspective gives reason to see the case 2 superior. Renewable biocomposite products made from 90% of residues (lignin and cellulose fiber) of the pulp production could replace fossil based plastic products, add more value and is in certain context a more pro-environmental option compared to the alternative.

Although the results of the analysis are not highly accurate due to resolution of IOA, the ratio between the regional economic impact of the cases is clear. Additionally, the redeeming feature of the analysis conducted is that it is well applicable also to other applications – if they follow the similar chain of industries as in the analysis. So for example if lignin was to be refined differently first at chemicals industry and then again reprocessed at chemicals industry, the process could be applied to the results of this thesis. The results can also be supplemented if accurate process data was to be collected later and a hybrid-LCA conducted based on the analysis in the paper. However, the applicability of the results depends on the possible investments of refining lignin. Currently it is known that the start-up of the Bioproduct mill is expected to take place within Q3/2017. Metsä Group studies various processes and product paths, which will be realized gradually. It will take time to reach to target state of the new Bioproduct mill (Metsä, 2015c).

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APPENDIX 1

Industry	
1	Agriculture and hunting
02_03	Forestry and fishing
05_09	Mining and quarrying
10_12	Food industry
13_15	Textile, clothing and leather industry
16	Woodworking industry
17	Paper industry
18	Printing industry
19_22	Chemicals industry
23	Building material industry
24_25	Basic metal refining and manufacturing industry (excl. machinery)
26_27	Electrical and electronics industry
28	Manufacture of other machinery and equipment
29_30	Manufacture of vehicle
31_33	Manufacture of furniture; Other industrial production; Repair, maintenance and installation of machinery and equipment
35_39	Energy management; Water and waste management
41_43	Construction
45_47	Wholesale and retail trade, Repair of motor vehicles and motorcycles
49_53	Transportation and storage
55_56	Accommodation and food service activities
58_63	Publishing; Audio-visual activities; Telecommunications; Data processing services
64_66	Financial and insurance activities
68	Real estate activities
69_75	Professional, scientific and technical activities
77_82	Administrative and support service activities
84	Public administration and defence; compulsory social security
85	Education
86_88	Human health and social work activities
90_98	Arts, entertainment and recreation; Other service activities; Housekeeping services

Appendix 1. Industrial classification (aggregated from standard industrial classification SIC).

APPENDIX 2

Jyväskylä sub-region	
	Hankasalmi
	Jyväskylä
	Laukaa
	Muurame
	Petäjävesi
	Toivakka
	Uurainen
Joutsa sub-region	
	Joutsa
	Luhanka
Keuruu sub-region	
	Keuruu
	Multia
Jämsä sub-region	
	Jämsä
	Kuhmoinen
Äänekoski sub-region	
	Konnevesi
	Äänekoski
Saarijärvi-Viitasaari sub-region	
	Kannonkoski
	Karstula
	Kinnula
	Kivijärvi
	Kyyjärvi
	Pihtipudas
	Saarijärvi
	Viitasaari

Appendix 2. Municipalities and sub-regions in Central Finland.