Vuosaari C Life Cycle Assessment

Helen Ltd.

Cecilia Salin

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1 Overview – Background Information

One of the current challenges of today's energy companies is the transition from fossil fuels to renewable energy sources. The idea of a society driven by renewable energy sources – such as wind, solar, tide, wave, biomass and geothermal energy – is becoming more and more topical, whilst the usage of fossil fuels is expected to decrease significantly in the future. Due to tighter greenhouse gas restrictions and climate policies, the usage of renewable energy sources is expected to increase drastically in the future and be the overall fastest growing energy source. (1)

In March 2007, the European Union presented its climate and energy policy that struggles against climate change and strives for increased energy security. The policy is known for its demanding "20-20-20" targets, which act as the guidelines for the main policy. The targets are to be met by the year 2020 and the idea is to encourage the member states to transform themselves into highly energy-efficient and low carbon countries. By the "20-20-20" targets, the following is intended:

- "A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels"
- "20% of EU energy consumption to come from renewable resources"
- "A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency". (2)

For the member nations to comply with these requirements, a significant increase of renewable resources is required, whilst simultaneously keeping the primary energy use and the growing electricity consumption as low as possible. (3)

In January 2014, the European Commission presented the framework for the new climate and energy policy, containing even tighter targets for the period 2020 – 2030. The policy implies: a reduction of greenhouse gas emissions of 40% below 1990-levels till the year 2030; increasing the share of renewable energy sources to at least 27% and increasing the energy efficiency with 27% till the year 2030. (3/4)

Amongst the varying forms of renewable energy sources, biomass is considered the most promising, as it has the largest potential for increased use (5). The utilization of biomass in energy production has not only increased in Finland, but also worldwide. The Intergovernmental Panel on Climate Change has estimated that the utilization of biomass in energy production will double till the year of 2050 from today's level. (6)

Biomass is, yet today, considered as a neutral carbon fuel, as the released carbon dioxin is seen as a natural part of the carbon cycle. This feature makes biomass a unique and attractive energy alternative, as the carbon cycle is sustainable and the biomass can be utilized in several forms. However, there is a strong need for improved biofuels in the future for the utilization to be efficient and profitable. (5)

1.1 The Development Program

In January 2010, Helsingin Energia presented a *development program* which strives to fulfill the city council's climate policy until the year 2020. The development program is based on the European Unions, Finland's and the city councils climate policies. The goal of the program is for the company to reduce its greenhouse gas emissions by 20% below 1990 level till the year 2020. Also 20% of the final energy produced needs to descend from renewable energy sources by the same year. As a follow-up of the development program, the company is aiming to be carbon-neutral till 2050. By carbon-neutral is in this case meant having zero carbon dioxide emissions. (7)

The company's carbon dioxide emissions in 1990 were approximately 3,4 Mt, which means a 20% reduction till 2020 would set an acceptable limit of roughly 2,7 Mt carbon dioxide. It had been estimated that it is going to be easier for the company to increase its use of renewable energy sources than to cut back on the carbon dioxide emissions. (7)

During the first phase of the of the development program, 2014 – 2015, the company will start co-firing wood pellets with coal at its two coal-fired power plants, Salmisaari B and Hanasari B. The wood pellet share in the fuel mix is estimated to be between 5 – 10%, equaling approximately 100 000 tons wood pellets annually. (7)

How the program will continue is still uncertain and is to be decided in 2015. It is up to the city council to decide how the development program proceeds. One option is to build a new multifuel power plant in Vuosaari, which would replace the existing Hanasaari B power plant. The new multifuel power plant would use both biomass and fossil coal as fuel. Another option is to start co-firing biofuels in large scale at both Salmisaari B and Hanasaari B power plants. In the case of co-firing, approximately 40% of the primary energy consumption would be biofuels. In both options, the company reaches the goals of the development program. (7)

1.2 Vuosaari C Power Plant

One of Helens pathways, in reaching the goals of the development program, is to build a new multifuel power plant in Vuosaari. The new plant, Vuosaari C, would be built at the northern side of the existing Vuosaari A and B power plants. The power plant would have fuel power of 740 MW, electrical power of 240 MW and thermal power of 410 MW. Except for the new power plant, new fuel storages and processing equipment need to be built. The harbor installations need to be renewed and a new energy tunnel needs to be constructed to Hanasaari area, for the heat distribution. (7)

The power plant is designed to have a boiler, based on circulating fluidized bed combustion, for biomass and coal. The baseline for Vuosaari C is that the power plant can use exclusively biomass or exclusively coal as fuel. In the case of 100% biomass combustion (in such a scenario, it is assumed that 90% would consist of wood chips and 10% of wood pellets), approximately 1,8 million tonnes of wood chips and 103 000 tonnes of wood pellets is required. On the contrary, in the case of 100% coal combustion, approximately 697 000 tonnes of coal is required. As the energy density is much smaller in biofuels than that of coal, much larger amounts of biofuels are needed to get the similar amount of energy as coal. (7)

The fuels can also be co-combusted with different rates of mixture and for Helsingin Energia to reach its sustainability goals, it is estimated that approximately 60% of the power plants fuel mixture needs to consist of biomass and 40% of coal. (7)

Figure 1: Illustration of the new multifuel power plant, Vuosaari C

The raw material can be transported to Vuosaari by trucks, train or ships. As the power plants fuel consumption is significant, most of the raw material transportations are planned to be delivered by ship. Ship transportations will be used for all raw materials: coal, oil and biofuels. Truck and train transportations will, however, mainly be used for biofuels. (7)

1.2.1 Fuel Features and Qualities

Coal is one of the most utilized energy sources worldwide and therefore, also considered as one of the most important ones. The largest coal sources are found in the United States, Russia and China and the fuel is generally extracted from deep within the ground. (8) The fuels energy and volumetric densities are considered high, making the fuel desired. The energy density may vary between 6,5 and 8 MWh/m3, whereas the volumetric density can range from 750 – 900 kg/m3. Due to the high energy and volumetric density, the fuel is quite easy to transport and store. (9) However, the extraction of the fuel is considered to be a laborious and energy intensive process that causes air pollutions. (10)

Wood pellets are generally made from by-products from the sawmill industry. Roundwood is commonly used as feedstock in the sawmill industry and wet sawdust is normally generated as a by-product from sawmills. Therefore, wood pellets are often produced out of compacted sawdust. In case of poor raw material availability, roundwood, small-diameter thinning wood or other residues as bark, can be used as feedstock in the pellet production. (11)

During the pellet production process, the biomass is dried and compressed into small pellets. Pellets have low moisture content, normally between 8 – 10%, giving them higher energy density than wood chips. (12) The energy density of wood pellets can range from 2,9 – 3,4 MWh/m^3, whereas the fuel can have a bulk density ranging from 500 to 650 kg/m^3 (9). Since the wood pellets are dense and small in size (6 – 12 mm), they are fairly easy to store and transport. However, the fuel is extremely responsive to dampness, meaning that they must be handled under dry conditions. Compared to wood chips, pellets are quite expensive and the production process energy intensive. (12)

Wood chips are often made of forest residues or wood that cannot be used in the forest industry’s processes (13). The moisture content of wood chips is normally quite high and can range from 40 – 60%. The high moisture content gives the wood chips low energy density as well as low volumetric density, meaning that large volumes of the fuel is needed to produce energy. The volumetric density of wood chips normally ranges between 250 – 400 kg/m^3, whereas the energy density ranges between 0,7 – 0,9 MWh/m^3.(9)

Wood chips are mainly produced from three different raw-material feedstock – *logging residues, stump residues* and *small-diameter thinning wood.* The term *logging residues* normally refers to waste stem wood, branches, needles and leaves that are left at the logging site after a logging process. *Logging residues* are generally assembled after clear cutting, since the residue amounts are often multiplex when compared to the amounts gathered from a normal logging site. Also the harvest technology is more efficient and more profitable when used at a clear cutting site, due to better productivity. (14)

Logging residues are commonly considered the most important raw-material source in the production of wood chips. This is because it is the cheapest raw-material source for producing wood chips, as well as the fact that that large amounts can be obtained from clear cutting sites. (14)

Stump residues generally refer to the residues that are left in the ground after cutting a tree. Stump residues can solely be lifted from areas where clear cutting has been performed, as only large stumps are utilized, and heavy-duty machines are consequently needed for the lifting. Because of impurities, the raw-material is commonly used as a wood chip feedstock. (14)

Small-diameter thinning wood is often harvested from young stands, to improve the quality of the forest. The removal of the trees may depend on that the trees are growing too tight and needs to be thinned out to get a better profitability. The procedure is commonly called early thinning and is generally carried out on young stands. The removed trees are usually chosen so that they are of bad quality or malformed. (14)

Trees may also be removed due to forest refitting. This implies there are lots of trees with insufficient diameter and therefore, the trees are not accepted as industrial wood. In this case, the activity can also be called *energy wood thinning*, since the removed wood is solely used for firing in energy production. Small-diameter thinning wood is, however, the most expensive wood chips source and thereby also the least utilized. On the contrary, the quality of *small-diameter thinning wood chips* is generally considered better than that of logging/stump residues chips. (14)

2 Life Cycle Assessment

The aim of a life cycle assessment, LCA, is to identify and analyze a product or process environmental impacts, during its complete life cycle. Environmental impacts arise from a supply chains different phases and from the usage of a product. The main phases normally include: the raw material procurement and handling, the transportations, the manufacturing, the usage, the disposal and the possible land filling of a product. (15)

The method is used to recognize at what point of the life cycle the environmental impacts arise and how significant they are. The method can also be used to improve a products lifecycle and reduce the environmental impacts. As a balancing tool, the international ISO 14040 standards has been put into action to support and facilitate the performance of LCAs. (15)

A life cycle assessment comprises of four different phases. During the first phase, the goal and scope of the study is determined. How broad and detailed the assessment is and what purpose it serves, plays an important role and is decided. During the second phase, the life cycle inventory (LCI), the material needed to perform the assessment is gathered. (15)

The third phase, life cycle impact assessment (LCIA), consists of analyzing the prominence of the environmental impacts noted so far and determining how the material shall be presented, so that the material and impacts are easily understood. The last phase consists of interpreting the results and making final observations and conclusions. (15)

3 Goals and Scope of the Study

The study is made as a part of the BEST (Sustainable Bioenergy Solution for Tomorrow) research program, which is a collaboration between CLEEN Ltd. (Cluster for Energy and Environment) and FIBIC Ltd. (the Finnish Bioeconomy Cluster). The study is also made in collaboration with the Finnish Environmental Institute.

The aim of the study is to analyze Vuosaari C power plants climate and environmental impacts during the power plants entire life cycle. The study focuses on emitted carbon dioxide, sulphur dioxide and nitrogen dioxide emissions as well as particular matter formation. Data regarding the processes is gathered from internal and external sources and the data is divided into foreground and background processes.

There is still some uncertainty of how Vuosaari C power plant will operate and what the final raw material allocation will be. Therefore some assumptions are made in this study. It is assumed that the power plants fuel consumption is approximately 4,8 TWh annually. The basis for the new power plant is that coal and biomass can be co-combusted and it is presumed that 60% of the power plants primary energy consumption is biomass. Of the biomass, it is further assumed that 90% is wood chips and 10% wood pellets. The remaining 40% is coal. In the study, a 100% fossil coal comparator will also be implemented.

In the study, the coal supply chain begins with the coal extraction process, whereas the biomass supply chain from the forest activities. Climate impact of biomass supply chains do not contain impacts from annualized emissions from carbon stock changes caused by land use change (16). Much attention is paid in investigating the raw material feedstock and supply chains. The coal is imported from Russia and Poland and information from background processes are used to calculate the emissions that arise from the supply chain. The wood pellets are, on the contrary, domestic and made from sawdust from the sawmill industry. As the wood chip amount is so significant, several supply chains are taken into consideration. This is done to get a good comparison of how different supply chains differ from each other. Apart from Finland, wood chips imports are made from Russia and the Baltic countries. The wood chips are made from varying raw material feedstock, affecting the supply chain structure. In this study, wood chips are produced from inter alia whole trees, delimbed wood, forest residues, stump residues and by-products from the forest industry.

One point of interest is to see how the emissions diverge from each other when biomass and coal are co-combusted, compared to 100% coal combustion when the complete life cycle is taken into consideration. Another point of interest is to see at what stage of the supply chain the most significant emissions arises and how the emissions vary between the different countries supply chains.

Figure 1 illustrates the processes taken into consideration in the assessment when biomass and coal are co-combusted, whereas Figure 2 illustrates the processes, when solely coal is utilized as primary energy source.

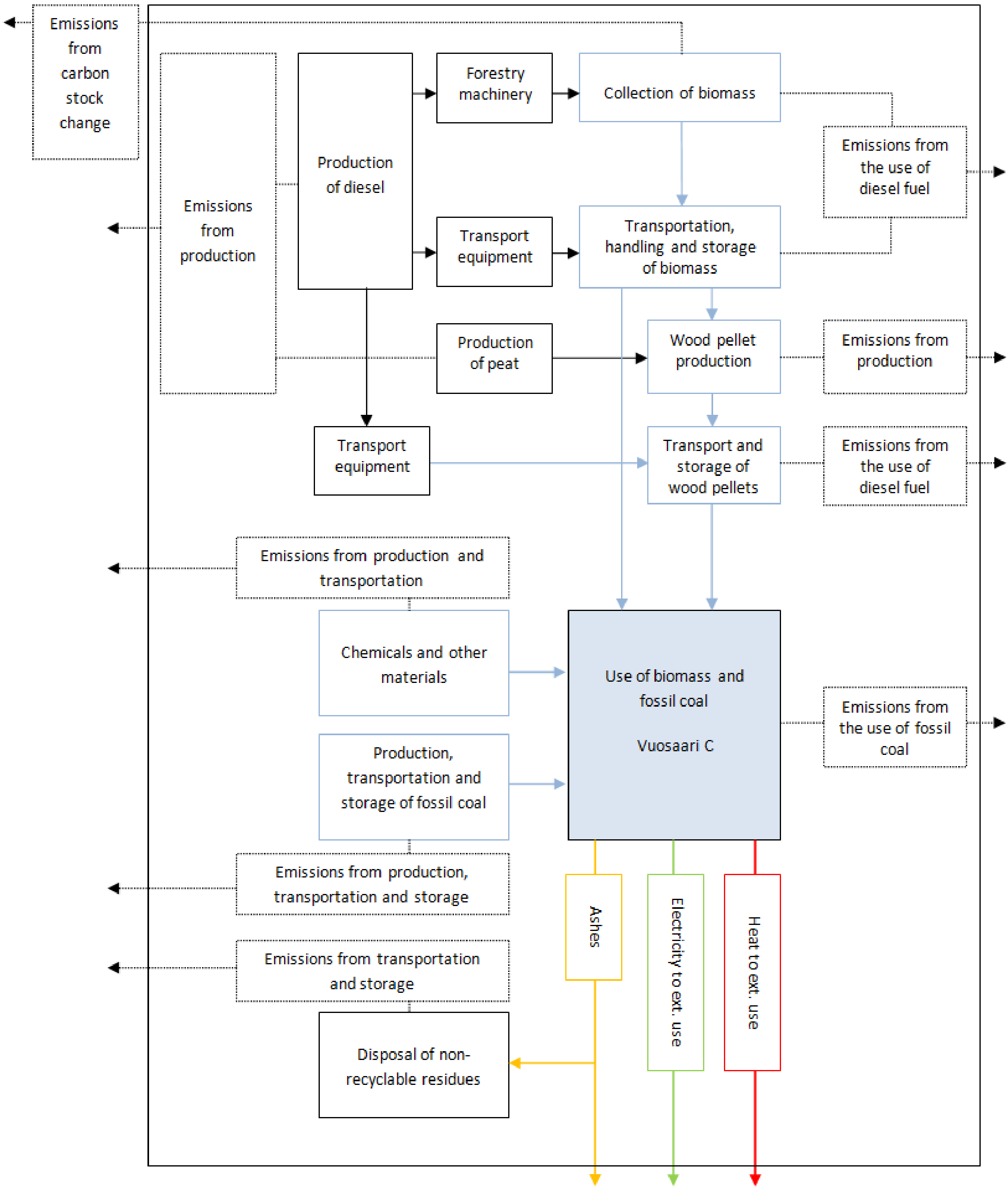

Figure 2: Processes and emissions taken into consideration in the life cycle assessment when biomass and coal are co-combusted

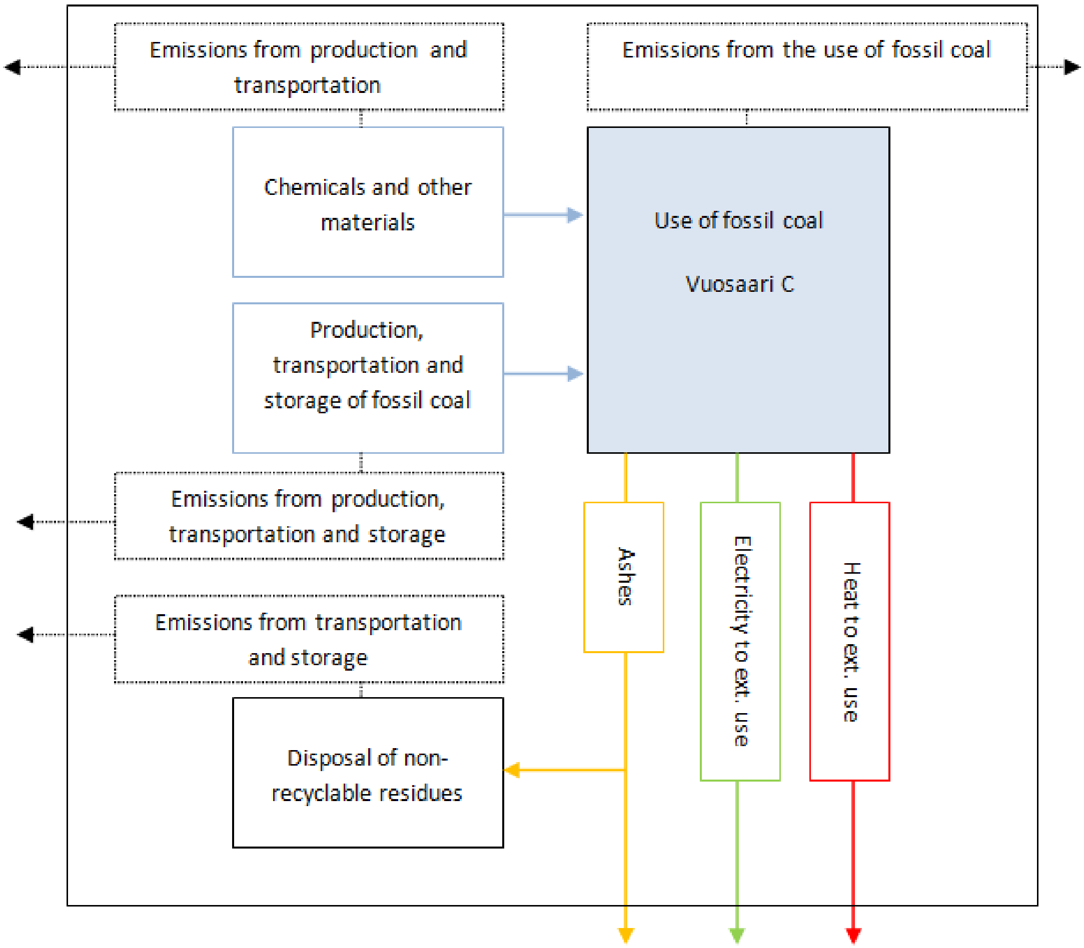

Figure 3: Processes and emissions taken into consideration in the life cycle assessment when solely coal is combusted

4 Life Cycle Inventory Analysis

In this study, the foreground data is collected from internal and external sources. Measured data is primary used, but is not available for all processes. Therefore calculated data is used as secondary option. Also background information has been taken into consideration and different databases are used. In case of completely lacking data, some estimates have been made.

4.1 Collection, Processing and Transportation of Biomass

In the study, biomass stands for over 60% of the power plants primary energy consumption. Of the biomass, 90% is wood chips and 10% wood pellets. This means that approximately 2,615 TWh of the primary energy consumption is wood chips and 0,290 TWh is wood pellets. (7) The wood pellets are of domestic origin and the information used in the assessment is based on Daniela Bqains (17) study. In this study, several wood chips supply chains are taken into consideration, so that the emissions from the different sources can be compared. Approximately two thirds of the wood chips are domestic and one third is imported.

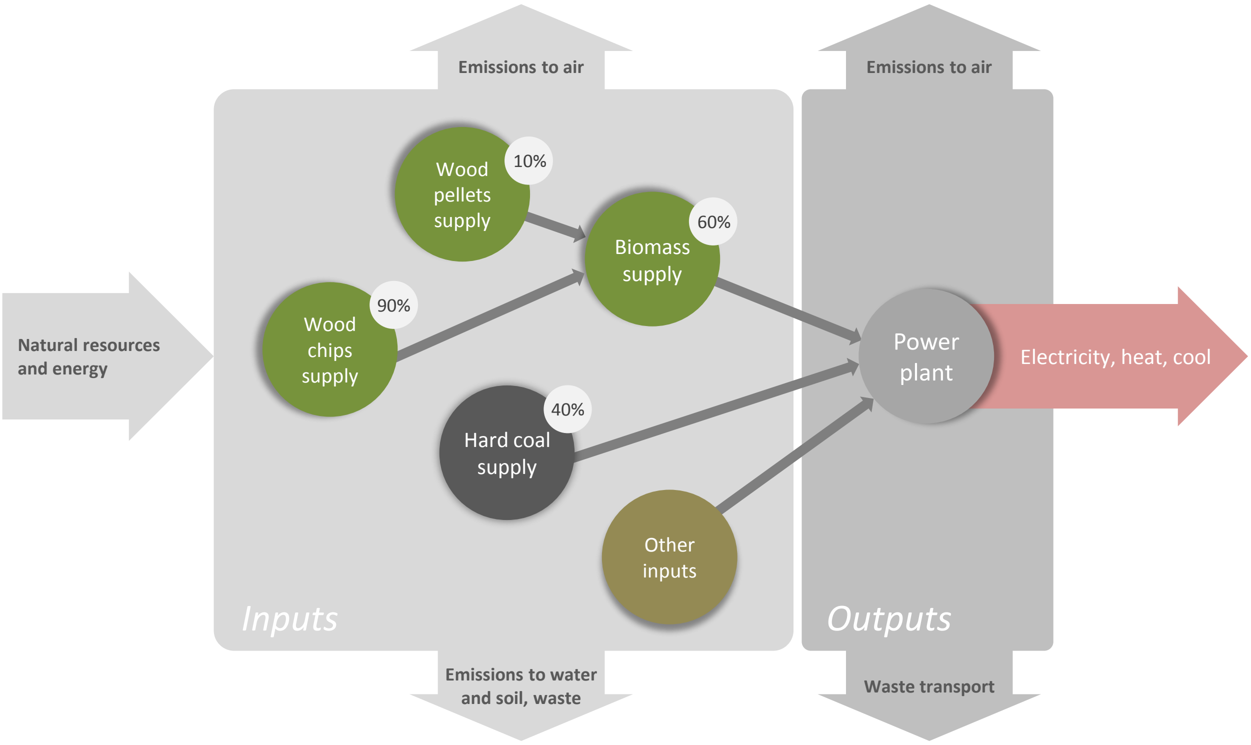

Figure 4: Vuosaari C – Input and output flows (16)

Imports are made from Russia and from the Baltic countries, Estonia and Latvia. The forest land utilization is assumed to remain the same and therefore, no emissions from carbon stock changes are taken into consideration.

4.1.1 Wood Pellets

The domestic wood pellet supply and supply chains have previously been investigated by Helsingin Energia. Daniela Bqain investigated in her study “The environmental and climate impacts of the entire life cycle of co-firing coal and wood pellet” the domestic wood pellet potential and the environmental impacts arising from the pellet supply chains. All information used in this study, concerning wood pellets is based on Bqains (17) study.

It is assumed that three different pellet factories secure the pellet supply for the new power plant. In the assessment, wood waste and sawdust from the sawmill industry is used as raw material in the pellet production. Roundwood is considered as raw material base in the sawmill processes and the average transportation distance for the roundwood, is estimated to 50 kilometers.

Pellet factories are generally located near the sawmill industry, as the raw material for producing pellets mainly descend from the sawmill processes. This is also considered in this study and therefore, no transportation distances between the sawmill industry and the pellet factories are taken into consideration in the assessment.

During the pellet production process, the raw material is dried, using either peat or wood waste as drying fuel. Peat is considered as a fossil fuel and the utilization of the resource increases CO_2 emissions in the atmosphere. The utilization of peat as drying fuel has a significant impact on the pellets CO_2 emissions. Depending on the pellet factories, the proportion of peat and biomass used for drying may vary and at some factories solely biomass is used as fuel in the drying process. In this study, it is assumed that the pellet raw material is dried using 66% peat and 33% biomass as drying fuel.

The wood pellets are transported by truck from the pellet factories straight to Vuosaari and the average transportation distances from the three factories are estimated to 105,120 and 250 kilometers.

4.1.2 Wood Chips

In this study, wood chips are made from *logging residues, stump residues, small-diameter thinning wood (both whole trees and delimbed wood)* and *by-products* from the forest industry. It is presumed that fresh wood chips have a moisture content of 50%. Of the *domestic wood chips*, approximately 1,2 TWh is supplied by the *Finnish forest companies*, whereas 0,5 TWh would be brought from *Kainuu*. Of the *imported wood chips*, approximately 0,55 TWh is brought from the Baltic countries, whereas approximately 0,36 TWh descends from Russia.

Of the amount supplied by the domestic *forest companies*, the majority of the chips would be made of logging residues and small-diameter thinning wood. Roughly 30% would be made from by-products. The by-products mainly consist of bark and other wood residues that are not used in the forest industries own processes.

The wood chip supply chain starts from the forest, from the logging. After the logging, the raw material is transported to the roadside using forestry machinery. By the roadside, the feedstock is chipped to maximize the load size of the long-haul transportation vehicle. The wood chips are delivered to Vuosaari C power plant with truck and the average long-haul transportation distance is estimated to be between 70-110 kilometers. The figure below describes the supply chains for the different raw material bases for the Finnish forest companies.

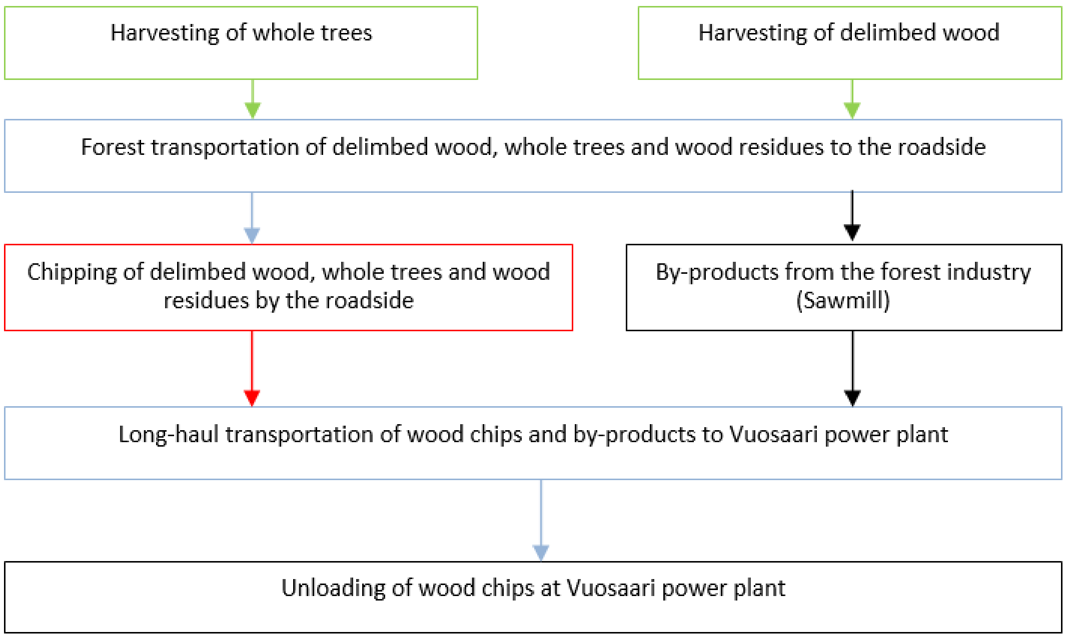

Figure 5: Supply chain when wood chips are supplied by Finnish forest companies

The wood chips descending from *Kainuu*, are made from logging residues, stumps and small-diameter thinning wood. After the logging/stump lifting, the raw material is transported to the roadside using forestry machinery. By the roadside, the majority of the raw material is chipped. Due to high volumetric density, delimbed wood is not chipped by the roadside.

The wood chips and the delimbed wood are transported by truck to a terminal that is provided with good logistics and storage possibilities. The truck transport is estimated to 35 kilometer. At the terminal, the delimbed wood is chipped and the wood chips are loaded onto train for further long-haul transportation. The train transportation from

Kainuu to Vuosaari is estimated to approximately 720 kilometers. Figure 6 illustrates the different stages of the supply chains.

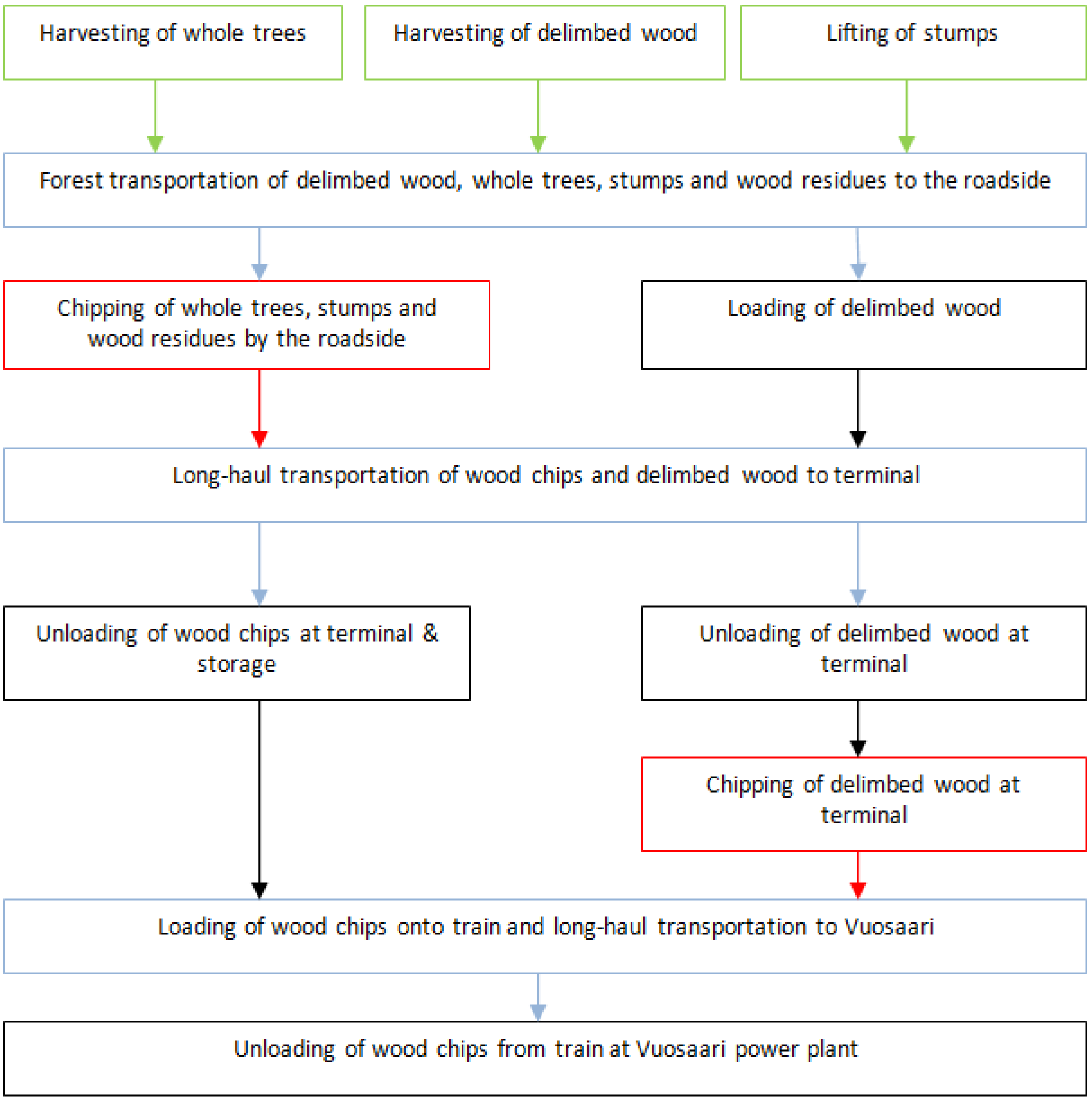

Figure 6: Supply chain when wood chips descend from Kainuu

The wood chips imported from the *Baltic countries*, Estonia and Latvia, are made of logging residues and small-diameter thinning wood. It is assumed that the raw material is harvested and transported to the roadside, using forestry machinery. By the roadside the raw material is chipped, regardless of the feedstock.

The wood chips are transported by truck to the port of shipping. The average transportation distance is estimated to 80 kilometers in Estonia and 70 kilometers in Latvia. In the assessment, Paldiski, Kunda and Salacgrīva ports are taken into consideration. At the ports, the wood chips are loaded onto bulk carriers. The bulk carriers from Estonia are assumed to have a payload of 3000 tonnage, whereas the carriers from Latvia are assumed to have a payload of 4000. It is assumed that there are loading and unloading equipment (cranes) at the shipping harbor as well as at Vuosaari harbor. The cranes are assumed to run on electricity.

The shipping distance from Paldiski port to Vuosaari is estimated to 110 kilometers, whereas it is 117 for Kunda port. The distance from Salacgrīva port to Vuosaari is, on the contrary, estimated to 365 kilometers. The wood chip supply chains are very similar for both Estonia and Latvia and these are illustrated in figure 7.

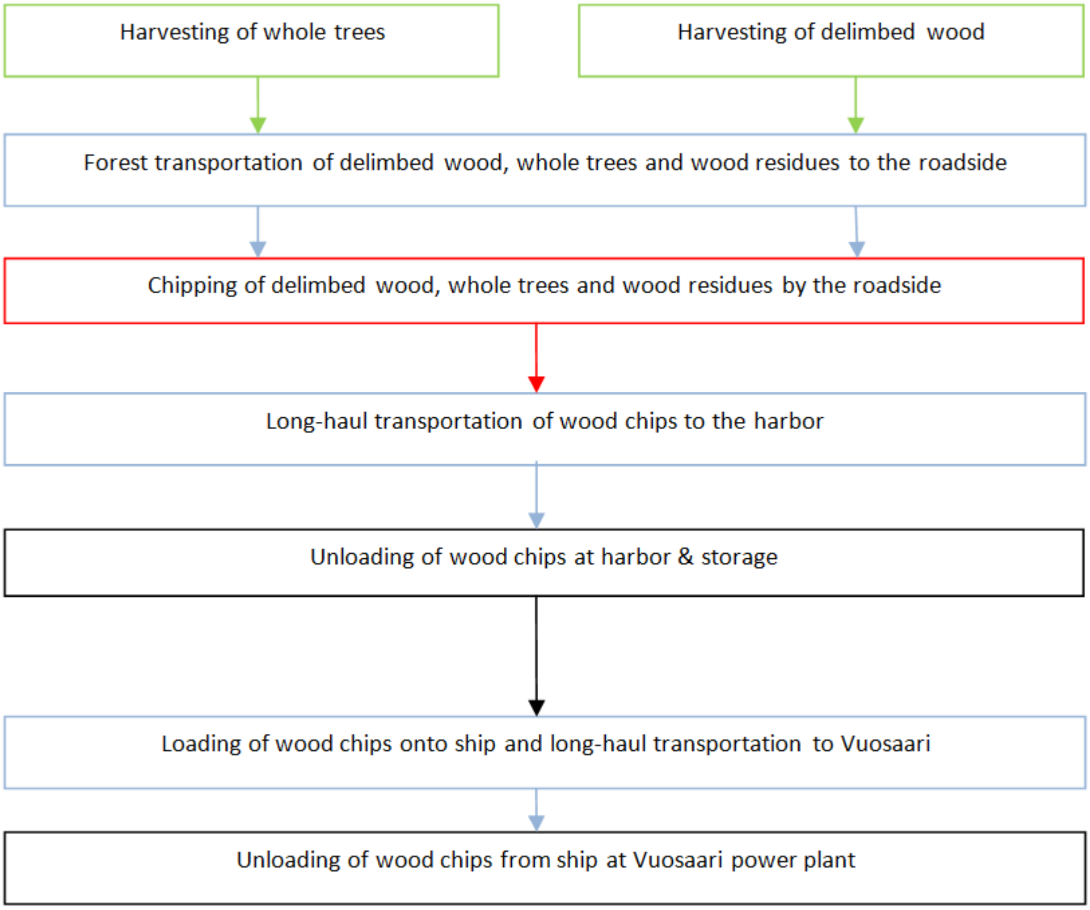

Figure 7: Supply chain when wood chips are imported from the Baltic countries

The wood chips descending from Russia are, on the contrary, made from exclusively small-diameter thinning wood. Solely delimbed wood is used as feedstock and the raw material is harvested and transported to the roadside using forestry machinery. The raw material is further transported by truck to the port of shipping, where the raw material is chipped. The truck transport is estimated to 160 kilometers and the shipping harbor taken into consideration in Russia is the port of Vyborg.

At the harbor, the wood chips are loaded onto bulk vessels. The payload of the vessels used is estimated to 7500 ton and the shipping distance from Vyborg to Vuosaari to 244 kilometers. It is assumed that there are loading and unloading equipment (cranes) at the shipping harbor as well as at Vuosaari harbor. The cranes are assumed to run on electricity. Figure 8 illustrates the supply chain for the Russian wood chips.

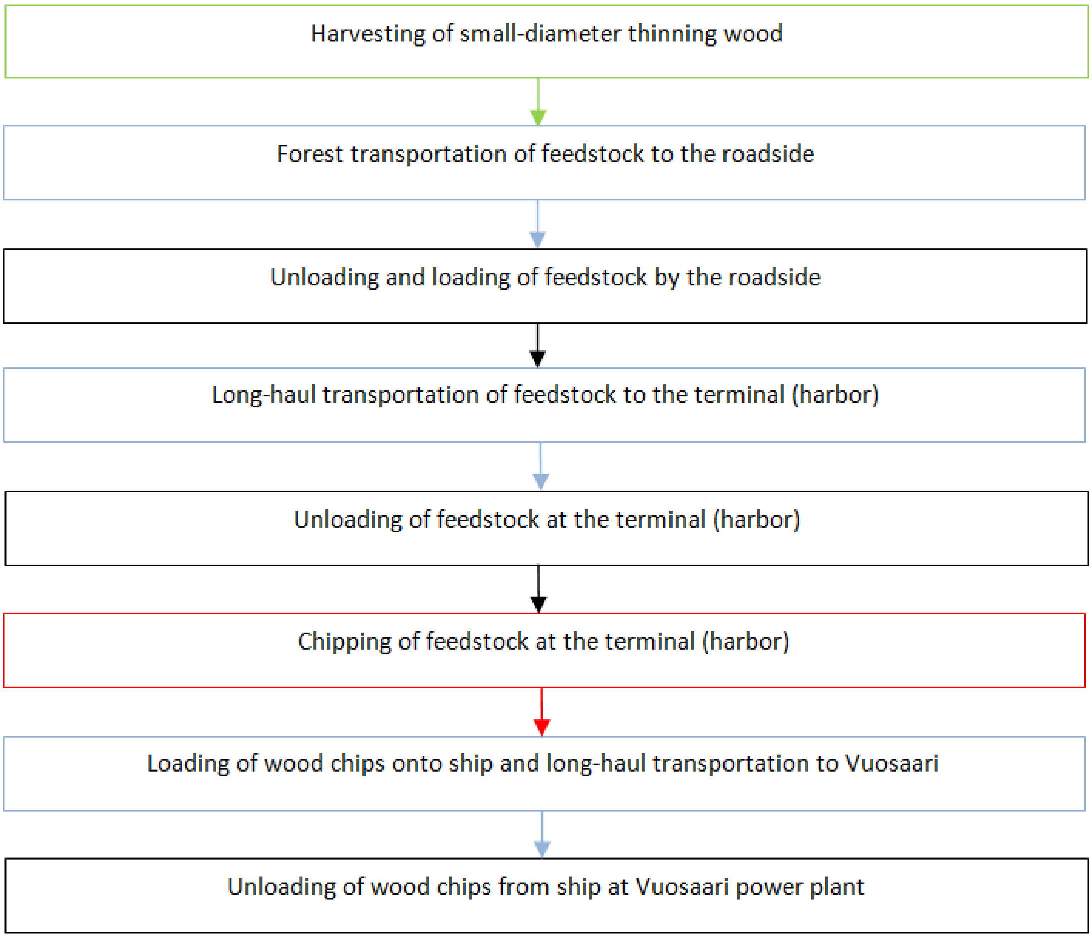

Figure 8: Supply chain when wood chips are imported from Russia

4.2 Co-firing Biomass and Coal at Vuosaari Power Plant

It is expected that the utilization of biomass as fuel, compared to fossil coal, reduces the formation of incineration residues due to lower ash content. The fly and bottom ash formation is expected to correlate with the biomass usage. At the moment it is however, uncertain how co-firing biomass affects the usability and recyclability of the ashes. The company's coal ashes are currently further utilized in the concrete industry and for excavation. It is however possible that the ash content will change when biomass is co-fired with coal, resulting in decreased utilization of the ashes. Therefore in this assessment, it is assumed that the ashes from co-firing biomass cannot be utilized and are land filled. The transportation distance to the landfill is estimated to 40 kilometers.

4.3 Background Processes

Apart from the ISO 14040 standards, there are several databases and software's that can be utilized to facilitate the lifecycle assessment performance. The databases can contain information regarding different processes and services that might be necessary, but difficult to find. The services or processes may include: electricity production, production of different chemicals, diesel production or oil extraction. The databases may also contain information concerning raw material qualities and transportations.

Ecoinvent is considered to be the most utilized database, containing over thousands of different processes. Due to a large variety of information of different unit processes, the database can be used to create personal production processes. The database is also used in this assessment for gathering information about the coal mining and the production processes for the chemicals and the diesel, amongst others. (16)

Different softwares are, on the contrary, used to facilitate the handling and the usage of the information. The information flow is generally quite encompassing, when performing an assessment and softwares are generally used to analyze and interpret the results.

The LCA modelling work was performed in the SimaPro® 8.01 LCA tool. The results were calculated according to the ReCiPe Midpoint (H) impact assessment method. The normalized results were calculated based on the European normalization set. (16)

4.4 Fossil Fuel Comparator

In the study a fossil fuel comparator is also implemented. In this case, it is considered that 100% coal is combusted at Vuosaari C power plant. The background processes are considered the same as in the case where biomass is co-fired and the coal is transported to Vuosaari with similar coal vessel as in the biomass case. The coal ash is further utilized in the concrete industry and it is assumed that the ash is transported to Lappeenranta and Parainen.

5 Life Cycle Impact Assessment

In this stage environmental impacts associated with the functional unit of the defined system are calculated. These impacts are grouped as impact categories. There are two main steps in the impact assessment: *characterization* and *normalization*.

Characterization: all the substances are multiplied by a characterization factor which reflects their relative contribution to the environmental impact.

Normalization: the quantified impact is compared to a certain reference value, for example in this study the average environmental impact of a European citizen in one year. (16)

A brief introduction of the selected impact categories and the environmental interventions which they describe:

Climate change impact category is contributed to by GHGs (greenhouse gases). The main GHGs are carbon dioxide, methane or dinitrogen oxide. The source of GHGs is typically combustion of fuels or anaerobic decomposition. When released to the atmosphere, the gasses trap sun energy (heat) reflected from the Earth's surface. As a consequence climate changes and atmospheric temperature rises. The reference unit of climate change impact category is carbon dioxide equivalent (CO_2-eq.).

Fossil depletion correlates closely with climate change impacts as it represents a direct consequence of consumption of fossil fuels (expressed in oil equivalent).

Terrestrial acidification is mainly caused by sulphur and nitrogen oxides, as well as ammonia emissions to air. The principle behind this impact category is that e.g. sulphur in (fossil) fuels oxidises when exposed to high temperatures. Formed sulphur oxides react in the atmosphere with water and form acid rain. Subsequently, acid rain increases acidity of terrestrial ecosystems. The reference unit is sulphur dioxide equivalent (SO_2-eq.).

Photochemical oxidant formation impacts are caused by emissions of organic compounds, often classified as NMVOC (non-methane volatile organic compounds) and nitrogen oxides and their reaction with sunlight. Photochemical oxidants contribute to ozone formation. The reference unit is NMVOC equivalent.

Particulate matter formation is an impact category which represents dust and fine particulates emissions to atmosphere. The origin of fine particles is typically transport and combustion of fuels. The reference unit is PM10. (16)

6 Interpretation Of Results

The results were calculated according to the ReCiPe Midpoint (H) impact assessment method. The normalized results were calculated based on the European normalization set. For the studied product system of energy production were selected five impact categories as the most relevant. These are *climate change*, *fossil depletion*, *terrestrial acidification*, *photochemical oxidant formation* and *particulate matter formation*. (16)

Note that climate impact of biomass supply chains do not contain impacts from annualized emissions from carbon stock changes caused by land use change. Conventionally, emissions from carbon stock change related to land use (positive or negative) have not been accounted in a standard approach to Life Cycle Analysis because it is implicitly assumed that an almost immediate uptake via plant re-growth of the initially released biogenic carbon takes place. According to the 2013 Commission's Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations (2013/179/EU), biogenic carbon removals and emissions should be accounted but kept separate in the resource use and emissions profile of products/organizations. (16)

The *internally normalized* characterized results are presented in Figure 9. Internal normalization was performed in order to see the relative contribution of the different life cycle stages of the product system. (16)

Direct emissions of the power plant are the main contributor to four impact categories, climate change, terrestrial acidification, photochemical oxidant formation and particulate matter formation. They contribute between 63 to 83 % of the total impacts of each impact category. Although providing 60 % of primary energy, biomass supply has similar impacts to those of supplying hard coal (between 6 and 19 %; 11-20 % for hard coal). Coal supply is a dominant contributor to fossil depletion. (16)

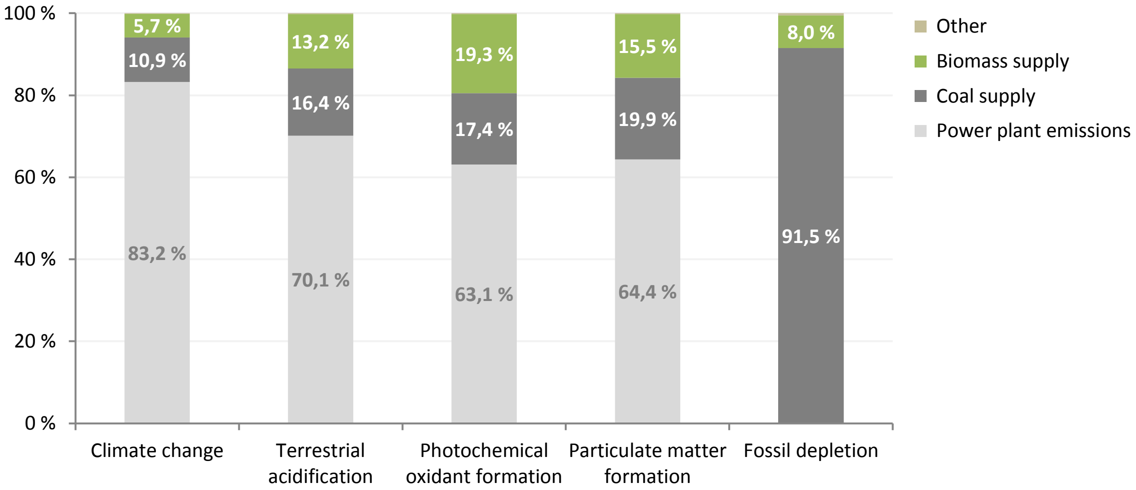

Figure 9: Characterized results for Vuosaari *60 % biomass system*, internally normalized (16)

In Figure 10, the normalized results are presented. Characterized results (as shown above) cannot be compared with each other due to different units. In order to do that, they must be normalized to a common denominator. (16)

The normalized results indicate the extent of the contribution to each category compared to the annual impacts of an average European citizen (based on the ReCiPe European normalization set). The normalized results can be interpreted so that the fossil depletion impact category is the most relevant to tackle. Similarly, climate change impacts should be also of high interest and where to the environmental protection actions should be focused with a higher priority. The contributions of other impact categories in a broader context (European level) are not as relevant as in the case of climate change and fossil depletion. (16)

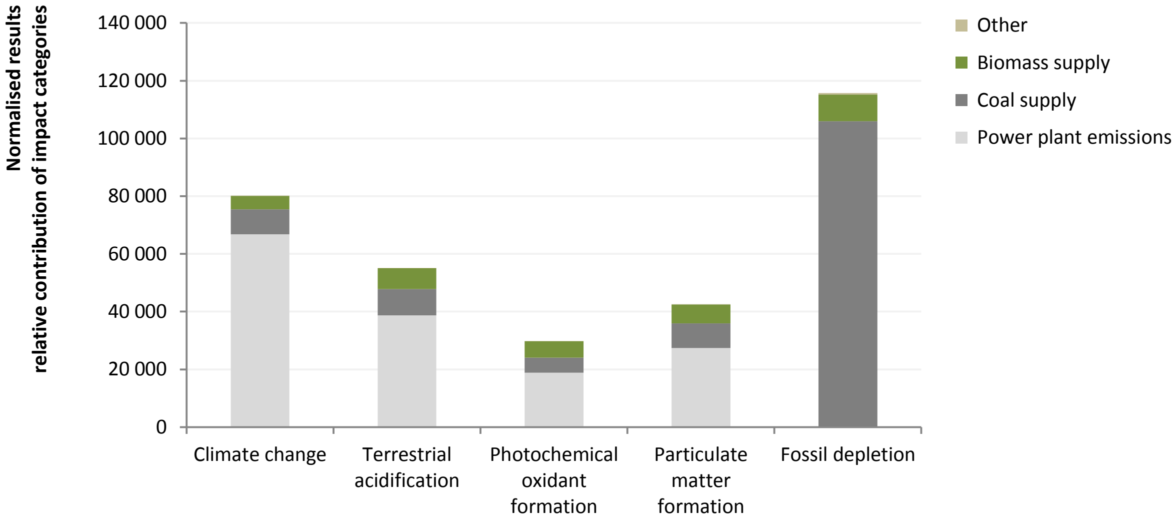

Figure 10: Normalized results for Vuosaari *60 % biomass system.* (16)

Figure 11 presents a comparison between the *Vu 100 % coal* system, where 100 % of energy is obtained from hard coal, and the *Vu 60 % biomass* system, where 60 %

of energy is obtained from biomass and 40 % from hard coal. The biomass co-combustion system under the defined conditions of this study appears to have the potential to cause considerably lower climate change impacts and fossil depletion impacts (reduction of 56 %). Reduction in the other impact categories is not as significant, ranging between 4 and 10 %. (16)

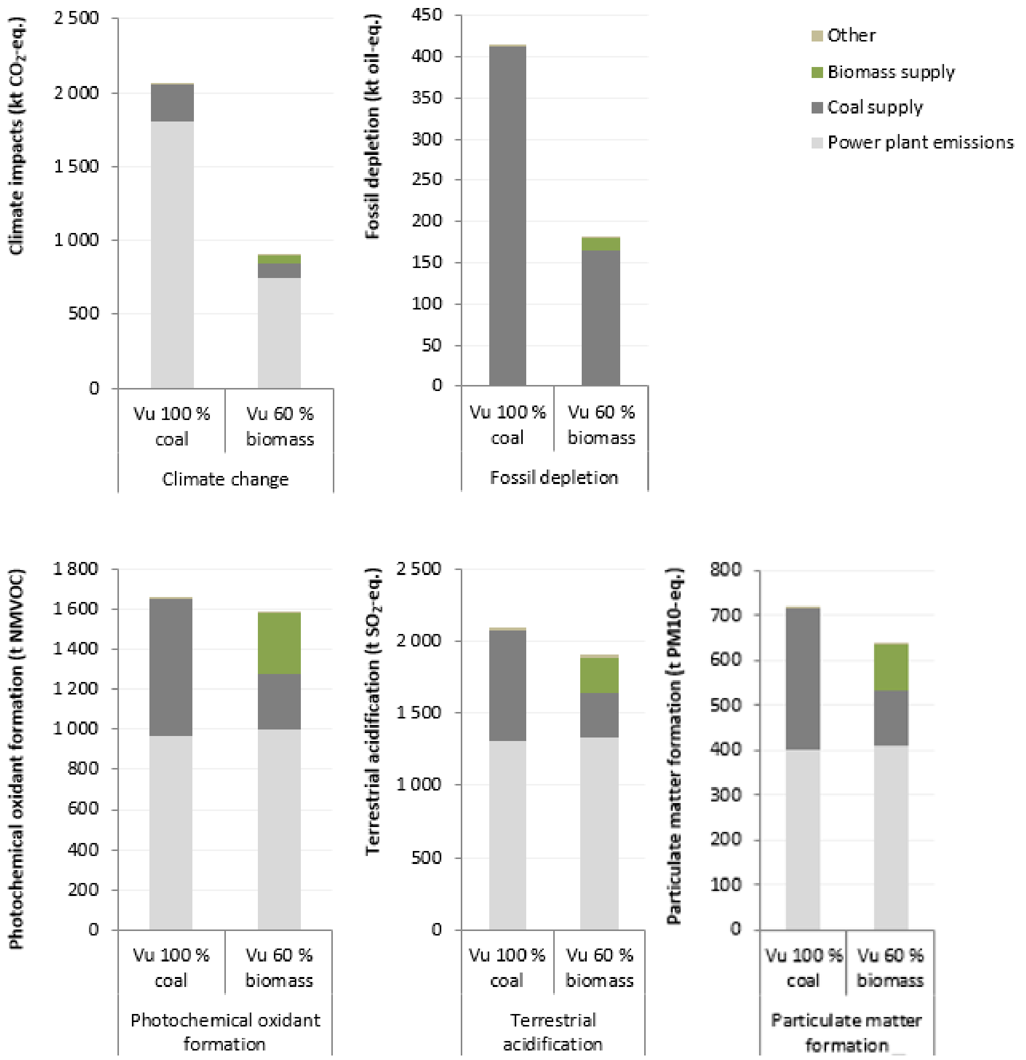

Figure 11: Characterized results; a comparison between the *coal system* (100 % coal) and the *60 % biomass system*. (16)

Carbon dioxide emissions of any origin have an effect on climate change. However, biogenic CO_2 emissions are commonly (according to a scientific consensus) excluded from calculations of climate change impacts as the CO_2 that arises from biomass combustion is seen as carbon neutral. In Figure 12 we illustrate the actual volume of biogenic CO_2 in the *Vu 60 % biomass* system. Note that the blue section of the third bar in the figure does not indicate the climate change impacts as such. It indicates the volume of biogenic CO_2. (16)

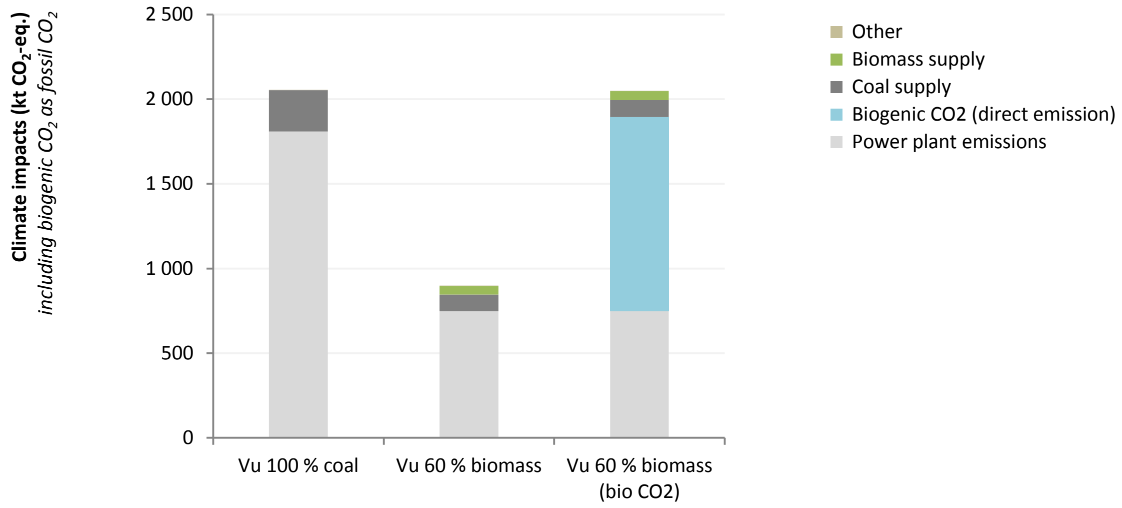

Figure 12: Climate impacts completed with the amount of biogenic CO_2. (16)

A comparison of normalized impacts for both *Vu 100 % coal* and *Vu 60 % biomass* systems are presented in Figure 13.

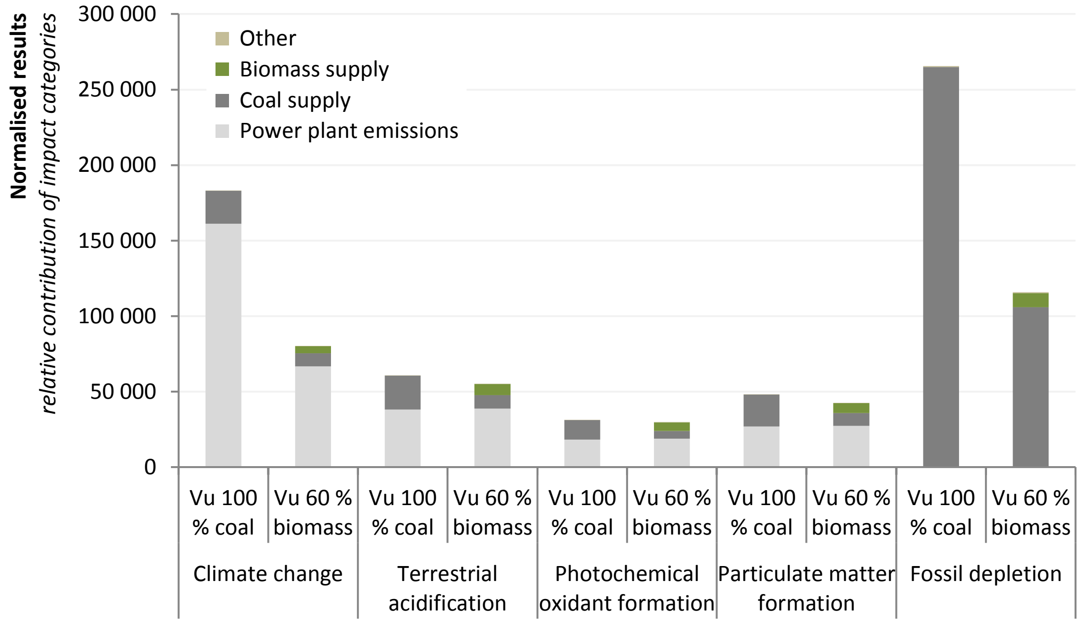

Figure 13: Normalized results for Vuosaari *coal* and *60 % biomass* systems. (16)

The results of biomass supply chains are presented more in detail, and compared to each other, in the following figures. Figure 14, 15 and 16 show comparison of impacts of different biomass supply chains calculated per 1 MWh of primary energy in biomass. (16)

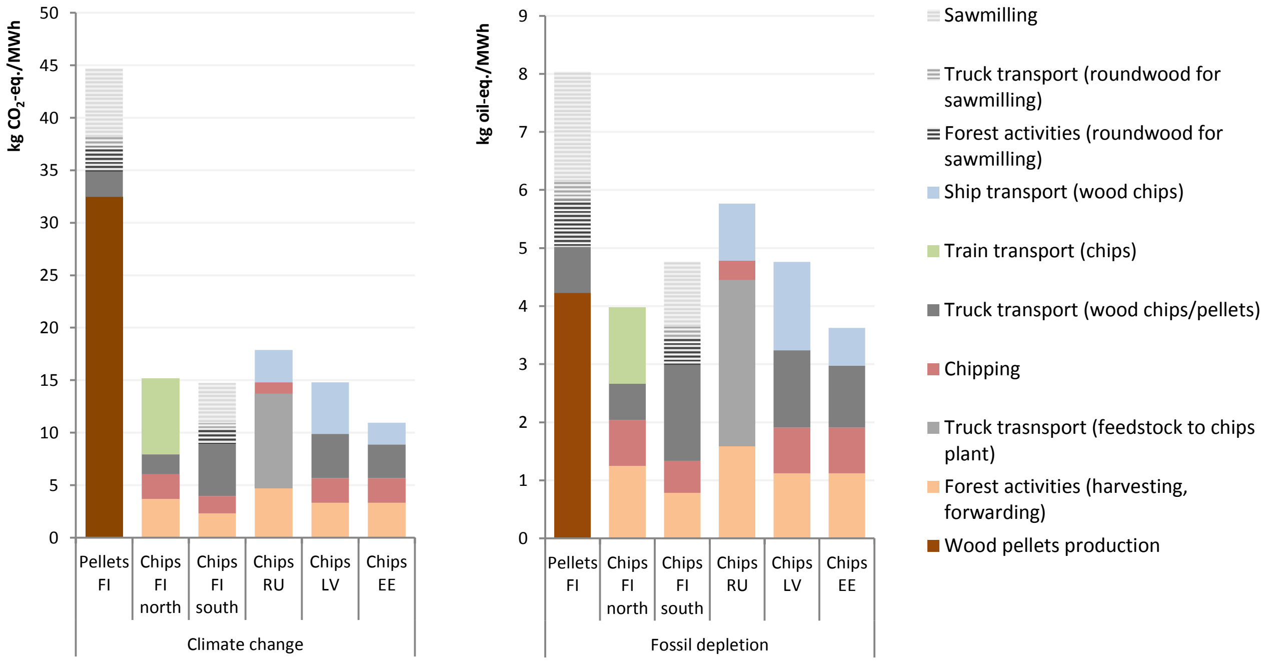

Figure 14: Climate impacts and fossil depletion *per 1 MWh of primary energy in fuel*; comparison of biomass supplies. (FI = Finland, RU = Russia, LV = Latvia, EE = Estonia) (16)

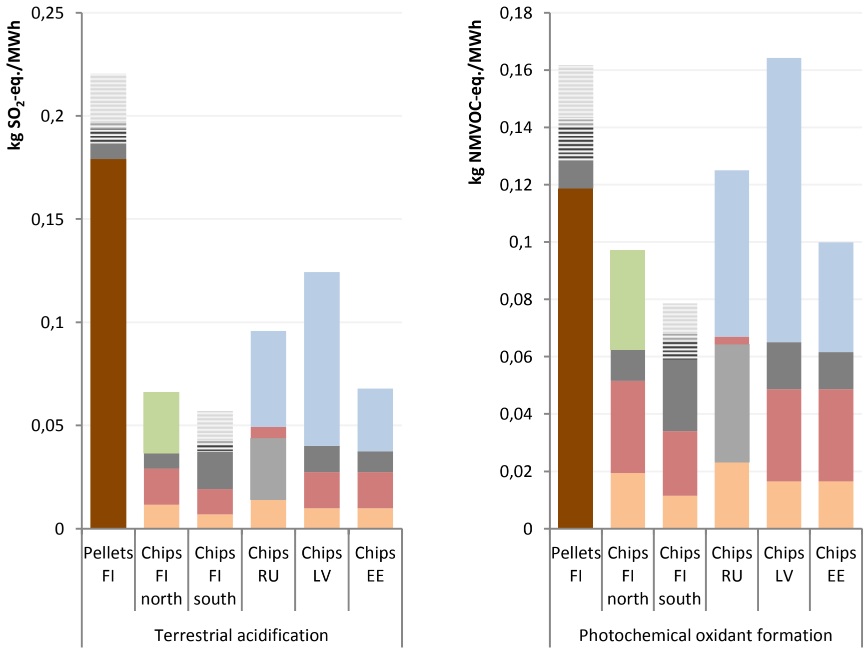

Figure 15: Terrestrial acidification and photochemical oxidant formation per 1 MWh of primary energy in fuel; comparison of biomass supplies. (FI = Finland, RU = Russia, LV = Latvia, EE = Estonia) (16)

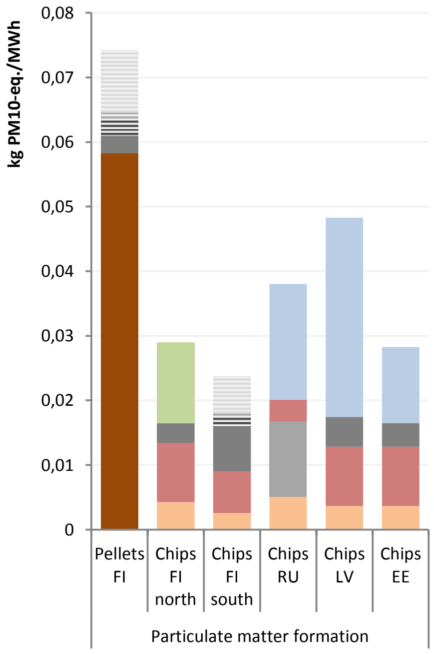

Figure 16: Particular matter formation per 1 MWh of primary energy in fuel; comparison of biomass supplies. (FI = Finland, RU = Russia, LV = Latvia, EE = Estonia) (16)

The main contributor to all impact categories in wood pellets supply chain is the wood pellets production due to heat and electrical energy requirements. The share of truck transport is only minor. (16)

On the other hand, the contribution of all types of transport (truck, ship and train) is much more important in case of wood chips supply chain. In most cases transport contributes to a half (or even more) of the impacts. In case of Russian and Baltic wood chips the contribution of ship transport to the terrestrial acidification, photochemical oxidant and particulate matter formation impact categories is especially significant. Forest activities contribute more than chipping in climate change and fossil depletion impact categories. (16)

According to this assessment pellets production cause higher environmental impacts (per MWh of primary energy) compared to wood chips (16). Noteworthy is however, that this is mainly due to the fact that peat is used as drying fuel in the pellet production. The peat can easily be compensated with biomass, decreasing the CO_2 emissions.

However in this study, the utilization of wood chips seems as a preferable option when implementing biomass (co-)combustion. However, better site specific data on biomass supply chains would be needed in order to rank the different supply options with higher certainty. (16)

Note that there are two approaches to treat the sawdust in the LCA methodology: sawdust as by-product or as waste. In the results the impacts related to all the upstream activities before pellet production are highlighted for Finland and Latvia (plotted as hatched). They can be excluded if sawdust is considered as waste.

Note to train transport of chips from the north of Finland (second bar from left): The emissions reported in Lipasto database are calculated as a ten years average in 2007. Therefore the information is slightly outdated. Even more importantly, other than traction electricity consumption reported in Lipasto (0.03 kWh/tkm) contributes to over 50 % of climate impacts of 1 tkm train transport when using this electricity is supplied from the grid. If this electricity was a certified hydropower, its contribution to climate impacts of train transport would be only in the range of percent, not tens of percent. Therefore, the presented results are the “worst case scenario”. In the “best case scenario” the climate impacts of train transport would be almost 50% lower. This would make the northern wood chips one of the favorable options. (16)

7 Conclusions

Based on the results it can be concluded that the operation of the prospective power plant in Vuosaari would cause lower environmental impacts when co-combusting 60 % of biomass and 40 % of hard coal, compared to combusting only hard coal. The main benefit is in reduced fossil greenhouse gases. (16)

In the 100% coal system approximately 88% of the total emissions are from the power plant, whereas 12% are from the supply chain. In the 60% biomass system, approximately 83% of the complete greenhouse gas emissions are from the power plant, whereas 17% are from the fuel supply chains. Noteworthy is, that the realized emissions are however much smaller in the 60% biomass system compared to the 100% coal system. The realized emissions from *the supply chain* in the biomass system are in fact 39% smaller. The higher emissions from the coals system supply chain can probably be explained by the fact that the extraction of coal is a more energy intensive process than harvesting of wood.

The second greatest benefit is considerably lower fossil depletion (and dependence on imported coal). The other three categories indicate only a very small potential for impact reduction and these reductions can be in the range of uncertainties. Therefore no major conclusions can be drawn from the potential reductions in terrestrial acidification, photochemical oxidant formation and particulate matter formation. However, the normalized results reveal that these impact categories are of lower relevance than climate change and fossil depletion. (16)

The analysis of environmental impacts of biomass supply indicates that wood chips are more environmentally sound option than wood pellets. Noteworthy is, that mainly peat is used as drying fuel in the pellet production. The differences between supply chains of wood chips are not so significant. Better site specific data is needed in order to draw more robust conclusion about the impacts of wood chips supply chains. (16)

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