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TALLINN UNIVERSITY OF TECHNOLOGY

Department of Civil Engineering and Architecture

THE IMPACT OF SUSTAINABLE FOREST MANAGEMENT ON THE GREENHOUSE GASES OF A WOOD PELLET PRODUCER

JÄTKUSUUTLIKU METSAMAJANDAMISE MÕJU PUIDUGRAANULITOOTJA KASVUHOONEGAASIDELE

MASTER'S THESIS

EA70LT

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(*On the reverse side of title page)*)

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material.
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TASK FOR THE FINAL PAPER

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Initial data:

- Renewable Energy Directive (2009/28/EC)
- Estonian Forest Law (RT I 2006, 30, 232)
- Forest management certification scheme standards and databases
- Interviews with Estonian pellet producers
- Sustainability policies of European energy producers

Contents of the final paper:

- Overview of sustainable forest management
- Overview of European wood based bioenergy sector
- Introduction to wood pellet production
- Data analysis and GHG calculations
- Results and conclusions

Explanation letter:

Summary in Estonian:

Tunnustatud sertifitseerimiskavade läbi sertifitseeritud puit on laialdaselt saadaval, aga kuna see on metsamajandamisüksuse ehk asukohapõhine siis selle varumiseks läbitavad vahemaad tõenäoliselt erinevad sertifitseerimata puidu omadest. On oluline teada kas need erinevused on, keskkonna kohapealt, positiivsed või negatiivsed, et hinnata kõige levinumate metsa sertifitseerimiskavade usalduslikkust ja et mõista Euroopa taastuvenergia jätkusuutlikkuse nõuete mõju Eesti biomassitootjate emissioonidele. Töö käigus kogutakse reaalseid tööstuse andmeid Eesti puidugraanulitootjatelt, mida kasutatakse lähteandmetena kasvuhoonegaaside arvutusmudelites. Kasutatavad kolmanda osapoole arvutusmudelid on loodud spetsiaalselt Euroopa puidupõhise biomassi jaoks ja nende tulemused võimaldavad määrata eelmainitud mõju ulatust ja suunda.

Summary in English:

Wood that is certified by acknowledged forest management schemes is widely available but it is forest management unit i.e. location based so the raw material sourcing distances are expected to differ from the non-certified wood supply chain parameters. Whether the differences are, from the environmental point of view, positive or negative is important to understand in order to determine the credibility of the most acknowledged forest management certification schemes as well as to evaluate the potential impact that European renewable energy sustainability requirements have on the emissions of Estonian biomass producers. This thesis will aim to evaluate this impact by using real life industry data from Estonian wood pellet producers. The resulting emissions for different raw materials are calculated with third party greenhouse gas calculators which are specifically designed for European wood based biomass. The final results will allow to determine the scale and direction of the assumed impact.

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Supervisor: **Arvo Iital** ………………………..

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Glossary of Terms and Definitions

AEBIOM – European Biomass Association

CoC - Chain of Custody

EPC – European Pellet Council

FMU – Forest Management Unit

FMP – Forest Management Plan

FSC® - Forest Stewardship Council

GHG - Greenhouse Gas

MJ – Mega Joule

NCV – Net Calorific Value

PEFC - Programme for the Endorsement of Forest Certification

PP1 – Pellet Plant One

PP2 – Pellet Plant Two

RMK – Estonian State Forest Management Centre

UNCED - The United Nations Conference on Environment and Development

RED - Renewable Energy Directive

1. Introduction

1.1 Initial Overview

The European climate and energy targets for 2020, also known as the "2020 climate and energy package", have had an impact on everyone from policy makers, goods manufacturers and energy producers to consumers, farmers and forest companies. The climate and energy package aims to reduce greenhouse gas emissions by 20%, increase the use of renewable energy and increase energy efficiency also by 20%. The first two targets are closely connected with alternative energy solutions. Alternative energy, most commonly means non-fossil renewable energy e.g. wind energy, solar energy, hydro energy, tidal energy and conditionally biofuels. There is not much debate whether wind, sun, flowing water or tides are renewable but there is little consensus over the sustainability and environmental benefits of using biofuels for energy. Still one biofuel type has received European Commission level acceptance and conditions for qualifying as a renewable energy source. This type is biomass. It can be the mass of whatever plant or crop but in the European energy sector mainly wood based biomass is used. This is largely because of the higher heat content per unit of weight but also because there is a lot wood available in Europe. Woody biomass is transported and processed in different formats the most common of them being pellets, chips, briquettes and firewood. Considering that this report is written is Estonia and Estonia is a very big wood pellet producer then the followed research will focus on woody biomass is pellet form – wood pellets.

The industrial scale demand for wood based biomass comes from coal-firing energy plants that, in light of the European energy and climate targets, have only two future options – either to close down or convert to biofuels. Some plants get closed but many start co-firing biomass with coal while gradually phasing out fossil fuels i.e. coal. This method allows them to stay in business and reduce emissions while still using their original technology. Co-firing also requires significant technological changes but these can be done gradually while staying operational. Woody biomass used for energy is considered renewable if the wood has been discarded by other industries. Meaning that material is strictly wood and forest industry leftovers that has no other alternative but to be disposed. Since energy recovery has a higher priority in waste treatment hierarchy then disposal, the burning of residual wood is considered green energy. The requirement for following the cascading principles of wood (industry priority for wood based on function) are not the only restrictions that biomass has. The environmental stakeholders are also concerned of the origin of wood that is being used in bioenergy. This means that the forests where the wood is harvested from are also under attention. Forests can be managed in different ways and unfortunately in many areas these ways are not environmentally sustainable. Therefore the controversially managed forests have been forbidden as sourcing areas for the bioenergy sector while the well managed forests receive certificates of approval. These globally acknowledged sustainable forest management certificates are forest area (location) specific and therefore forest harvesting companies have had to adjust their sourcing patterns in order to get their hands on certified wood. Different sourcing patterns mean different supply distances and potential differences in fuel consumptions. This report will aim to calculate the differences in the average sourcing distances that wood travels from certified and non-certified Estonian forests to the pellet plants under research. These values will provide input for calculating the differences in emissions related to producing pellets from both certified and non-certified wood. The final difference in the pellet plant GHG profiles will enable to evaluate the overall impact that sustainable forest management has on the pellet producer's GHG profiles and whether it is positive or negative.

The research will be based on two large Estonian pellet producers who produce approximately 35% of the country's annual 1 300 000 ton production total. The plants are located in different parts of Estonia (one in the Northern part and the other in the South) and therefore their raw material supply areas do not overlap. This is important for getting more representative and unbiased data from different sources located as sparsely as possible. The 2016 raw material shipments of both plants are analysed to determine the total volumes of certified and non-certified roundwood as well as the average sourcing distances associated with both wood types. Wood is also supplied as sawdust, chips and dry shavings but only roundwood shipments are analysed because roundwood is the only raw material stream that starts from the forest and is therefore directly influenced by the physical location of certified and non-certified forests. Sawdust, chips and dry shavings are brought from sawmills and other wood processors who's locations do not change with certification. The calculated results from the gathered data will be put through GHG calculators specifically developed for European pellet production and the results of these calculators should provide comparable emission values for pellets produced from certified and non-certified wood. This will provide grounds to answer the title question of this thesis.

1.2 Pellet Plant Profiles

1.2.1 Pellet Plant 1 (PP1)

Located in the southern part of Estonia in Võrumaa county, approximately 10 km from the Võru city. The plant was constructed in 2014 and is one of the biggest wood pellet plants in the country. They produce both industrial (energy production) and premium quality (residential use) pellets. The annual production volume and other key figures of PP1 are listed in (*Table 1)* below.

Table 1 2016 key fact and figures for pellet plant 1 (PP1) Source: pellet plant staff

Production volume	250 000 t
Raw material volume	1 800 000 m3 (270 000 t)
Raw material split	60% Roundwood, 40% Sawmill residues
Supply base average radius (all material)	70 km
Wood species used	Pine, Spruce, Birch, Alder, Aspen, Willow
Transportation method (Raw material)	Truck
Transportation method (Pellets)	Truck
Electricity Consumption	35 900 600 kWh
Biomass Consumption (heating)	45 800 t
Pellet diameter	6-8 mm
Pellet NCV (net calorific value)	18 MJ/kg

1.2.2 Pellet Plant 2 (PP2)

Located in the center of the northern part of Estonia in Järvamaa county, approximately 50 km from the Viljandi city. The plant was built in 2003 but when through reconstruction and expansion in 2015 becoming almost the same size a PP1. They produce both industrial (energy production) and premium quality (residential use) pellets. The annual production volume and other key figures of PP2 are listed in *Table 2* below.

Table 2 2016 key fact and figures for pellet plant 2 (PP2) Source: pellet plant staff

Production volume	220 000 t
Raw material volume	1 500 000 m3 (225 000 t)
Raw material split	55% Roundwood, 45% Sawmill residues
Wood species used	Pine, Spruce, Birch, Alder, Aspen, Willow
Supply base average radius (all material)	75 km
Transportation method (Raw material)	Truck
Transportation method (Pellets)	Truck
Electricity Consumption	31 200 700 kWh
Biomass Consumption (heating)	52 500 t
Pellet diameter	6-8 mm
Pellet NCV (net calorific value)	18 MJ/kg

1.3 Confidentiality Restrictions

The researched pellet plants are under the same ownership so all the provided industry information came through the same sources. Due to sensitivity of the production and raw material sourcing information the names of the pellet companies are not mentioned and only average values and ranges are used in formats that were requested by the pellet plant personnel. The industry sources confirm that the provided numbers represent accurate values for the specified reference period of 12 months (the whole 12 months of 2016).

Much of the background information of the European biomass market and the future trends was gathered during interviews with pellet plant personnel. These insights are not referenced to a source but can be confirmed by contacting the purchase manager of PP1. The author of this thesis should be approached for contact requests.

2. Sustainable Forest Management

2.1 The Concept of Forest Management

Forest management could be viewed as gardening in a farm or one's back yard. The principle is the same – to sustain a healthy habitat that would serve the purpose why the plants were planted in the first place. This could be a decorative purpose, a plan to produce food, plants or material, or maybe to improve the biodiversity or conditions of a certain area. The key activity in all cases would be regular maintenance. Whether this is collecting fruits and crops, cutting grass, clear felling or thinning forests, replanting, irrigating or even fertilizing and pesticide poisoning, the regular controlled maintenance procedures are what increase the probability of meeting the initial goal of the managed area. And like with many things that have existed for centuries these agricultural maintenance procedures have been developed to be very effective and efficient.

The goal of a forest is normally either production or protection. It is cruel to categorize nature or try to define its goal but very bluntly put, forests either protect the flora and fauna within them or are managed to produce timber and other forest products. Of course these two aspects widely overlap but production cannot happen without forest management and strict forestry rules are what make sure the production would not diminish the forests ability to protect.

Estonian State Forest Management Center (RMK) is an organization that manages all Estonian state forests (approximately 40% of all forest area) and is the largest forest management enterprise in the country. When talking about Estonian forestry then just focusing on RMK already provides a comprehensive overview of all the regional practices. The forestry activities of this large governmental entity are viewed as the example to follow by other Estonian forest management companies, putting RMK under great pressure to demonstrate exemplary implementation of the local forest law and forest management practices. RMK itself has identified their main processes of forest management to be forest resource planning, silviculture, production, marketing, forest protection and surveillance, forest improvement *(1)*.

Forest resource planning like any resource planning is calculating all the available resources, future resources and the function of those resources. In forestry this means to measure the total forest area of the FMU and the total timber growing on that area as well as to record the age of trees, the species mix, soil type and accessibility of the specific location. This information enables to develop a forest management plan (FMP) for that specific forest area which states the allowed timber cutting rates, future maintenance actions and limitations for the next 10 years. Silviculture by definition of the U.S Forest Service is *"Silviculture is the art and science* *of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society such as wildlife habitat, timber, water resources, restoration, and recreation on a sustainable basis"(2)*. In Estonian forestry the silvicultural process is reforestation or simply replanting. This is done by planting seeds or very young small trees of local species. According to RMK reforestation also includes cleaning and thinning of forests which improve the site conditions for young trees through removing weeds or fallen trees and cutting branches that block light *(3)*.

Production of timber is the main purpose of the forest industry. Production is achieved by cutting down trees that have reached a certain age and dimensions. Cutting rates have to be in accordance with the forest management plan (FMP) and have to be carried out with equipment that meets the requirements of local forest laws. Timber is harvested and cut to the required size and then shipped to the customers normally in the form of logs, chips, branches and even bark. Marketing is identified as a main forest management process for RMK but has no physical connection with the forest and therefore is not a maintenance procedure. It is important for forestry companies for finding customers but this aspect is not in any way addressed in forest laws or best management practices.

Forest protection is maintaining the good health of the forest through direct and indirect actions. The more hands on approaches would be the protection areas where cutting is forbidden or limited and removing trees with diseases or not cutting the forests too thin to prevent damage from extreme winds. Indirectly the forest life can be improved by adding nest boxes in order to invite birds to areas that require additional biological protection.

Forest surveillance is also a method of forest protection and a way to receive feedback or data directly from the source. The biggest threat to a forest is human activity. Illegal harvesting or careless use of fire have had devastating effects throughout history. During fire-risk periods the forests have to be constantly monitored from the air and from the ground to prevent the worst from happening. RMK has built roads in their forests to improve accessibility for surveillance and firefighting. Constant monitoring also provides input to future resource planning and harvesting plans.

Forest improvement is very much all of the above mentioned forest management procedures combined but according to RMK *"...forest improvement is understood as the maintenance, renewal and reconstruction of roads and drainage systems (i.e. ditch networks) (4)*. Once a forest becomes a managed forest it is reliant on continued maintenance and improvement. Keeping roads open for forest managers and controlling the water levels through drainage is important in order not to further upset the biodiversity of the habitat. Managed forests have adapted the routine and actions of the forest managers and are dependent on continued management. A flooded forest area may not survive the new severe conditions the same way as young trees may not survive without light from additional forest thinnings.

Viewing a forest management unit (FMU) as a garden under single ownership and with a uniform action plan (FMP) is an accurate parallel from everyday life. The gardener is not required to take care of the garden but when he or she does the new conditions can only be preserved with regular maintenance. This work can be done by the owner or outsourced to professionals – forestry companies. The maintenance work and harvesting can be carried out for personal use without much intervention of third party controls but once the forest products are sold for economic gain then more strict rules apply. This is not because the forest law only applies to companies selling forest companies, Estonian forest law applies to all forest areas larger to 0,5 ha *(5)*, but because the entities that purchase forest products want to make sure the permits, wood origin and legality are in order. Wood can change ownership many times until it reaches its end-user but the obligation to prove the legality and sustainability of the harvested wood is put on the shoulders of the forest owner and the forest manager. Who can be and often are the same person or legal body.

2.2 Sustainable Forest Management

Sustainable forest management means *"the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" (6)*. In other words it is a forest management system that addresses and benefits all stakeholders while being environmentally acceptable, socially considerate and economically beneficial. The added value cannot be achieved at the expense of the nature, the people who live there or the future.

In order to be able to objectively evaluate sustainability some criteria has to be established along with measurable indicators which can establish whether or not the criteria has been met.

For example in Estonia after clear felling a forest the felling site has to be renewed within a certain time by replanting small trees (reforestation). A felling site is only counted as renewed once the following criteria has been met: on one hectare there are minimum 1500 pines trees with a height over 0,5 meters or minimum 1000 spruce trees with a height over 0,5 meters or minimum 1500 oak trees with a height over 0,5 meters or minimum 1500 other species of local trees with a height over 1 meter *(7)*.

Regionally it would be expected that sustainable forest management is achieved and guaranteed by enforcing the local forest law. National laws should and often do regulate the environmental as well as socio-economic aspects of local forestry but problems arise when the local government does not monitor the implementation of the law or does not punish forest managers who break it. The legislation might be strong but if there are weak or biased control mechanisms then the law is not implemented at the most important level – the forest. Consumers or end-users have no way of knowing whether the wood they received was actually harvested and managed according to the local forest law or the documentation was just forged and approved by a corrupt government officials. Neither do they know if the country of origin has enforced a forest law that actually addresses the key aspects of sustainability. These issues have caused big problems in international timber trade and have brought bad light to the forestry industry.

The demand for a global acknowledged system for identifying sustainable forest management and sustainable wood called for a neutral third party organization that would take into account all the demands of each stakeholder and put together a system of uniform rules that could determine the sustainability of a forest in every part of the world. Thus far two systems have achieved that with global recognition: Program for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC).

2.3 Forest Management Certification

Forest certification is essentially a process that evaluates the maintenance routine of a forest manager against certain criteria. If specific criteria is met then the entity that carried out the monitoring and controlling will issue a certificate of accordance for the specific forest management unit (FMU). For every forest management scheme there is a different set of standards which have to be followed to a certain level in order to qualify for their label e.g. certificate. The credibility of each certification scheme is down to how well their standards address, implement and monitor all the sustainability aspects – environmental, economic and social – on a regional level.

The need of a forest certification phenomenon came into light at the 1992 UN Earth Summit, more officially named The United Nations Conference on Environment and Development (UNCED**)** *(8)***.** The summit, attended by world leaders, resulted in a non-legally binding document that made strong recommendations for sustainable forest management as well as resource control and species preservation. The name of this document was „*Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests*" *(9)* and it could be viewed as the document that created forest certification. By that time the concerns over forest preservation were global and the demand for a unified system was imminent. It is important to point out that on governmental level no consensus was ever reached in form of a legally binding document or set of laws but the concerned stakeholders managed to establish two standard setting bodies. FSC *(left on Figure 1)* was founded in 1993 and PEFC *(right on Figure 1)* was founded in 1999. The later addition of PEFC was due to the fact that FSC was not active in Europe and did not meet the requirements of small forest owners. At that time FSC focused more on rainforests and third world countries but today both schemes have global coverage and are viewed as fierce rivals in the forestry industry.

Figure 1 Forest certification scheme logos for FSC and PEFC Source: www.fsc.org; www.pefc.org

The main difference between FSC and PEFC is the direction of acknowledgment and implementation. PEFC accepts local forest laws and smaller certification schemes if they meet the base requirements established by PEFC. Once approved then the indicators of the regional laws are included in the European or even global standards of PEFC. Therefore the direction of this scheme is from down to up. Whereas FSC is a downwards moving scheme that approves a standard on a European or global level and then requires it to be implemented on a country level. Since forests around the world have very different regional specifics, many of which FSC does not consider, forest managers find FSC more difficult to implement.

The criteria with very similar goals but different names and indicators for both PEFC and FSC are listed below.

Specific requirements for PEFC sustainable forest management from international standard "*PEFC ST 1002:2010" (10)*:

- Criterion 1: Maintenance and appropriate enhancement of forest resources and their contribution to the global carbon cycle
- Criterion 2: Maintenance of forest ecosystem health and vitality
- Criterion 3: Maintenance and encouragement of productive functions of forests (wood and non-wood)
- Criterion 4: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems

- Criterion 5: Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water).
- Criterion 6: Maintenance of other socio-economic functions and conditions
- Criterion 7: Compliance with legal requirements

Sustainable forest management principles that apply to FSC-certified forests according to *"FSC Principles and Criteria for Forest Stewardship FSC-STD-01-001 V5-2 EN" (11)*:

- Principle 1: Compliance with laws and FSC principles
- Principle 2: Tenure and use rights and responsibilities
- Principle 3: Indigenous people's rights
- Principle 4: Community relations and worker's rights
- Principle 5: Benefits from the forest
- Principle 6: Environmental impact
- Principle 7: Management plan
- Principle 8: Monitoring and assessment
- Principle 9: Maintenance of high conservation value forests
- Principle 10: Plantations

As mentioned the requirements are similar regardless of how they are phrased and can be reduced to the three main sustainability aspects – environmental, social and economic. The real differences appear in evaluation methodology and criteria but these are not investigated further due to being irrelevant for this report. The information to take forward is that the globally most acknowledged sustainable forest management practices focus on the above listed principles and that certified forests have achieved to follow and implement them.

The FSC certified forest area in Estonia is 1 370 289 ha *(12)* while the PEFC certified area is 1 174 151 ha *(13)*. Out of total forest area of 2 300 000 ha this means 59,6% for FSC and 51% for PEFC. There are overlaps because some forest management units have decided to be both PEFC and FSC certified. One does not exclude the other. For perspective the certified forest areas in neighboring countries are listed in *Table 3* below.

Table 3 PEFC and FSC certified forest areas in the Baltic and Nordic region; Source: www.fsc.org; www.pefc.org

Country	PEFC area in ha	FSC area in ha
Latvia	1 683 604	1 010 491
Lithuania	0	1 089 532
Russia	12 039 345	43 753 261
Finland	16 571 224	1 357 012
Sweden	11 549 700	12 259 756

The reasons behind the differences between PEFC and FSC areas can only be speculated but they are mainly connected to forest manager preference, local demand and governmental grants. Although forest management certificates are location and FMU based this does not mean that certified forest areas can be allocated to a certain part of the country. In Estonia the larger forest owners and managers might own large areas of land but they are usually scattered around the whole country because so are the forests. This is well illustrated below by the forest coverage map of Estonia *(Figure 2)*.

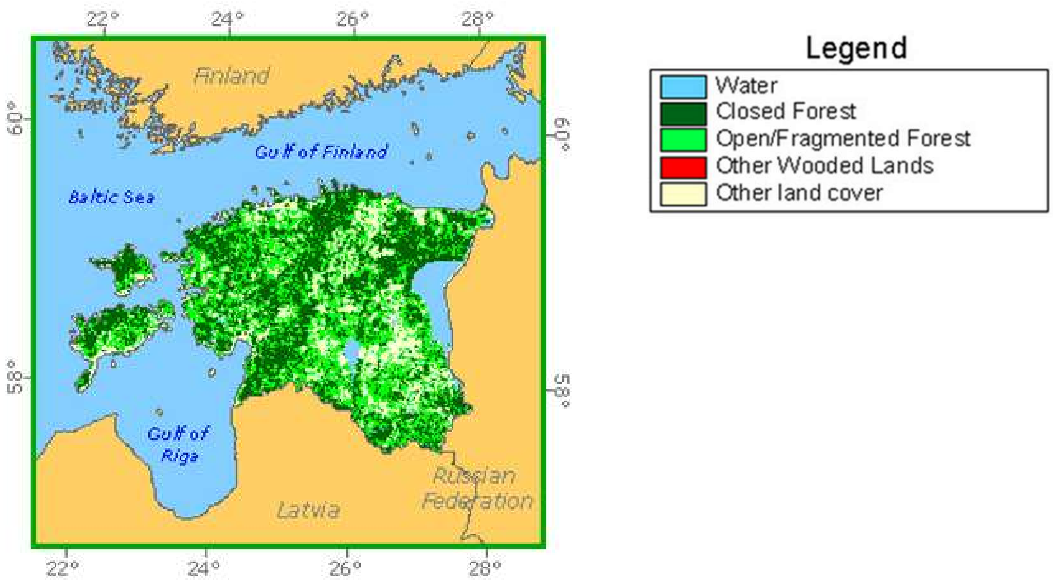


Figure 2 Indicative locations of forests in Estonia; Source: data.worldbank.org

Judging by the even coverage of forest land in Estonian, the pellet plants under study seem to have equal access to timber in their respective areas of the country.

The wood harvested from certified forests continues to carry the certification label once it is sold and therefore can be traced back to the forest site it was cut from. The specific volume of that wood is recorded and cannot be increased throughout the value chain. The forest management certification claims e.g. labels are “FSC 100%” and “100% PEFC Certified”. The certified wood volumes provide input to a chain of custody system which, simply put, is the process of getting wood out of the forest, storing, processing and then selling it with appropriate labelling and documentation.

2.4 Chain of Custody (CoC) Certification

Wood is one of the most versatile materials available and can have numerous applications. Despite the final form or application it often goes through a rigorous supply and production chain. Timber travels long distances and spends time in multiple storages where wood with different properties and origins can easily mix. The certified chain of custody systems are procedures where the risk of mixing non-certified wood with certified wood has been excluded and the traceability of wood is guaranteed up to the end user level. This is usually done by physical separation and careful volume control throughout the supply chain. Here PEFC and FSC have even fewer differences and their respective standards address the following *(14)*:

- Management system
- Material sourcing
- Material handling
- Certified material records
- Labelling requirements
- Outsourcing

Without going into further detail, the CoC system requires the sustainability aspects to be implemented to the above listed areas with emphasis on volume control and traceability. The main goal – bringing wood products to end users without disrupting any environmental, social or economic trends. The CoC claims are “FSC Mix Credit” and “100% PEFC Certified”. The chain of custody claim for PEFC is the same then its previously mentioned forest management claim.

2.5 Non-certified Controlled Wood

There will always be forest areas that are not certified. Areas that are not under regular maintenance or in fact not under any human attention at all. Such forests might be hard to access, too old to harvest, full of rare species or just owned by people who do not use them or do not know how to use timber for economic gain. More than 40% of Estonian forests are not certified but many of them are still regularly harvested. Many forest owners also cut their forests for personal firewood or construction material but these are very small volumes compared to what can be sold to the wood industry. In order to do the latter, forest owners must meet the industry's sustainability requirements. For a small forester with very limited funds, this is extremely difficult to achieve and on top of the very strict standards, certification audits also cost a lot of money. The practiced solution is to outsource the harvesting to large certified forest companies. Who simply come in with their own machinery and procedures that meet the FSC and PEFC requirements and sell the timber through their own CoC system. In such cases where the forest is not certified but the forest is harvested by a certified company, the wood is called "controlled". This is a term from the certification schemes to represent wood that is legally harvested, has a traceable origin and is processed by a competent certified company. The claims that this type of wood carries can be "FSC Controlled Wood" or "PEFC Controlled Sources". Through this method the wood can be brought into the PEFC and FSC systems and also meet the international sustainability requirements in the wood industry. Albeit controlled wood is the minimum requirement and therefore its price and demand are lower than for certified wood. For example, in the wood based bioenergy sector, controlled wood is already being phased out and is forbidden in the European energy markets from 2020.

In cases where the forest is not certified and the entity which cuts or manages the forest is also not certified, the resulting timber is considered high risk and cannot be sold between legal entities. This type of wood is used for own use or sold to private individuals with minimal paper trace. Of course this type of wood products are already forbidden in the European energy markets as well as in many other industries.

3. Wood Based Bioenergy in Europe

3.1 Biomass Used in the European Energy Sector

With the 2020 European energy and climate targets made legally binding from 2009 many energy giants were forced to seek ways for reducing their carbon emissions by increasing their renewable energy volumes and improving energy production efficiency. Huge investments were and are made to construct windfarms and install solar panels that have already significantly improved the carbon footprint of many European energy producers. The difficulty lies with the coal based power plants that still carry a big role in the European energy production. They occupy large infrastructures and are integrated to the most important residential and industrial power grids. Power networks that are not accessible from distant windfarms but require a quick solution for reducing their emissions. Furthermore these energy grids often cannot be serviced with the inconsistent energy from solar panels or wind turbines and if they can, the vast investments and construction works needed might not be economically nor environmentally feasible. Furthermore the 280 *(15)* still working coal-fired power plants employ thousands of people and closing those plants within a few years would have devastating social impacts. The best and only renewable option thus far is to gradually convert the coal plants to biomass. Coal plants require a steady flame and this can be achieved by co-firing biomass e.g. wood pellets or wood chips parallel with coal. While co-firing the power plant can be gradually modified to be able to take in more and more biomass until it can run without coal and become 100% sustainable. This method is widely used for western European coal plants that are located in densely populated areas (high energy demand but very little space).

Looking at actual companies, the Danish energy giant DONG Energy has committed to reduce their CO_2 emission by 60% towards 2020 compared to 2006 *(16)*. They have started early and are already co-firing wood pellets and wood chips with coal. In 2013 DONG Energy used 900 000 tons of wood pellets and 300 000 tons of wood chips and towards 2020 they expect these numbers to increase to 1 800 000 tons and 1 100 000 tons respectively *(17)*. This is already a massive increase in demand initiated by one single company. The pellets plants researched in this report would need 7-8 years to produce the volume of pellets that DONG Energy needs annually. Another energy giant from the UK, Drax Power Station, is currently Europe's largest wood pellet consumer with an annual demand of over 6 500 000 tons of wood pellets *(18)*. This was with only 2 of their 3 production units converted to biomass. Within a few years Drax expects to also convert their third production unit to biomass reaching an annual demand of 8 000 000 tons of wood pellets. So taking into account the many of the 280 still working coal plants that will convert to biomass as well as the future unimaginable amounts of DONG Energy and Drax Power Station it is clear to say that the European wood pellet demand is high and rapidly increasing.

There of course other shapes of woody biomass. On top of wood chips that were mentioned before, there are briquettes and firewood. Wood chips are just wood industry leftovers that have been chipped and then dried to reach the desired moisture content. No molding or further treatment takes place. Briquettes are essentially big wood pellets that are 20-60 mm in diameter and 40-160 mm in length and firewood is the most traditional chopped roundwood that is not processed in any way and is used in every household with a fireplace. Out of all the biomass types only wood pellets and chips have industrial scale use and demand. The main advantage of wood pellets is that they are the most durable and easiest to handle while having the highest heat content per unit of weight.

3.2 Wood pellets

Heat and pressure compressed cylindrical granules of low quality wood are called wood pellets. The most common wood pellets have a 6-8 mm diameter and range between 20-40 mm in length. They are produced from crushed wood industry residues that are force dried and then milled to pellets. With appropriate equipment and production methods pellets do not require any glue or additives to stay intact. Heated wood lignin acts as a natural glue and strengthens the pellet after it is shaped and cooled down. The higher quality premium wood pellets are lighter in color then industrial pellets *(Figure 3)* because they are produced mainly from sawmill residues and debarked timber. The industrial pellets are produced by mixing all wood available to the pellet producer without segregating different qualities. Like the name indicates the industrial pellets are mainly used by energy producers who generate biomass heat and electricity for grid use. The premium pellets are used in small households in stoves or boilers for extra heat during extreme colds.

Figure 3 Premium and industrial quality wood pellets; Source: www.wisegeek.net

Wood pellets are produced from all types of wood and forest industry leftovers. The only excluded type is chemically treated wood. Whatever is discarded from production is often used as heating material for the pellet plant dryers. The wood species used in pellet production are characteristic to the forests located in close proximity of the pellet producer.

3.2.1 Premium and Industrial Quality Pellets

According to the wood pellet quality system *"ENplus"* established by the European Pellet Council (EPC) a pellet meets the requirements of the European market if it meets the criteria from the ENplus handbook *(Figure 4, next page).* The premium quality pellets meet the *"ENplus A1"* parameters and industrial pellets meet the *"ENplus A2"* and *"ENplus B"* parameters. The real difference is only in ash content and mechanical durability.

Property	Unit	EN*plus* A1	EN*plus* A2	EN*plus* B	Testing standard [11]
Diameter	mm	6 ± 1 or 8 ± 1			ISO 17829
Length	mm	3,15 < L ≤ 40 [4]			ISO 17829
Moisture	w-% [2]	≤ 10			ISO 18134
Ash	w-% [3]	≤ 0,7	≤ 1,2	≤ 2,0	ISO 18122
Mechanical Durability	w-% [2]	≥ 98,0 [5]	≥ 97,5 [5]		ISO 17831-1
Fines (< 3,15 mm)	w-% [2]	≤ 1,0 [6] (≤ 0,5 [7])			ISO 18846
Temperature of pellets	°C	≤ 40 [8]			
Net Calorific Value	kWh/kg [2]	≥ 4,6 [9]			ISO 18125
Bulk Density	kg/m^3 [2]	600 ≤ BD ≤ 750			ISO 17828

Figure 4 fragment from ENplus handbook version 3 pellet quality table; Source: ENplus

The higher mechanical durability for premium pellets is necessary because they are mainly used in small households and sold in hardware stores so the pellets usually change hands many times and spend longer periods in storage. For constant movement and for staying in one piece the higher durability value is essential. The low ash requirement is because small household have very basic cleaning and exhaust systems for their stoves and higher ash contents would mean these could get clogged up very quickly. Industrial quality pellets are almost always shipped in large bulk volumes and almost immediately burned in large boilers with constant filtration. Therefore the requirements for pellet strength and ash content can be lower.

3.2.2 Wood pellets in Estonia

In 2015 Estonia's pellet producers produced 972 400 tons of wood pellets *(19)* the statistics for 2016 are not yet final but the industry estimates the annual volume to be in the 1 200 000 – 1 300 000 ton range. This makes Estonia the 4th biggest pellet producer in Europe, behind Germany (2,1 million tons), Sweden and Latvia, and 7th in the world *(20).* The two larger producers outside of Europe are USA and Canada. The Estonian total production is divided between 7 larger producers: Warmeston OÜ, Ebavere Graanul OÜ, Purutuli OÜ, Osula Graanul OÜ, Graanul Invest AS, Stora Enso AS and Helme Graanul OÜ. There are also many smaller producers who sell to the local markets but don't really register pellet production as their primary activity. The regional pellet market is small, less than 20% of all Estonian pellets are sold locally. Because of high production volumes but small local demand, Estonia is the world's 4th largest exporter of wood pellets behind USA (4,5-5 million tons), Canada and Latvia *(21).* In the 20-25 million ton European wood pellet market (consumption changes with average temperatures) the biggest consumers are United Kingdom, Italy, Denmark, Germany and

Sweden. The Estonian 2016 wood pellet export was mainly divided between United Kingdom and Denmark, both markets purchasing only industrial quality products.

The species used in Estonian pellet production are the most common species of regional forestry: spruce (picea abies), pine (pinus sylvestris), gray alder (alnus incana), black alder (alnus glutinosa), willow (salix), aspen (populus tremula) and birch (betula).

3.3 Importance of Certification in the European Bioenergy Sector

The sustainability of using woody biomass for heat and power has been widely debated and the consensus between all stakeholders has resulted in very strict criteria which has to be met before the biomass produced energy qualifies as renewable energy. This is a very important aspect of the whole bioenergy sector because renewable fuels also qualify for governmental subsidies. Wood pellets can economically only compete with fossil fuels with the support of subsidies. The agreed criteria for wood based renewable bioenergy is reliant on forest certification schemes which were introduced and explained earlier in this report (2. Sustainable Forest Management). FSC and PEFC forest certification schemes have established themselves as the main indicators of sustainable wood and due to global recognition their standard requirements have been copied into the qualification criteria for renewable bioenergy subsidies.

FSC and PEFC are mentioned as base requirements in the Netherlands Enterprise Agency's renewable bioenergy grants system *"SDE+"*. The governmental regulator of gas and electricity in Great Britan has also listed FSC and PEFC criteria in the biomass sustainability requirements for energy stations eligible for grants. The same criteria has also been established by the Danish, Swedish, Finnish, French and German governments. As can be seen the European powers have already decided on the sustainability requirements and policy of the biomass generated energy. Therefore first indications of forest certification requirements have been seen in the European Commission's Renewable Energy Directive (RED). On November 30th of 2016 the commission itself proposed for a revised RED, also known as RED II, which includes two sustainability requirements taken straight from a forest management certification standard *(22)*:

- Biofuels cannot be grown in areas converted from land with previously high carbon stock such as wetlands or forests
- Biofuels cannot be produced from raw materials obtained from land with high biodiversity such as primary forests or highly biodiverse grasslands.

Without further explaining these forestry requirements it is safe to conclude that in order for wood pellets to qualify as renewable energy in the European Union they have to be produced from wood that originates from PEFC or FSC certified forests. This reality has been one of the main drivers behind the initial task of this thesis.

3.4 Importance of the Pellet Producer’s GHG Profile in the European Bioenergy Sector

One main part of the European 2020 energy and climate targets is reducing the GHG emissions. While burning wood pellets or other renewable fuels for energy is already doing that on a very large scale, there is still room for improvement. While the energy production efficiency is every energy producers own responsibility then the emissions generated during biomass production are not. This however does not mean that the pellet production emissions do not affect their overall performance indicators – greenhouse savings. Referring back to the sustainability criteria for biofuels stated in the RED there is a point about greenhouse gas savings that clearly states that the biomass production emissions are taken into account *(23)*:

- To be considered sustainable, biofuels must achieve greenhouse gas savings of at least 35% in comparison to fossil fuels. This savings requirement rises to 50% in 2017. In 2018, it rises again to 60% but only for new production plants. All life cycle emissions are taken into account when calculating greenhouse gas savings. This includes emissions from cultivation, processing, and transport.

The raw material supply, production and transportation chain of every pellet producer involves the use of fossil fuels or fossil fuel generated electricity. These values have to be carefully recorded and made available to the end users – energy producers. Based on this data and the renewable energy amounts produced from the associated wood pellets (or other biomass) the governmental regulators calculate the final amount of subsidy that the energy producer is eligible for. Very simply put the calculation goes as follows:

(GHG emissions saved by using renewable biomass – GHG emission generated throughout the supply chain) * Monetary value of unit of saved emissions = Subsidy for energy producer.

Through this very simple green energy supporting mechanism the GHG performance of a pellet producer is suddenly under the focus of large European energy producers and a factor in renewable energy subsidy schemes. This aspect of the bioenergy market was the other main driver behind the initial task of this thesis.

4. Wood Pellet Value Chain

The whole value chain of a wood pellet producer can be divided into three sections as illustrated *(Figure 5)* and explained below (4.1- 4.3).

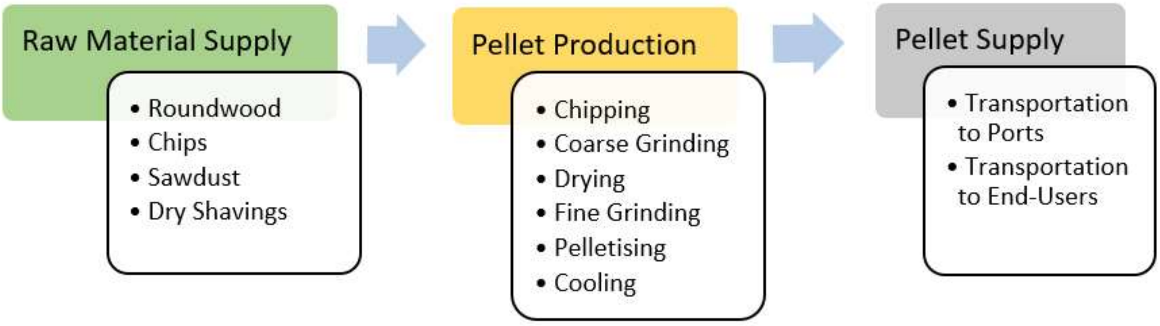


Figure 5 Common value chain of a wood pellet producer

There can of course be differences in the sub-sections but the general three sections are always the same. The exact sub-division presented above and explained below is based on the researched Estonian pellet plants PP1 and PP2.

4.1 Raw Material Supply Chains

The four main raw material categories roundwood, chips, sawdust *(Figure 6)* and dry shavings are brought to pellet producers from forests, sawmills and secondary producers (furniture manufacturers, wooden component manufacturers) respectively. The chips, sawdust and dry shavings are also called wood industry residues.

Figure 6 Pellet production raw material types: sawdust, roundwood, chips; Source: graanulinvest.com

Roundwood is the natural shape of wood that has been stripped from branches and cut to logs. This material comes straight from the forest harvesting sites usually in 3-5 meter logs with a diameter from 5-40 centimeters. Wood pellet plants are not diameter or quality sensitive and can accept roundwood from all species in all shapes and sizes. The pellet producers do not compete with sawmills for the same roundwood and only buy logs that have already been rejected by the sawmill industry. Even crooked or rotten roundwood is in most cases an acceptable raw material for producing wood pellets. The wood is being transported from the forests to the pellet plants with 40 ton diesel trucks which on average travel less than 70 km per roundwood shipment (one way). This sourcing distance is the maximum range that is still economically viable for a roundwood supplier to operate in. The diesel consumption of roundwood transport is taken into account when calculating the GHG profile of a wood pellet plant and that is why the physical location of certified forests has an impact on the pellet plant emission profile.

The industry residues come to the pellet plant straight from the sawmills and other wood production units. The transportation distances always remain the same because the locations do not change. Therefore the sourcing distances for industrial residues are not impacted by sustainable forest management because certified and non-certified wood always travels the exact same distance. The raw material supply chains of a sawmill are also affected by the locations of certified forests but this is outside of the pellet plant's scope. The emissions connected with pellet production are the emissions from transporting the residues from the sawmill to the pellet plant.

Wood chips are the byproduct of sawmill upstream production processes where the excess wood gets removed before the log is cut to beams and other timber products. Wood chips vary from 20-70 mm in size and 2-10 mm in thickness. Sawdust is generated at sawmill downstream processes where the log is being cut. It is finer in fraction but very similar in moisture content ranging between 18-50%. Dry shavings are, like the name indicates, with a lower moisture content then the other residues 12-18%. They are the byproduct of furniture manufacturers and producers who further process sawn timber e.g. beams and boards.

4.2 Pellet Production Chain

The production chain begins with accepting the raw material shipments of chips, roundwood (log wood), sawdust or dry shavings at the pellet plant gate and offloading them to the type-specific storage area. From there frontloaders take the material to the production line where there is a different starting point for each material type *(Figure 7).*

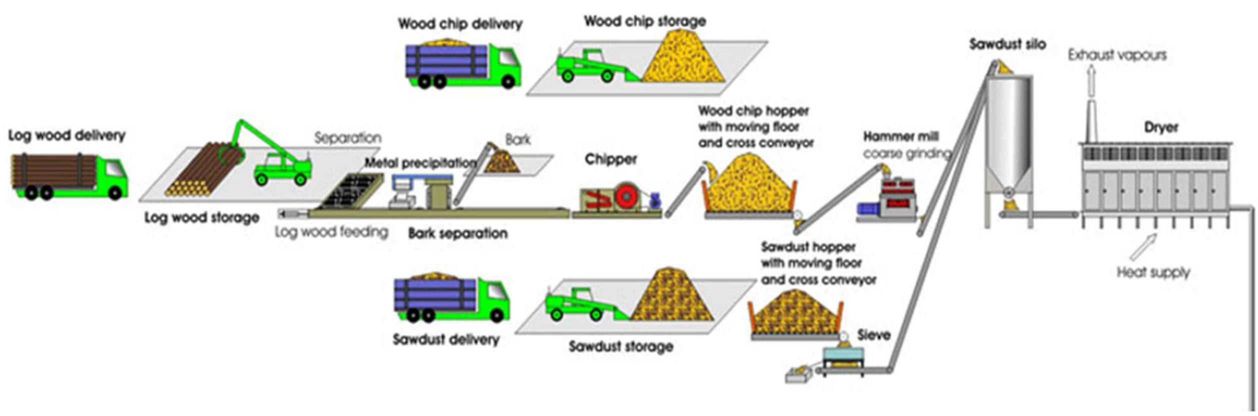


Figure 7 Pellet production chain from raw material input to drying; Source: www.bios-bioenergy.at

Roundwood gets placed on a debarking line where bark is separated from the wood. The chemical properties of bark are not suitable for pellet production and therefore bark is removed from the supply line and directed to dryer heat generation. After debarking the wood gets chipper to small particles – chips. The chips are collected into a large hopper/silo and mixed with other raw material that was already received as chips. All chips are forwarded to a hammer mill to be coarsely grinded into sawdust. The resulting sawdust is collected into a large silo where it is mixed with other raw material that was already received as sawdust. All sawdust, regardless of its original input form, is force dried until the moisture content is 18 %. The dryer heat supply is from burnt biomass (bark from debarking line). The resulting dried material is conveyed to another silo where it is mixed with other raw material that was accepted as dry shavings *(Figure 8).*

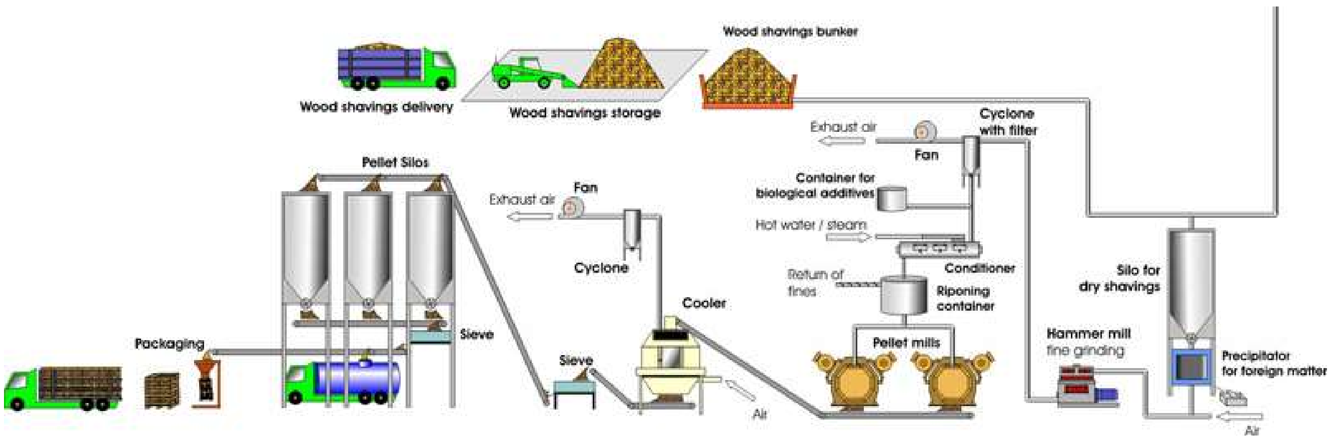


Figure 8 Pellet plant production chain from dry shavings storage to pellet supply; Source: www.bios-bioenergy.at

The dry material gets put through another hammer mill for finer grinding also known as "flaking". After flaking comes the section in pellet production where it is possible to add additives to increase the durability or to steam condition the material in case it is too dry or cold. Once the desired material mixture as well as moisture content and temperature is reached the material goes into pelletising. This is a high pressure centrifugal process happening in the pellet mills where biomass gets pushed through dyes to give it the cylindrical shape and smooth surface. On the other side of the dyes the pellet gets cut off and forwarded to the coolers. Once cooled the pellets achieve their required durability and can be moved to storage ready for transportation.

4.3 Pellet Supply Chain

The majority of wood pellets get transported via ocean transport but very few pellet plants are located next to water. The common practice is to use intermediate storage for building up volume at before a large order is filled. This intermediate storage is located at the ports in close proximity of the quayside to enable quick vessel loading. The pellets get transported from production units to intermediate port storage with 40t trucks and from thereon to destination ports with 3000-50 000t vessels.

The other supply methods for wood pellets are direct truck transport from the pellet plant to the customer or in case of packed pellets the pellets are transported via truck to distributors who arrange their own logistics towards end-users.

The part of pellet supply transportation that is arranged by the pellet plant i.e. trucking to intermediate storage is accounted in the GHG profile of a pellet plant. The vessel transport is usually arranged by the end-users and is therefore accounted into their GHG calculations. Regardless how the pellet supply of the researched pellet plants is arranged the product supply emission values are ignored in this report because they are not affected by certified wood in any way.

5. Greenhouse Gas (GHG) Analysis

The same calculation methodology is used for both researched pellet plants. Total volume is taken from the 2016 records and inserted to third party GHG calculators a long with production volume and energy consumption figures. It is important to keep in mind that the calculations below focus only on roundwood because it is the only raw material supply chain that is affected by the physical location of certified and non-certified wood.

5.1 GHG Calculator

There are numerous different ways for calculating the greenhouse gases along a supply chain of a wood pellet producer. There are global averages values, European statistics and even country specific methods to choose from and equally as many different programs or preset calculators. Since this report is focusing on Estonian pellet producers and the European bioenergy market then for credible results a widely acknowledged European GHG calculator was chosen – EPC GHG calculator. This calculator was developed by the European Pellet Council (EPC) which is a branch of the European Biomass Association (AEBIOM) that focuses on the European wood pellets market. According to EPC itself they are *"a platform for the pellet sector to discuss the issues that need to be managed in the transition from a niche product to a major energy commodity. These issues include the standardisation and certification of pellet quality, safety, security of supply, education and training, and the quality of pellet-using devices"(24).* Their GHG calculator was developed specifically for calculating the CO_2 emissions of a wood pellet production chain in a uniform, accurate and acknowledged way. This calculator, which is publicly available on EPC website http://www.enplus-pellets.eu/downloads/ghg-calculator/, is accepted by all European energy producers, auditors and certification schemes. The calculator also estimates the CO_2 savings compared to emissions from fossil energy carriers like oil, gas, coal etc. It is constantly improved and updated whenever the requirements, average data or emission factors change.

For the analysis made in this report version 1.2 of the EPC calculator was used. It was published on the 6th of February 2017 and at the time of this thesis it is the latest available version. The EPC calculator relies on European emission factors and default values from the following sources *(25)*:

- European Commission (2010): Report on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling, COM(2010)11
- Joint Research Center of the European Commission (2010): Impact assessment accompanying the report on biomass sustainability (SEC(2010)65)
- JEC (2011): Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context WTT APPENDIX 1 Description of individual processes and detailed input data
- BioGrace list of standard values
- BioGrace list of additional standard values

- Austrian Institute of Construction Engineering (OiB) (2011): Energieeinsparung und Wärmeschutz
- Ecoinvent v2
- Globales Emissions-Modell Integrierter Systeme (GEMIS) Version 4.7

The calculator has three main areas: raw material supply, production and packaging. Since pellet plant 1 and pellet plant 2 produce and sell all their pellets in bulk the packaging section is not relevant and will be ignored in the analysis. The supply section *(Figure 9)* requires the annual raw material amounts and average distances to be allocated to each different transportation method.

Energy consumption related to raw material supply			
Transport / biomass supply	**[t/a]**	**average transport distance [km]**	**[gCO_{2-eq}]**
Raw material produced at the site of the pellet plant as byproduct			No contribution
Raw material transported from other site (incl. transport			
40 t truck (Diesel)			0
12 t truck (Diesel)			0
Coastal/river shipping wood chips			0
Ocean going bulk carrier			0
Rail transport (European electricity mix)			0
Total CO2 from biomass supply			0

Figure 9 the raw material supply section of the EPC GHG calculator (without input data)

In case of the Estonian pellet plants all raw material is brought in with 40 t trucks that have an emission factor of 81,95 gCO_{2-eq}/t.km. The production section *(Figure 10)* records the electric and heat energy used on-site for producing pellets.

Energy consumption related for pellet on-site production			
Pellets prodcution - electricity consumption			
Total electricity consumption per year		[kWh]	0
CO2 emissions as stated in bill		[gCO_2/kWh]	0,00
Total annual GHG emissions from electricity consumption			0
Pellets production - energy consumed for heat		**[MJ]**	**[gCO_{2-eq}]**
Woody Biomass from residues (wood, bark,		0	0
Heating oil [1000l]		0	0
Natural gas [kWh]		0	0
Hard coal [t]		0	0
Lignite [t]		0	0
District heat (renewables) [kWh]		0	0
District heat (fossil) [kWh]		0	0
Total annual emissions for heat			0

Figure 10 the pellet production on-site electric and heat energy consumption section of the EPC GHG calculator (without input data)

The average emission factor for Estonian grid electricity is stated by the calculator to be 1156,61 $gCO_{2\text{-eq}}$/kWh. The source of heat energy used for drying raw material, for these pellets plants, is wood residues and bark. The emission factor for woody biomass is calculated though heat content 1 $gCO_{2\text{-eq}}$/MJ which is 18 MJ/kg. So for example 1000 kg of wood residues would result in 1000 kg*18 MJ/kg* 1 $gCO_{2\text{-eq}}$/MJ =18000 $gCO_{2\text{-eq}}$. The production section also has an option to include emissions related to additives like corn, grain and vegetable oil but this is not applicable for the pellet plants in question and therefore is ignored. The results *(Figure 11)* are given in total amount as well as for kg of pellets and MJ of pellets. Like mentioned above a comparison is also made against reference fossil fuel carriers.

Results		
Total emissions	0	[$gCO_{2\text{-eq}}$]
Total emissions without packaging	0	[$gCO_{2\text{-eq}}$]
Total emissions per MJ bulk pellets	#DIV/0!	[$gCO_{2\text{-eq}}$/MJ]
Total emissions per kg bulk pellets	#DIV/0!	[$gCO_{2\text{-eq}}$/kg]
Total emissions per MJ packed pellets	#DIV/0!	[$gCO_{2\text{-eq}}$/MJ]
Total emissions per kg packed pellets	#DIV/0!	[$gCO_{2\text{-eq}}$/kg]

CO2 emission reduction based on real values	**GHG reduction with bulk pellets**	**GHG reduction with baged pellets**
Reference energy carrier		
Heating oil	**#DIV/0!**	**#DIV/0!**
Natural gas (EU mix quality)	**#DIV/0!**	**#DIV/0!**
Diesel	**#DIV/0!**	**#DIV/0!**
Hard coal	**#DIV/0!**	**#DIV/0!**
Lignite	**#DIV/0!**	**#DIV/0!**
Disctrict heat (non-renewable)	**#DIV/0!**	**#DIV/0!**

Figure 11 The results and emission reduction comparison section of the EPC GHG calculator (without input data)

The GHG calculator demonstrated above is a simple tool for clients or end-users to compare the performance and efficiency of different pellet producers. Similarly a pellet producer can evaluate itself as well as the emissions related to a specific raw material stream i.e. supply chain. This possibility is now used for certified and non-certified roundwood in pellet plants 1 and 2.

5.2 GHG Data Input

Every single raw material shipment accepted by both pellet plants carries a document called the *"waybill"*. For residues coming from sawmills and furniture manufacturers the waybill is used to record (in addition to legal information) the production unit it was shipped from, the volume it carries, the distance it travelled and the certification details. For roundwood the waybills include all the same information already mentioned, as well as the harvesting site details and reference to harvesting permits (see roundwood waybill in *Appendix 1)*. The information from the waybills is automatically recorded by both pellet plants and the data for roundwood from their 2016 archive *(Figure 12)* was used as input data for the analysis made in this report. The production, raw material split and energy consumption key figures were provided by pellet plant responsible personnel.

The data from 11 817 waybills for PP1 and 12 222 for PP2 was processed to calculate the following values for certified and non-certified wood:

- Total volume (t)
- Average volume of each shipment (t)
- Total distance (km)
- Average distance of each shipment (km)

Kuupäev	Koorma km	Kogus	Sertifikaadi (materjali) tüüp	Sertifikaadi nr
02.01.2016	90,00	31,130	PEFC_FC	TT-PEFC-FM006 100% PEFC Certified
02.01.2016	90,00	32,160	PEFC_FC	TT-PEFC-FM006 100% PEFC Certified
02.01.2016	90,00	31,120	PEFC_FC	TT-PEFC-FM006 100% PEFC Certified
02.01.2016	90,00	32,120	PEFC_FC	TT-PEFC-FM006 100% PEFC Certified

Figure 12 fragment from waybill data archive of pellet plant 2 (in Estonian)

The shipments counted as certified wood had “100 PEFC Certified” or “FSC 100%” written in their certificate column. The shipments of non-certified wood had either no claim or the labels “PEFC Controlled Sources” or “FSC Controlled” written in the certificate column.

The total and average values from data as well as the GHG results for both types of roundwood are presented below.

5.3 Pellet Plant GHG Profiles

5.3.1 Pellet Plant 1 (PP1)

The total volume of certified and non-certified wood and the average travelled distances were calculated using the raw material waybill data from PP1 archive. The pellet plant’s annual production volume, pellet calorific value as well as production energy consumption were taken from the 2016 SAR report of PP1, provided by the pellet plant personnel. These values as well as the key facts used as input data for GHG calculator are presented in *Table 4* on the next page.

Table 4 PP1 key facts and figures with waybills data analysis results; Source: Pellet plant 1

Production volume	250 000 t
Raw material volume	1 800 000 m3 (270 000 t)
Raw material split	60% Roundwood, 40% Sawmill residues
Supply base average radius (all material)	70 km
Wood species used	Pine, Spruce, Birch, Alder, Aspen, Willow
Transportation method (Raw material)	Truck
Transportation method (Pellets)	Truck
Electricity Consumption	35 900 600 kWh
Biomass Consumption (heating)	45 800 t
Pellet diameter	6-8 mm
Pellet NCV	18 MJ/kg
Total volume of roundwood	99 845,31 t (205 741,84 tm)*
Total volume of certified wood	79 056,97 t (79,18 % of total roundwood)
Total volume of non-certified wood	20 788,33 t (20,82 % of total roundwood)
Average load of certified wood	11,10 t
Average load of non-certified wood	12,68 t
Average distance of certified wood	43,85 km
Average distance of non-certified wood	40,17 km

**initial roundwood volume of solid cubic meters "tm" converted to tons, coefficient 0,4852*

It is important to point out that since the calculations focus on roundwood then the calculator input data for annual production volume and energy consumption has to be reduced by 40% to only represent the values associated with processing the specified raw material type (raw material split 60% roundwood and 40% sawmill residues) and these results are further reduced to represent the percentage of either certified (79,18% of all roundwood) or non-certified wood (20,82 % of all roundwood). It should also be noted that the total volume calculated from the raw material archive (99 845,31 t) does not correspond to the 60% indicated in the pellet plant's key facts and figures. This is due to the fact that the raw material split is calculated after all production feedstock in converted to the same weight units. These conversion factors are only known to the production unit itself. The conversion factor provided for converting the roundwood solid cubic meters (tm) to tons is 0,4852. The actual values used for GHG calculations for PP1 are therefore as follows.

Table 5 PP1 certified and non-certified wood input values for the GHG calculator

	Certified wood	**Non-certified wood**
Production volume	118 770 t	31 230 t
NCV	18 MJ/kg	18 MJ/kg
Roundwood volume	79 056,97 t	20 788,33 t
Average distance	43,85 km	40,17 km
Electricity consumption	17 055 657 kWh	4 484 703 kWh
Biomass consumption (heating)	21 759 t	5 721 t

The values above are inserted to the corresponding areas of the EPC GHG calculator which are:

- Production volume => *"Pellets"*
- Net calorific value => *"Energy content: Net Calorific Value (NCV)"*
- Rounwood volume => *"40t truck (Diesel)"* (the total volume transported with a 40 t diesel powered truck).
- Average Distance => *"average transport distance (km)"*
- Electricity consumption => *"Total electricity consumption per year"*
- Biomass consumption (heating) => *"Woody Biomass from residues (t)"*

The GHG calculator generated emission values in grams of CO_2 equivalents (gCO_{2-eq}) for whole production, unit of weight (kg) and energy (MJ) for PP1 certified and non-certified wood are presented in the following table (*Table 6*).

Table 6 GHG calculator emission results for PP1

	Certified wood	**Non-certified wood**
Total emissions	20 402 491 265 gCO_{2-eq}	5 358 470 088 gCO_{2-eq}
Total emissions per MJ bulk pellets	9,54 gCO_{2-eq}	9,53 gCO_{2-eq}
Total emission per kg bulk pellets	171,78 gCO_{2-eq}	171,58 gCO_{2-eq}

The GHG calculator screenshots and full results for PP1 can we viewed from *Appendix 2*.

5.3.2 Pellet Plant 2 (PP2)

The total volume of certified and non-certified wood and the average travelled distances for pellet plant 2 were calculated exactly the same way as for the previous plant using the raw material waybill historic data. The same source (2016 SAR report of PP2) was used for the second pellet plant's annual production volume, pellet calorific value as well as production energy consumption. These values as well as the key facts used as input data for GHG calculator are presented in *Table 7* below.

Table 7 PP2 key facts and figures with waybills data analysis results; Source: Pellet plant 2

Production volume	220 000 t
Raw material volume	1 500 000 m3 (225 000 t)
Raw material split	55% Roundwood, 45% Sawmill residues
Supply base average radius (all material)	75 km
Wood species used	Pine, Spruce, Birch, Alder, Aspen, Willow
Transportation method (Raw material)	Truck
Transportation method (Pellets)	Truck
Electricity Consumption	31 200 700 kWh
Biomass Consumption (heating)	52 800 t
Pellet diameter	6-8 mm
Pellet NCV	18 MJ/kg
Total volume of roundwood	131 535,79 t (271 043,45 tm)*
Total volume of certified wood	97 332 t (74 % of total roundwood)
Total volume of non-certified wood	34 203,79 t (26 % of total roundwood)
Average load of certified wood	16,91 t
Average load of non-certified wood	25,92 t
Average distance of certified wood	47,45 km
Average distance of non-certified wood	33,29 km

**initial roundwood volume of solid cubic meters "tm" converted to tons, coefficient 0,4852*

It is important to repeat that since the calculations focus on roundwood then the calculator input data for annual production volume and energy consumption has to be reduced by 45% to only represent the values associated with processing the specified raw material type (raw material split 55% roundwood and 45% sawmill residues) and these results are further reduced to represent the percentage of either certified (74% of all roundwood) or non-certified wood (26 % of all roundwood). It should also be noted that the total volume calculated from the raw material archive (271 043,45 tm) does not correspond to the 55 % indicated in the pellet plant's key facts and figures. This is due to the fact that the raw material split is calculated after all production feedstock in converted to the same weight units. These conversion factors are only known to the production unit itself. The conversion factor provided for converting the roundwood solid cubic meters (tm) to tons is 0,4852. The actual values used for GHG calculations for PP2 are therefore as follows.

Table 8 PP2 certified and non-certified wood input values for the GHG calculator

	Certified wood	**Non-certified wood**
Production volume	89 540 t	31 460 t
NCV	18 MJ/kg	18 MJ/kg
Roundwood volume	97 332 t	34 203,79 t
Average distance	47,45 km	33,28 km
Electricity consumption	12 698 684,9 kWh	4 461 700kWh
Biomass consumption (heating)	21 368 t	7 508 t

The values above are inserted to the corresponding areas of the EPC GHG calculator in exactly the same way as explained for PP1 above (6.3.1).

The GHG calculator generated emission values in grams of CO_2 equivalents (gCO_{2-eq}) for unit of weight (kg) and energy (MJ) for PP2 certified and non-certified wood are presented in the following table (*Table 9*).

Table 9 GHG calculator emission results for PP2

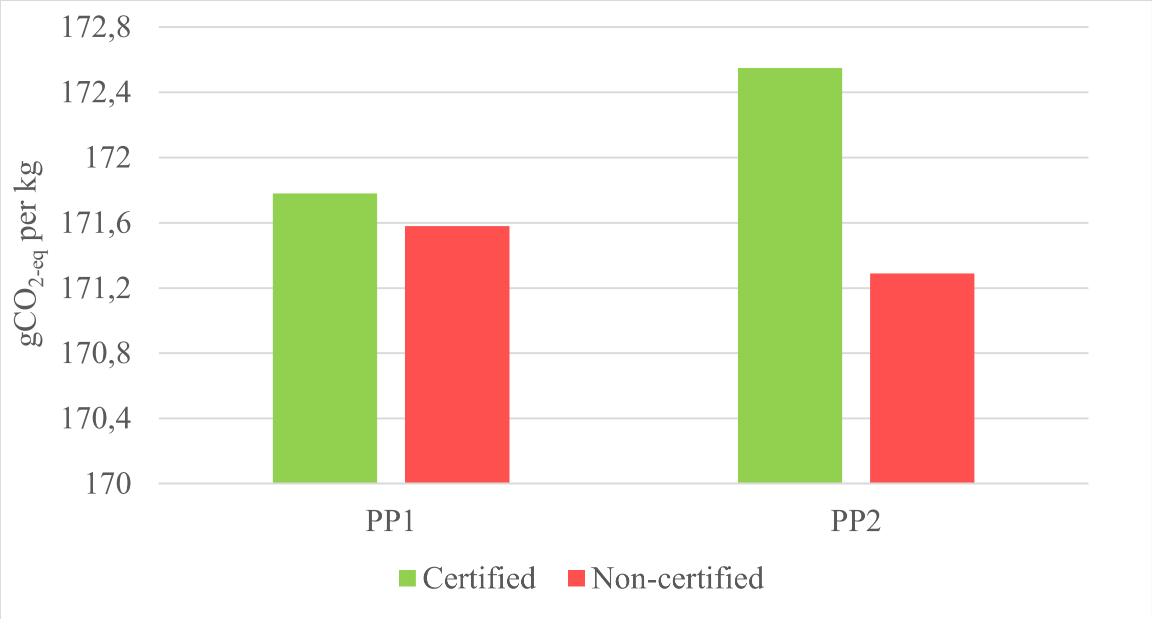
	Certified wood	**Non-certified wood**
Total emissions	15 450 519 118 gCO_{2-eq}	5 388 893 837 gCO_{2-eq}
Total emissions per MJ bulk pellets	9,59 gCO_{2-eq}	9,52 gCO_{2-eq}
Total emission per kg bulk pellets	172,55 gCO_{2-eq}	171,29 gCO_{2-eq}

The GHG calculator screenshots and full results for PP2 can we viewed from *Appendix 3*.

5.4 Results Analysis and Observations

It is expectable that the total emissions are higher for material that dominates the raw material supply. For both pellet plant the certified material makes up the large majority of all roundwood (79,18% for PP1 and 74% for PP2). The results become comparable only after dividing the emissions with the volume of produced pellets. The results can be presented per unit of weight (kg) or energy (MJ) but from the perspective of the pellet producer the weight aspect is more relevant if not more important. Numerically the differences do not seem to have significant differences but putting the emissions for pellet kilograms next to each other (*Figure 13*) indicates a tendency towards higher emissions for pellets produced from certified pellets.

Figure 13 Comparison between PP1 and PP2 emissions per kg of pellets produced from certified and non-certified wood



The emissions presented in grams of CO_2 equivalents range from 171,78 to 172,55 per kilogram of product for certified wood and 171,29 to 171,58 for non-certified wood. Pellet plant 2 shows higher emissions for certified wood 172,55 $gCO_{2\text{-}eq}$/kg but lower emissions 171,29 $gCO_{2\text{-}eq}$/kg for non-certified wood compared to the 171,78 and 171,58 of PP1. Knowing where PP2 is located it can be said from this data that the Northern part of Estonia has less certified forests then the Southern part of PP1. Southern roundwood suppliers are driving further to source certified wood. This was also supported by the higher average distance for certified wood which was 47,45 km for PP2 compared to the 43,85 km of PP1. The larger difference between emission values of 1,26 $gCO_{2\text{-}eq}$/kg can also be seen in the difference between PP2 average distances of both roundwood types – 14,16 km. The same differences for PP1 are 0,20 $gCO_{2\text{-}eq}$/kg and 3,68 km respectively. Knowing that both pellets plants are technically very similar then these results have established that sourcing distances have an impact on GHG emissions.

As already mentioned in this report the European wood pellet volumes are huge and in order to put the results into more industrial scale the weight unit should be increased to tons. This gives us a 200 $gCO_{2\text{-}eq}$/t emission value in PP1 and 1260 $gCO_{2\text{-}eq}$/t in PP2. Applying these values now to the annual volumes of pellets produced from roundwood by each plant (*Table 10)* would provide perspective of the potential impact that the certification requirements can have on a single wood pellet plant in Estonia.

Table 10 Roundwood pellet production potential emissions based on GHG differences

	Total Roundwood Pellets	**Potential Emissions**
PP1	150 000 t	30 000 000 $gCO_{2\text{-eq}}$
PP2	121 000 t	152 460 000 $gCO_{2\text{-eq}}$
Weighted Average	135 500 t	91 232 150 $gCO_{2\text{-eq}}$

The scale of these calculated potential emissions is comparable to the annual emissions of 20 passenger vehicles *(26)* in case of PP1, 100 vehicles in case of PP2 and almost 60 vehicles in case of the weighted average of both plants. This shows that this very special aspect of market requirements has a huge potential impact on the GHG profile of a pellet plant. The availability of certified wood is not uniform in Estonia and therefore the sustainability requirement influences the sourcing patterns of a roundwood supplier. In case of two Estonia's largest pellet plants who produce at least 35% of the country's total pellet production, the influence is negative – increased emissions in the supply chain. Considering the increasing demand for wood pellets in the European bioenergy sector and the consistent (gradually increasing) requirement for certified wood, this negative impact will most likely intensify.

An important factor to consider in these calculations could be the fuel consumptions of the 40t trucks used for roundwood transport. Performance figures for a truck can vary quite a lot giving different values for emissions. To improve the accuracy of the GHG emission results the actual fuel records of the shipments could be included. This data is very difficult to get but in practice it could improve the level of detail. In this report the data from almost 24 000 shipments and the standard emission values from a widely acknowledged GHG calculator were found to be sufficient for reaching a comparable and credible result.

Another improvement to the findings of this report would be to include the emissions related to roundwood supplied to sawmills. This link was ignored in the calculations because it is not usually included in the GHG profile of a pellet plant (falls under sawmill profile) and because this data is not accessible through a pellet plant but expanding the scope to include sawmills could benefit the research towards the impacts that sustainable forestry has on wood industry emissions.

7. Conclusions

The European energy and climate targets have impacted many and will continue to do so even after the initial targets of the year 2020. Its consistent policy and requirements have created a large industrial scale market (20-25 million tons) for wood pellets which will continue to expand for many years to come. Whenever the demand for a certain product increases there will be consequences upstream in the value chain. In case of Estonian wood pellets one of the impacts is at the raw material source – the forest. The requirement for sustainably managed wood from certified forests has changed the sourcing patterns of forest companies and as this report proves, it has had an impact on the GHG profile of a wood pellet producer. The impact is negative since the calculations for both researched plants showed higher emission values for pellets that were produced from certified roundwood compared to non-certified wood. The increase in emissions per ton of certified wood pellets were 200 $gCO_{2\text{-}eq}$ for pellet plant 1 and 1260 $gCO_{2\text{-}eq}$ for pellet plant 2. Annually these resulting emissions are equivalent to what 30-100 (weighted average 60) passenger cars produce in one year and therefore this negative impact can be concluded to be significant. Considering that the research was based on almost 24 000 roundwood shipments for two large pellet producers from both ends of the country it can also be concluded that the impact of sustainable forest management is similar for the whole Estonian wood pellet industry. Applying these results to the regional scale would bring up the total potential emissions 4-5 times.

In defense of certified wood it is important to point out that like the GHG calculators indicate the emissions of certified wood pellets are still 86-92% lower compared to other fossil energy carriers of equivalent energy content. This still means that the certified pellets are a sustainable energy source but the increased emissions should not be ignored. Especially when the volumes keep increasing.

The results of this report and the methodology can be used to provide real life feedback to European policy makers about the impacts of the Renewable Energy Directive’s sustainability policy. While there is no research to be found to explain and justify the requirement of certified wood in the Energy sector there is now a report that evaluates the potential impacts of that requirement on a country and industry level.

8. Summary

This thesis aimed to evaluate the impact that sustainable forest management has on Estonian pellet producer's emissions, based on the differences in the average sourcing distances that wood travels from certified and non-certified Estonian forests to pellet plants. The research is based on two leading Estonian pellet plants PP1 and PP2 located in different parts of the country. The records of their 2016 raw material purchases and production details are used as the main data input for analysis.

The report also explores the concept of sustainable forest management and establishes that a sustainably managed forest addresses and benefits all stakeholders while being environmentally acceptable, socially considerate and economically beneficial. Since sustainability is difficult to objectively assess neutral party approval systems are used. The report introduces two globally acknowledged forest certification schemes: Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC). The wood originating from forests certified by these schemes is counted as "certified" in the initial data set and the rest is processed as "un-certified".

The phenomenon and demand for certified wood in the wood pellet market came from the European Renewable Energy Directive as well as the governmental requirements of many European countries. These requirements state that an energy producer who uses wood based biomass can only qualify for a green energy subsidy if the biomass originates from certified forests. Considering that Estonia is the fourth largest pellet producer in Europe then the certified wood demand is a big factor in regional forestry and therefore the resulting impacts are important to understand and estimate.

The data collected from the pellet plants compiled a data set of approximately 24 000 roundwood shipments that were used to calculate the annual total volumes and average sourcing distances of both certified and non-certified wood. These values were fed into a GHG calculator designed specifically for wood pellet production by the European Pellet Council. The calculator generated comparable results in format of grams of CO_2 equivalents emitted per kilogram of pellet production for both plants and wood types. In both cases the emissions associated with pellets produced from certified wood were higher compared to non-certified wood. For PP1 the results were 0,2 gCO_{2-eq} higher and for PP2 1,26 gCO_{2-eq} higher per kilogram of production. When applying the weighted average emission increase of both plants to their average annual production then the values can be estimated to be equivalent to the annual emissions of 60 passenger cars. Which is definitely a very notable negative impact.

Overall this thesis very much met its objective to both establish the direction of the impact and evaluate the scale of the effect that sustainable forestry has on the Estonian wood pellet industry. The credibility of the results is supported by the fact that real life industry data with a country wide reach was used and no major assumptions had to be made in order to reach comparable results. The large scale of the data set and the associated volumes allow this thesis to be used as a pellet industry case study that provides real life feedback for European level sustainability policies. In order to be able to conclude on the whole wood industry the roundwood sourcing distances of sawmills can be introduced to the scope of this research with identical methodology. For now the report focuses and concludes on the two Estonian wood pellet plants but considering that the researched plants combine over 35% of the country's annual production then similar impacts (negative) can be assumed for all regional producers.

8.1 Eestikeelne kokkuvõte (Summary in Estonian)

JÄTKUSUUTLIKU METSAMAJANDAMISE MÕJU PUIDUGRAANULITOOTJA KASVUHOONEGAASIDELE

Mihkel Jugaste

Antud töö eesmärgiks on hinnata jätkusuutliku metsamajandamise mõju Eesti puidugraanulitootjate emissioonidele, tuginedes sertifitseerimata ja sertifitseeritud puidu keskmiste varumisdistantside erinevustele. Uurimistöö tugineb kahel Eesti puidugraanulitootjal PP1 ja PP2, mis asuvad riigi erinevates osades. Nende 2016 aasta ümarpuidu ostudokumentide ja tootmisnäitajaid kasutatakse analüüsi algandmetena.

Uuringus avatakse jätkusuutliku metsamajandamise olemust, kus määratletakse, et säästlikult majandatud mets adresseerib ja toob kasu kõikidele seotud osapooltele olles samal ajal keskkonnale sõbralik, sotsiaalselt arvestav ja majanduslikult tulus. Kuna jätkusuutlikkust on objektiivselt raske hinnata on selle fikseerimiseks kasutatud neutraalseid kinnitussüsteeme. Sellega seoses tutvustatakse kahte globaalselt tunnustatud metsade sertifitseerimisskeemi: Forest Stewardship Council (FSC) ja Programme for the Endorsement of Forest Certification (PEFC). Puitu, mis pärineb nende sertifitseerimisskeemide poolt sertifitseeritud metsadest käsitletakse analüüsis „sertifitseerituna“ ja ülejäänut „sertifitseerimatana“.

Nõudlus sertifitseeritud puidu järele puidugraanuli turul tuleb Euroopa Taastuvenergia Direktiivi ja ka mitme Euroopa riigi valitsuse nõuetest. Need nõuded märgivad, et energiatootja, kes kasutab puidupõhist biomassi kvalifitseerub taastuvenergia toetustele ainult siis kui biomass pärinev sertifitseeritud metsadest. Arvestades, et Eesti on Euroopas suuruselt neljas graanulitootja siis on antud nõudel regionaalsele metsandusele suur mõju, mida on oluline mõista ja hinnata.

Graanulitehastelt kogutud andmed moodustasid umbes 24 000-st ümarpuidu veosest koosneva andmekogu, mida kasutati nii sertifitseeritud kui ka sertifitseerimata puidu aastaste üldkoguste ja keskmiste varumisvahemaade arvutamiseks. Need väärtused sisestati kasvuhoonegaaside kalkulaatorisse, mis on loodud European Pellet Council’ili poolt spetsiaalselt graanulite tootmise jaoks. Kalkulaator genereeris võrreldavaid tulemusi formaadis gramm CO_2 väärset heitgaasi kilogrammi graanulitoodangu kohta. Mõlema tehase puhul oli sertifitseeritud puiduga seotud emissioonid kõrgemad sertifitseerimata puidu omadest. PP1 puhul oli see väärtus 0,2 $gCO_{2\text{-eq}}$ võrra suurem ja PP1 puhul 1,26 $gCO_{2\text{-eq}}$ suurem kilogrammi toodangu kohta. Kandes saadud tulemuste kaalutud keskmised üle tehaste aastasele keskmisele toodangule siis on

emissioonide suurenemise kogumaht võrreldav 60 sõiduauto aastase heitgaaside kogusega. See on kahtlemata väga märkimisväärne negatiivne mõju.

Kokkuvõttes saavutas antud töö oma eesmärgi - jätkusuutliku metsamajandamise mõju Eesti puidugraanulitootjate esmissioonidele sai fikseeritud nii suunas kui ka skaalas. Antud aruande tulemuste usutavust toetavad tõsisasjad, et kasutati üleriigilisi reaalse tööstuse andmeid ja et kasutatavate tulemusteni jõudmiseks ei pidanud tegema suuri oletusi. Andmete suur maht ja seotud materjali kogused võimaldavad antud uurmistööd kasutada graanulitööstuse juhtumiuuringuna, mis pakub päris elu tagasisidet Euroopa ülesele säätlikkuse poliitikale. Võimalik oleks sama metoodikat kasutades teha järeldusi ka kogu puidutööstuse kohta, kui uurimistööd laiendada saeveskite ümarpuidu varumisaladele. Praeguseks keskendub antud töö kahele Eesti graanulitootjale, aga kuna nende tehaste toodang moodustab üle 35% riigi aastasest kogutoodangust siis võib sarnast mõju (negatiivset) eeldada ka teistel regionaalsetel tootjatel.

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Appendix 1 – Pellet Plant Waybill Example

METSAMATERJALI VEOSELEHT NR

Veoselehe nr metsamaterjali omaniku süsteemis: mELVIS149

Veotellimuse nr: RP10

Kinnitatud: **17.05.2017**

Staatus: Lõpetatud 17.05.2017

Veotellimus esitatud: 17.05.2017

METSAMATERJALI OMANIK

Nimi			
Kood			
Telefon	+372 516	E-post	
Aadress	Lääne-Virumaa, Väike-Maarja vald,		

METSAMATERJALI OMANIKU ESINDAJA

Nimi			
Kood		Volitusalus	
Telefon		E-post	
Aadress			

SAAJA

Nimi			
Kood			
Kontaktisiku nimi			
Telefon		E-post	
Aadress	Harjumaa, Tallinn,		

SIHTKOHT

Nimi			
Kood			
Kontaktisiku nimi			
Telefon		E-post	
Aadress			
XY		Geo	

TRANSPORTIJA

Nimi			
Kood			
Kontaktisiku nimi			
Telefon		E-post	
Aadress	Lääne-Virumaa, Väike-Maarja vald, Väike-Maarja		

Autojuht			
Veok		Haagis	
Ettesõidu km	0,00	Koorma km	24,00
Veo algus	17.05.2017 13:39:48	Veo lõpp	17.05.2017 14:27:11

LÄHETAMINE

Lähtekoht 1		Kood	
Nimi			
Kontaktisiku nimi			

Telefon		E-post	
Aadress			
XY		Geo	

Sortimendi kood, nimetus	Valdamise alus*	Kogus	Eelmise omaniku nimi	Metsamaterjali päritolukoht
HKP3, Hakkpuit	MVL	92,000 m3	10934040	38901:001:

VASTUVÕTMINE

Kood	Sortiment	Kogus
HKP3	Hakkpuit	92,000 m3
	KOKKU	**92,000 m3**

Vastuvõtuaeg	17.05.2017
Vastuvõtja	Isikustamata ;0000000000

SERTIFIKAADID

NC-COC- (FSC Mix Credit)

* MT – Metsateatis, RVL – Raieõiguse võõrandamise leping, MVL – Metsamaterjali võõrandamise leping, IA – Inventuuri akt, KA – Koondakt, MS§41(14) – Metsaseadus §41 lõige 14

14.04.2017

Pellet Plant 1 - Certified Roundwood

GHG Balance of Pellet production

Template to calculate the GHG emissions of a pellet production plant and emission factors to be used

Please fill in yellow fields !

Total annual production		
Pellets	118 770	[t/a]
Energy content Net Calorific Value (NCV)	18	[MJ/kg] (Value from pellets analysis of the inspection)

Energy consumption related to raw material supply

Transport / biomass supply	[t/a]	average transport distance [km]	[gCO_{2-eq}]
Raw material produced at the site of the pellet plant as byproduct			No contribution
Raw material transported from other site (incl. transport from			
40 t truck (Diesel)	79 057	44	284 091 815
12 t truck (Diesel)			0
Coastal/river shipping wood chips			0
Ocean going bulk carrier			0
Rail transport (European electricity mix)			0
Total CO2 from biomass supply			284 091 815

Energy consumption related for pellet on-site production

Pellets prodcution - electricity consumption				
Total electricity consumption per year	17 055 657	[kWh]	61 400 365	[MJ]
CO2 emissions as stated in bill	1 156,61	[gCO_2/kWh]	321,28	[gCO_2/MJ]
Total annual GHG emissions from electricity consumption			19 726 743 498	[gCO_2]

Pellets production - energy consumed for heat		[MJ]	[gCO_{2-eq}]
Woody Biomass from residues (wood, bark,	21 759	391 655 952	391 655 952
Heating oil [1000l]		0	0
Natural gas [kWh]		0	0
Hard coal [t]		0	0
Lignite [t]		0	0
District heat (renewables) [kWh]		0	0
District heat (fossil) [kWh]		0	0
Total annual emissions for heat			391 655 952

Pellets production - additives	[t/a]	[gCO_{2-eq}]
Corn		0
Grains		0
Vegetable oil		0
Total annual emissions for additives		0

Packaged delivery	bagged	[gCO_{2-eq}]
10-kg-bag		0
15-kg-bag		0
Total emissions packaging		0

Results		
Total emissions	20 402 491 265	[gCO_{2-eq}]
Total emissions without packaging	20 402 491 265	[gCO_{2-eq}]
Total emissions per MJ bulk pellets	9,54	[gCO_{2-eq}/MJ]
Total emissions per kg bulk pellets	171,78	[gCO_{2-eq}/kg]
Total emissions per MJ packed pellets	#DIV/0!	[gCO_{2-eq}/MJ]
Total emissions per kg packed pellets	#DIV/0!	[gCO_{2-eq}/kg]

CO2 emission reduction based on real values	reduction with bulk pellets	GHG reduction with baged pellets
Reference energy carrier		
Heating oil	**89%**	**#DIV/0!**
Natural gas (EU mix quality)	**86%**	**#DIV/0!**
Diesel	**89%**	**#DIV/0!**
Hard coal	**91%**	**#DIV/0!**
Lignite	**92%**	**#DIV/0!**
Disctrict heat (non-renewable)	**88%**	**#DIV/0!**

Appendix 2.1 – PP1 GHG Calculator Results; Non- Certified Roundwood 14.04.2017 Pellet Plant 1 - Non-certified Roundwood

GHG Balance of Pellet production

Template to calculate the GHG emissions of a pellet production plant and emission factors to be used

Please fill in yellow fields !

Total annual production		
Pellets	31 230	[t/a]
Energy content Net Calorific Value (NCV)	18	[MJ/kg] (Value from pellets analysis of the inspection)

Energy consumption related to raw material supply

Transport / biomass supply	[t/a]	average transport distance [km]	[gCO_{2-eq}]
Raw material produced at the site of the pellet plant as byproduct			No contribution
Raw material transported from other site (incl. transport from			
40 t truck (Diesel)	20 788	40	68 433 758
12 t truck (Diesel)			0
Coastal/river shipping wood chips			0
Ocean going bulk carrier			0
Rail transport (European electricity mix)			0
Total CO2 from biomass supply			68 433 758

Energy consumption related for pellet on-site production

Pellets prodcution - electricity consumption				
Total electricity consumption per year	4 484 703	[kWh]	16 144 931	[MJ]
CO2 emissions as stated in bill	1 156,61	[gCO_2/kWh]	321,28	[gCO_2/MJ]
Total annual GHG emissions from electricity consumption			5 187 052 281	[gCO_2]

Pellets production - energy consumed for heat		[MJ]	[gCO_{2-eq}]
Woody Biomass from residues (wood, bark,	5 721	102 984 048	102 984 048
Heating oil [1000l]		0	0
Natural gas [kWh]		0	0
Hard coal [t]		0	0
Lignite [t]		0	0
District heat (renewables) [kWh]		0	0
District heat (fossil) [kWh]		0	0
Total annual emissions for heat			102 984 048

Pellets production - additives	[t/a]	[gCO_{2-eq}]
Corn		0
Grains		0
Vegetable oil		0
Total annual emissions for additives		0

Packaged delivery	bagged	[gCO_{2-eq}]
10-kg-bag		0
15-kg-bag		0
Total emissions packaging		0

Results		
Total emissions	5 358 470 088	[gCO_{2-eq}]
Total emissions without packaging	5 358 470 088	[gCO_{2-eq}]
Total emissions per MJ bulk pellets	9,53	[gCO_{2-eq}/MJ]
Total emissions per kg bulk pellets	171,58	[gCO_{2-eq}/kg]
Total emissions per MJ packed pellets	#DIV/0!	[gCO_{2-eq}/MJ]
Total emissions per kg packed pellets	#DIV/0!	[gCO_{2-eq}/kg]

CO2 emission reduction based on real values	reduction with bulk pellets	GHG reduction with baged pellets
Reference energy carrier		
Heating oil	**89%**	**#DIV/0!**
Natural gas (EU mix quality)	**86%**	**#DIV/0!**
Diesel	**89%**	**#DIV/0!**
Hard coal	**91%**	**#DIV/0!**
Lignite	**92%**	**#DIV/0!**
Disctrict heat (non-renewable)	**88%**	**#DIV/0!**

Appendix 3- PP2 GHG Calculator Results (Screenshot): Certified Roundwood

14.04.2017 | Pellet Plant 2 - Certified Roundwood

GHG Balance of Pellet production

Template to calculate the GHG emissions of a pellet production plant and emission factors to be used

Please fill in yellow fields !

Total annual production		
Pellets	89 540	[t/a]
Energy content Net Calorific Value (NCV)	18	[MJ/kg] (Value from pellets analysis of the inspection)

Energy consumption related to raw material supply			
Transport / biomass supply	**[t/a]**	**average transport distance [km]**	**[gCO_{2-eq}]**
Raw material produced at the site of the pellet plant as byproduct			No contribution
Raw material transported from other site (incl. transport from			
40 t truck (Diesel)	97 332	47	378 478 175
12 t truck (Diesel)			0
Coastal/river shipping wood chips			0
Ocean going bulk carrier			0
Rail transport (European electricity mix)			0
Total CO2 from biomass supply			378 478 175

Energy consumption related for pellet on-site production

Pellets prodcution - electricity consumption				
Total electricity consumption per year	12 698 685	[kWh]	45 715 266	[MJ]
CO2 emissions as stated in bill	1 156,61	[gCO_2/kWh]	321,28	[gCO_2/MJ]
Total annual GHG emissions from electricity consumption			14 687 425 942	[gCO_2]

Pellets production - energy consumed for heat		**[MJ]**	**[gCO_{2-eq}]**
Woody Biomass from residues (wood, bark,	21 368	384 615 000	384 615 000
Heating oil [1000l]		0	0
Natural gas [kWh]		0	0
Hard coal [t]		0	0
Lignite [t]		0	0
District heat (renewables) [kWh]		0	0
District heat (fossil) [kWh]		0	0
Total annual emissions for heat			384 615 000

Pellets production - additives	**[t/a]**	**[gCO_{2-eq}]**
Corn		0
Grains		0
Vegetable oil		0
Total annual emissions for additives		0

Packaged delivery	**bagged**	**[gCO_{2-eq}]**
10-kg-bag		0
15-kg-bag		0
Total emissions packaging		0

Results		
Total emissions	15 450 519 118	[gCO_{2-eq}]
Total emissions without packaging	15 450 519 118	[gCO_{2-eq}]
Total emissions per MJ bulk pellets	9,59	[gCO_{2-eq}/MJ]
Total emissions per kg bulk pellets	172,55	[gCO_{2-eq}/kg]
Total emissions per MJ packed pellets	#DIV/0!	[gCO_{2-eq}/MJ]
Total emissions per kg packed pellets	#DIV/0!	[gCO_{2-eq}/kg]

CO2 emission reduction based on real values	**GHG reduction with bulk pellets**	**GHG reduction with baged pellets**
Reference energy carrier		
Heating oil	**89%**	**#DIV/0!**
Natural gas (EU mix quality)	**86%**	**#DIV/0!**
Diesel	**89%**	**#DIV/0!**
Hard coal	**91%**	**#DIV/0!**
Lignite	**92%**	**#DIV/0!**
Disctrict heat (non-renewable)	**88%**	**#DIV/0!**

Appendix 3.1 – PP2 GHG Calculator Results; Non-Certified Roundwood 14.04.2017

Pellet Plant 2 - Non-certified Roundwood

GHG Balance of Pellet production

Template to calculate the GHG emissions of a pellet production plant and emission factors to be used

Please fill in yellow fields !

Total annual production		
Pellets	31 460	[t/a]
Energy content Net Calorific Value (NCV)	18	[MJ/kg] (Value from pellets analysis of the inspection)

Energy consumption related to raw material supply

Transport / biomass supply	**[t/a]**	**average transport distance [km]**	**[gCO_{2-eq}]**
Raw material produced at the site of the pellet plant as byproduct			No contribution
Raw material transported from other site (incl. transport from			
40 t truck (Diesel)	34 204	33	93 311 884
12 t truck (Diesel)			0
Coastal/river shipping wood chips			0
Ocean going bulk carrier			0
Rail transport (European electricity mix)			0
Total CO2 from biomass supply			93 311 884

Energy consumption related for pellet on-site production

Pellets prodcution - electricity consumption				
Total electricity consumption per year	4 461 700	[kWh]	16 062 120	[MJ]
CO2 emissions as stated in bill	1 156,61	[gCO_2/kWh]	321,28	[gCO_2/MJ]
Total annual GHG emissions from electricity consumption			5 160 446 953	[gCO_2]

Pellets production - energy consumed for heat		**[MJ]**	**[gCO_{2-eq}]**
Woody Biomass from residues (wood, bark,	7 508	135 135 000	135 135 000
Heating oil [1000l]		0	0
Natural gas [kWh]		0	0
Hard coal [t]		0	0
Lignite [t]		0	0
District heat (renewables) [kWh]		0	0
District heat (fossil) [kWh]		0	0
Total annual emissions for heat			135 135 000

Pellets production - additives	**[t/a]**	**[gCO_{2-eq}]**
Corn		0
Grains		0
Vegetable oil		0
Total annual emissions for additives		0

Packaged delivery	**bagged pellets**	**[gCO_{2-eq}]**
10-kg-bag		0
15-kg-bag		0
Total emissions packaging		0

Results		
Total emissions	5 388 893 837	[gCO_{2-eq}]
Total emissions without packaging	5 388 893 837	[gCO_{2-eq}]
Total emissions per MJ bulk pellets	9,52	[gCO_{2-eq}/MJ]
Total emissions per kg bulk pellets	171,29	[gCO_{2-eq}/kg]
Total emissions per MJ packed pellets	#DIV/0!	[gCO_{2-eq}/MJ]
Total emissions per kg packed pellets	#DIV/0!	[gCO_{2-eq}/kg]

CO2 emission reduction based on real values	**GHG reduction with bulk pellets**	**GHG reduction with baged pellets**
Reference energy carrier		
Heating oil	**89%**	**#DIV/0!**
Natural gas (EU mix quality)	**86%**	**#DIV/0!**
Diesel	**89%**	**#DIV/0!**
Hard coal	**91%**	**#DIV/0!**
Lignite	**92%**	**#DIV/0!**
Disctrict heat (non-renewable)	**88%**	**#DIV/0!**