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CARBON FOOTPRINT OF THERMOWOOD

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Purpose of this Bachelor’s Thesis was to evaluate the carbon footprint of thermally modified wood and its manufacturing process and transportation cycle for several different ThermoWood producer.

Research included the whole production cycle from harvesting raw wood to ThermoWood transportation in destination area. Carbon dioxide emissions from these areas were determined and calculated for every ThermoWood producer at first hand.

Calculations were based on the PAS 2050:2011, which is a standard for specification for the assessment of the life cycle greenhouse gas emissions of goods and services. PAS 2050:2011 standard is suitable for companies, which estimate carbon dioxide emissions of product’s transportation cycle or manufacturing processes.

According to the results, the biggest carbon dioxide emissions were produced from the transportation and fossil fuel combustion. Transportation emissions were on average 48 % of the whole calculated carbon footprint. The second largest source of emissions were originated from combustion of fossil based fuel materials in production facilities. Reducing carbon dioxide emissions is possible by applying more efficient transportation methods and renewable fuel materials in production.

According to the calculations, average total carbon dioxide emissions from all companies studied and covering the whole production and transportation cycle was about 204 kg(CO_2)/s-m^3(ThermoWood).

LÄMPÖPUUN HIILIJALANJÄLKI

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Tämän opinnäytetyön tarkoituksena oli arvioida hiilijalanjälki usean eri ThermoWood, eli lämpöpuuyrityksen tuotannolle ja kuljetuksille.

Tutkimus sisälsi lämpöpuun koko tuotantoketjun aina puunkaadosta valmiin ThermoWood-tuotteen kuljetuksesta lopulliseen määränpäähän asti. Hiilidioksidipäästöt tuotannon kaikista osa-alueista selvitettiin ja laskettiin jokaiselle ThermoWood valmistajalle yksilöllisesti.

Laskut pohjautuivat PAS 2050:2011 standardiin, joka perustuu tuotteen tai palvelun elinkaaren kasvihuonekaasupäästöjen arvioitiin. PAS 2050:2011 standardi soveltuu yrityksille, jotka määrittelevät hiilidioksidipäästöjä tuotteen kuljetuksesta ja eri tuotantovaiheista.

Tuloksien mukaan suurimmat hiilidioksidipäästöt muodostuivat kuljetuksista ja fossiilisten polttoaineiden poltosta. Kuljetuksista muodostuneet hiilidioksidipäästöt olivat keskimäärin 48 % lopullisesta hiilijalanjäljestä. Toiseksi suurin päästölähde muodostui fossiilisten polttoaineiden poltosta tuotannon yhteydessä. Hiilidioksidipäästöjen vähentäminen on mahdollista kuljetusvaihtoehtoja tehostamalla ja suosimalla uusiutuvia polttoaineita tuotannossa.

Tulosten mukaan keskimääräinen hiilidioksidipäästö laskettuna jokaisesta arvioidusta yrityksestä, kun koko tuotanto- ja kuljetusketju huomioidaan, on 204 kg(CO_2)/s-m^3(ThermoWood).

SISÄLLYS

1 INTRODUCTION

In this final thesis the carbon footprint of ThermoWood was studied and estimated by calculations from its logistical cycle and manufacturing process. The primary goal was to get average carbon footprint estimation for ThermoWood's whole production and transportation cycle before final destination, which in this case was customer. Carbon footprint calculations were focused in released carbon dioxide from manufacturing ThermoWood and also from different transportation cycles.

2 CARBON FOOTPRINT PROJECT FOR THERMOWOOD

Project started in December 2014 just before holidays when every company, who have right to use the ThermoWood trademark, were sent an email information and data collection form. Participating companies were asked to complete a form with asked values which were later used in carbon footprint calculations. Overall six ThermoWood producers participated for this project from Finland and Sweden. Carbon footprint calculations started from the forest where the first step was raw wood harvesting for sawmills and later for ThermoWood production facilities. Project also included emission calculations from transportation by road or sea in every step in ThermoWood production cycle before the final customer.

The results were presented in Helsinki in April. Results were given to every participating ThermoWood producer. It was also agreed to make one more recheck to transportation values calculated from given data. After recheck every ThermoWood producer got recalculated carbon footprint results from their own production and transportation cycle. Also the average carbon footprint value based on all participating producers was determined.

In order to ensudere confidentiality, every ThermoWood company and every company related to ThermoWood production were handled anonymously in this final thesis because confidential values were used in the carbon footprint calculations.

3 THE INTERNATIONAL THERMOWOOD ASSOCIATION

The International ThermoWood Association was founded in 2000 and association's primary goal is to promote products labeled with ThermoWood trademark. Only members from the International ThermoWood Association, altogether fourteen companies, have right to use this trademark in the European Union. Members also work together with Thermowood's product classification, quality control and product development. There has been also unlicensed usage of ThermoWood trademark. Therefore association's advice is always to check if the company has right to use ThermoWood trademark when ThermoWood products is bought. Association gathers and publishes data and information from thermally modified timber but it is also important to know that not all data or information published by association is valid for all thermally modified timber that is available for the consumers. Published data and information are only valid for genuine ThermoWood products which are produced under the independent quality control system audited by accredited notified body. ThermoWood product has also two classes, Thermo-S and Thermo-D, which are also directly copied by some non-member companies. (1)

4 STRUCTURE OF WOOD

Wood has several layers and the main sections of wood are pith or core, sapwood, heartwood, cambium, inner bark and outer bark. Main chemical materials in wood are cellulose, hemicellulose, lignin, acetyl and extractive substances but also some minerals. (2, 3, 4, 5, 6)

The pith is located in the center of a tree running up from the roots and it is small and often pulpy. Main function of the pith is to store nutrients for next year’s growth and branching season. Pith is mostly starch and it is dead in the lower part of the trunk. (2, 3, 4, 5, 6)

Next section is heartwood which is clogged with resins, gums and other extractives like terpene and formaldehydes. Heartwood’s main purpose is to support the living surface wood and it is darker than the surface wood. Therefore heartwood is often the most valuable part of the whole tree. Heartwood’s formation occurs spontaneously. (2, 3, 4, 5, 6)

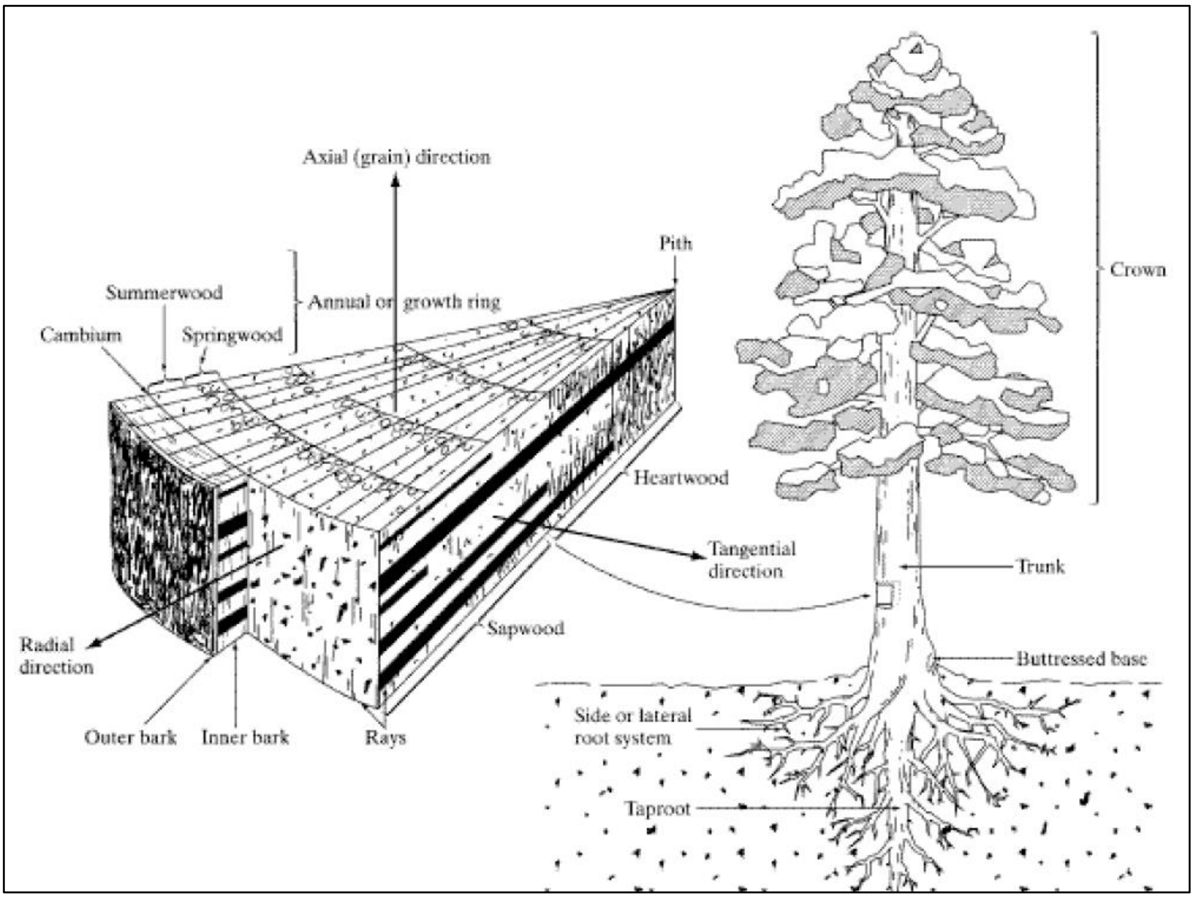
After the heartwood there is sapwood which consists of 10 to 15 of the most innermost yearly rings and is an active part in trunk where water and minerals are conducted from the roots to the leaves or needles. Sapwood also storages some nutrients and also helps to support tree alongside with heartwood. Because of the water and nutrient flow the sapwood has knots and the wood in this section cracks easily. Therefore sapwood is considered to be the worst quality wood in the trunk for after treatments or processes. (2, 3, 4, 5, 6)

Before outer layers there is cambium which is a thin, most active layer of the tree. Cambium’s main purpose is to form new tissue for the tree adding it to the phloem, located before bark and also called inner bark, and sapwood to increase a tree’s girth. (2, 3, 4, 5, 6)

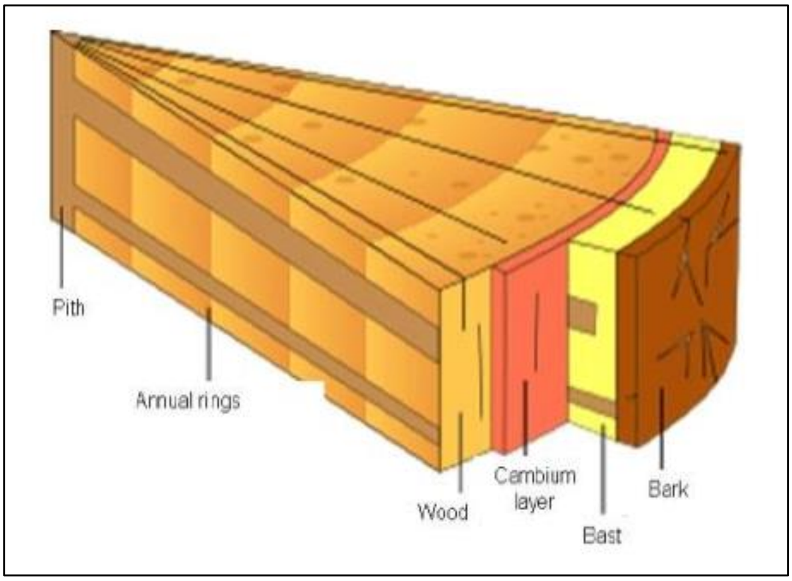
Phloem, also called as the inner bark, is a thin layer before outer bark which stores dissolved sugars and some growth hormones from the leaves or needles for further usage for other parts of a tree like cambium. (2, 3, 4, 5, 6)

Last layer from the trunk is the bark which protects tree from insects, temperature extremes and other threats which could harm the tree. One of the main aspects of the bark alongside with protection is to keep sapwood and phloem moist and not drying out which would harm sapwood's and phloem's functions. (2, 3, 4, 5, 6)

Summer- and springwood can be seen in sap- and heartwood from different colours. Springwood, also called as earlywood in hardwoods, is a darker area that begins to grow in the beginning of the tree's growth season. Summerwood's colour is lighter than springwood's and it is from the tree's rapid growth season. Summerwood is also called as latewood. (2, 3, 4, 5, 6)



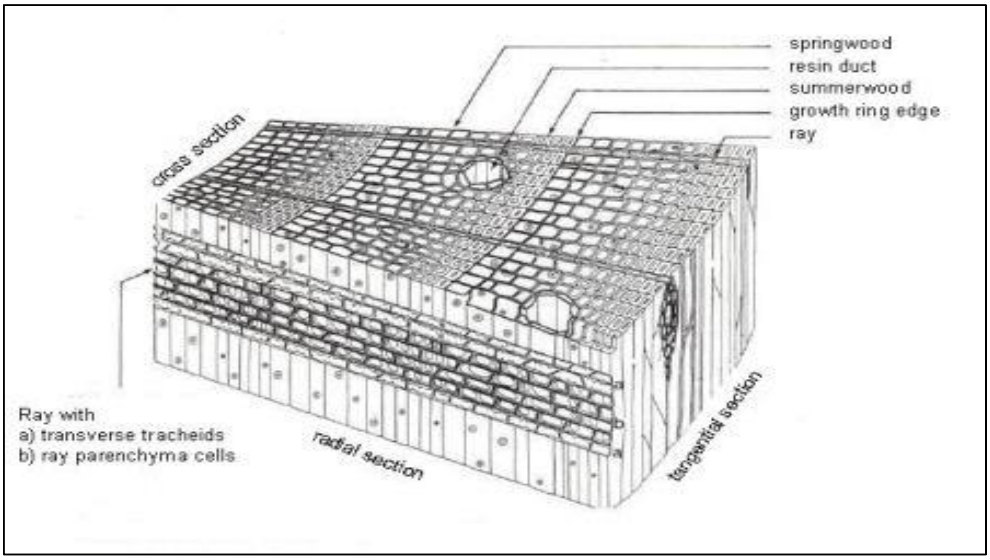
Picture 1 Structure of wood 1 (Monteiro) (7)



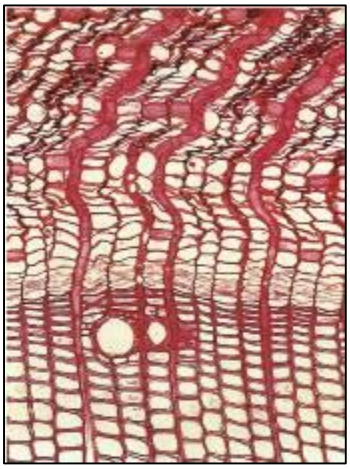
Picture 2 Structure of wood 2 (9)

4.1 Coniferous Wood

Coniferous wood is in evolutionary scale much older than deciduous wood. Structural differences are small and coniferous wood's cell structure is considered to be simple. Only noticeable difference between coniferous and deciduous wood is thickness of the cell walls. Coniferous wood grows at first in spring growing season thin-walled cells and large spores for water and nutrient flow. Later in the summer these cell walls get thicker which improves tree's stability and strength. Thicker walls can be seen as darker areas and narrow walls as lighter areas in the cross-section of wood. However there is no colour difference between the individual wood cells in spring- or summerwood. (10)



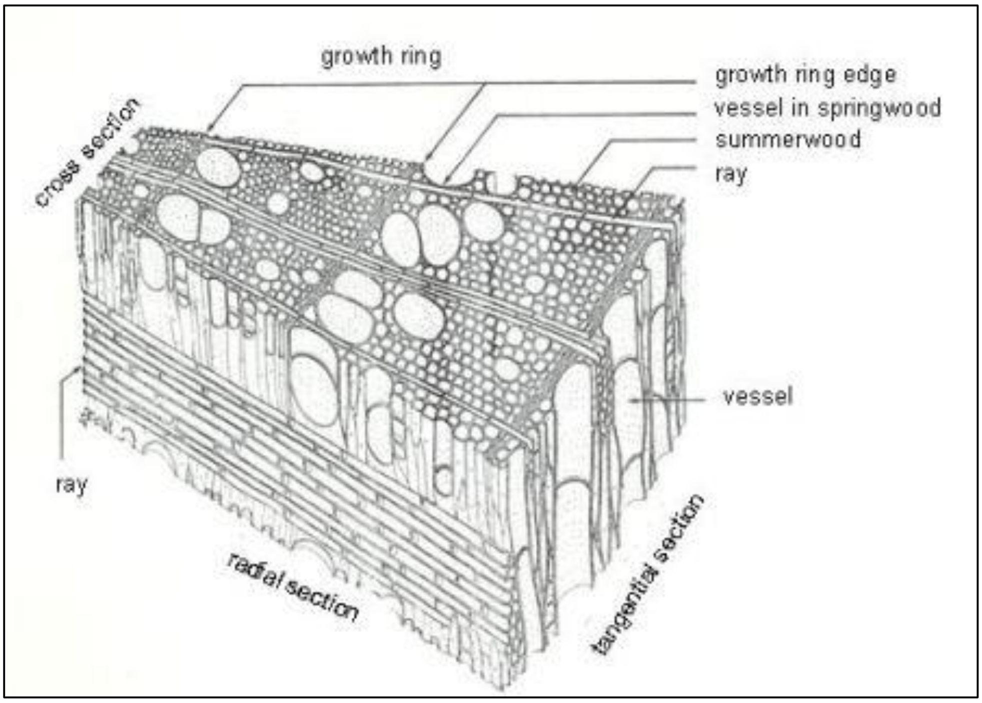
Picture 3 Structure of coniferous wood (10)



Picture 4 Cross-section of a spruce (Photo: Grosser, München) (11)

4.2 Deciduous Wood

Deciduous wood is considered to be evolutionary younger and it is also much more diverse by its structure than coniferous wood. Most characteristic thing for deciduous wood is that it has vessels in springwood which cannot be found in coniferous wood. These vessels can be seen with naked eye as small pores in cross-section of wood and noticeable grooves in a tangential area of wood. Unlike coniferous, deciduous wood can be separated in three different functional groups: conducting tissues, fiber tissues and storage tissues. Conducting tissues include every vessels that are located in summerwood. Fiber tissues consider libriform fibers and fiber tracheids. Storage tissues consider ray parenchyma cells, epithelium cells and elongated parenchyma cells. (11)



Picture 5 Structure of deciduous wood (Dr. Dietger Grosser, München) (11)

Picture 6 Cross-section of an oak (Dr. Dietger Grosser, München) (12)

5 DURABILITY OF DIFFERENT WOOD TYPES

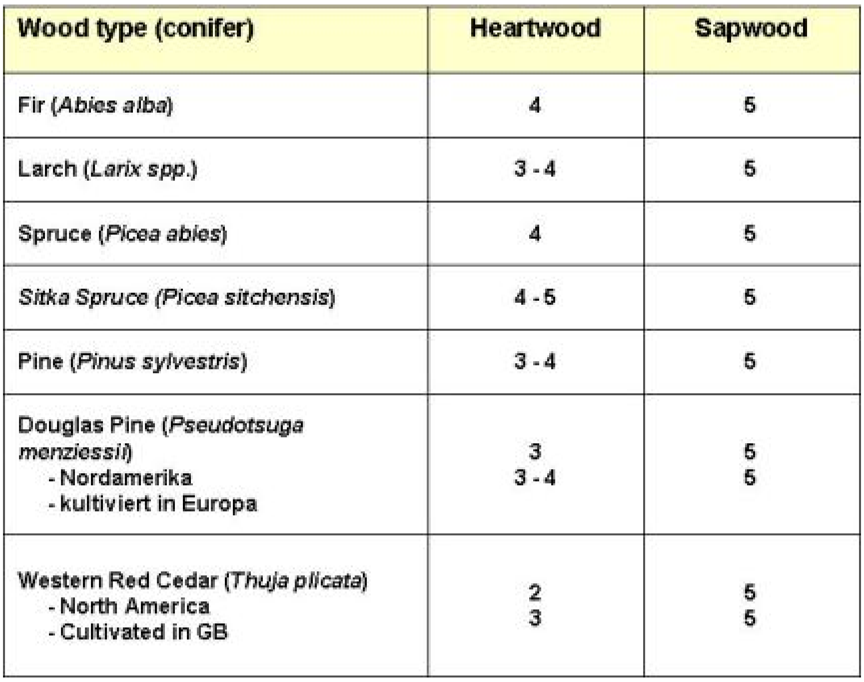
Different wood types behave differently when thermal treatment is applied for processing raw wood. Also behavioral differences are between heartwood and sapwood because the same tree has different durability classes in different sections of the trunk. The standard EN 350-2 “Natural durability of solid wood” gives rough estimation how well wood will endure biological stress such as fungi or drywood-destroying insects. This natural durability against biological threats is categorized in five durability classes listed below. (13, 23)

Table 1 Wood's durability categorization (13)

Durability class 1	**Highly durable**
Durability class 2	**Durable**
Durability class 3	**Moderately durable**
Durability class 4	**Slightly durable**
Durability class 5	**Non-durable**

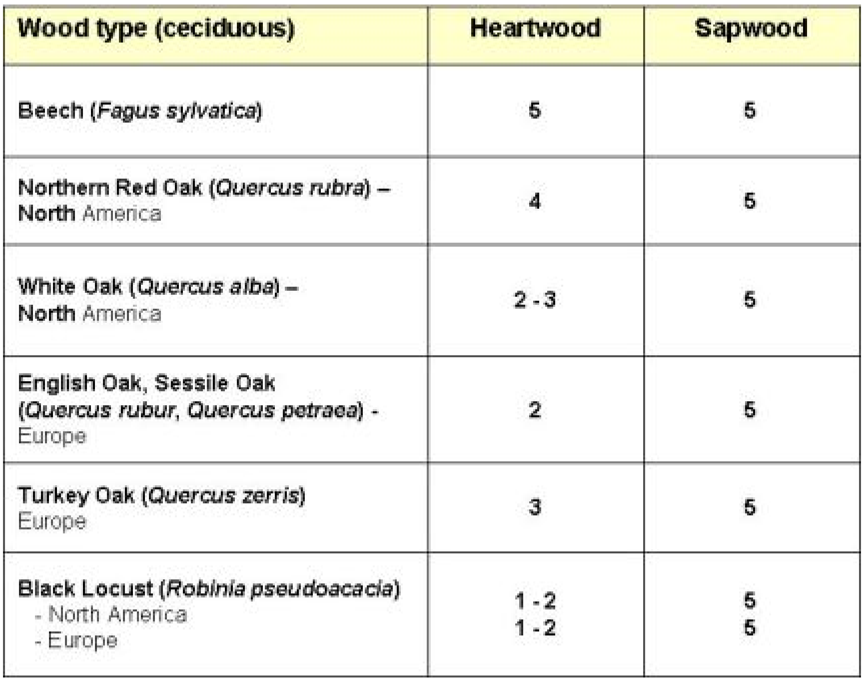
The sapwood is much more porous than the heartwood which makes it almost in all wood species non-durable against biological threats. Generally heartwood has better durability in raw wood before any treatment but when used as untreated material, it needs some protection against wood-destroying organisms especially when used in outdoor buildings or other applications. Durability classes for both heartwood and sapwood are listed below depending on wood type. (13, 23)

Table 2 Wood types durability classification 1 (13)



Wood type (conifer)	**Heartwood**	**Sapwood**
Fir (*Abies alba*)	4	5
Larch (*Larix spp.*)	3 - 4	5
Spruce (*Picea abies*)	4	5
Sitka Spruce (Picea sitchensis)	4 - 5	5
Pine (*Pinus sylvestris*)	3 - 4	5
Douglas Pine (*Pseudotsuga menziessii*) - Nordamerika - kultiviert in Europa	 3 3 - 4	 5 5
Western Red Cedar (*Thuja plicata*) - North America - Cultivated in GB	 2 3	 5 5

Table 3 Wood types durability classification 2 (13)



Wood type (ceciduous)	**Heartwood**	**Sapwood**
Beech (*Fagus sylvatica*)	5	5
Northern Red Oak (*Quercus rubra*) – North America	4	5
White Oak (*Quercus alba*) – North America	2 - 3	5
English Oak, Sessile Oak (*Quercus rubur*, *Quercus petraea*) - Europe	2	5
Turkey Oak (*Quercus zerris*) Europe	3	5
Black Locust (*Robinia pseudoacacia*) - North America - Europe	 1 - 2 1 - 2	 5 5

6 ANNUAL DRAIN OF GROWING WOOD IN FINLAND

As updated data from 2.10.2014 shows below, forest grows faster than wood is harvested in Finland. Finnish timber reserves have been increasing for the past 40 years and the reserves are increasing at the present day. Finland had estimated reserves 2332 million cubic meters in 2009-2012 and the annual average growth was 104 million cubic meters which means that Finnish growth rate is 4,5%. Train rate was between in 2009-2012 3,0% which means that an average of 70 million cubic meters of wood was harvested from the forest. Therefore Finnish forests grow annually 1,5% despite harvesting of wood. These numbers mentioned above consider all wood growth despite the area, so nature conservation areas are also included. (14, 15)

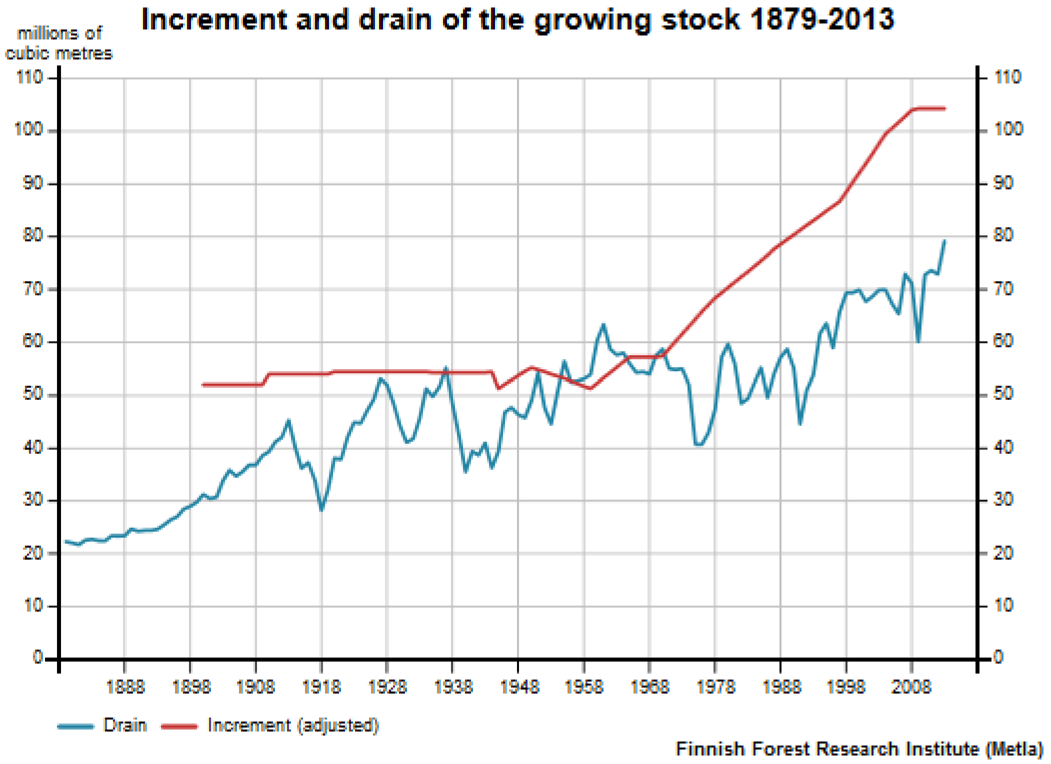
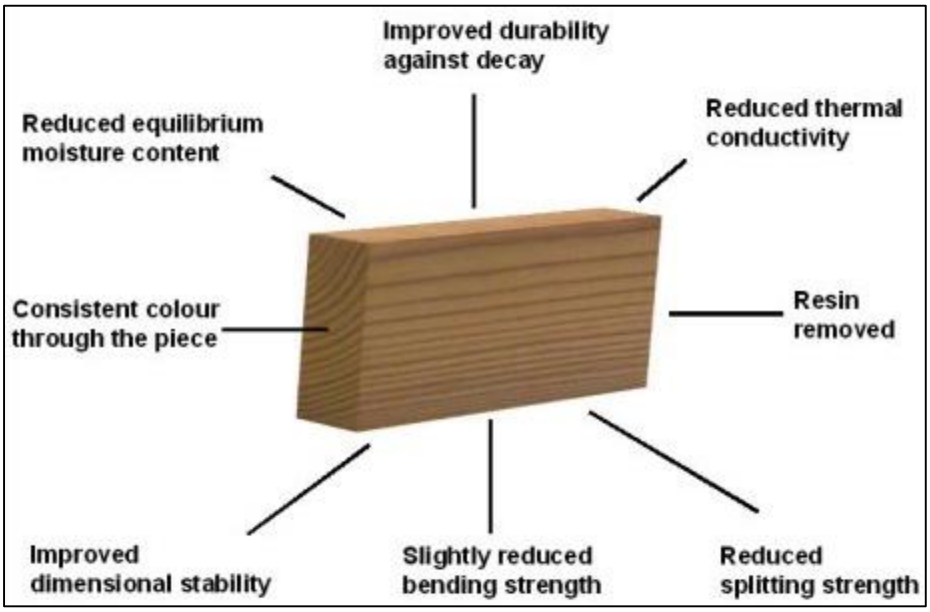


Figure 1 Increment and drain of the growing stock 1879-2013 (Metla 2.10.2014) (15)

7 THERMOWOOD PRODUCT

ThermoWood product is thermally modified soft- or hardwood. Most common wood materials are pine and spruce but many other wood species can also be thermally modified. However some wood materials tend to behave differently when thermal treatment is used and therefore all wood species cannot be used. For example some wood species tend to change physical shape by pending when the thermal treatment is used. Different wood specie's cell and pore structure and number of chemical enzymes effect on final product greatly. Most common properties for ThermoWood product are improved decay resistance, reduced heat conductivity and therefore improved insulation performance, resin removed, reduced splitting strength, slightly reduced bending strength, improved dimensional stability, consistent colour through treated wood, reduced wood's mass and reduced equilibrium moisture content. (16, 17, 18, 19)

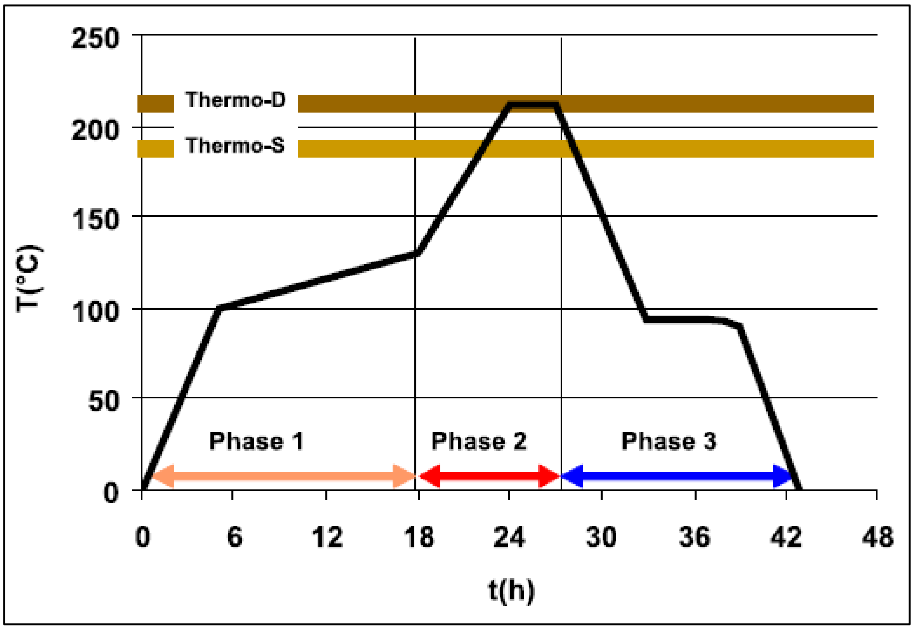


Picture 7 ThermoWood properties (17)

7.1 ThermoWood Treatment

ThermoWood products are thermally treated to ensure properties mentioned above. ThermoWood has two standard treatment classes, Thermo-S and Thermo-D. Thermal treatment takes normally five days, depending on wood species, by using a high temperature and water steam. No chemicals are used in the ThermoWood production process. The production process is divided in three different temperature working phases. By using steam and hot air in the process, temperature is in the first phase rapidly raised to 100 °C and then slowly to 130 °C. During this first phase the moisture content of the used wood is reduced to almost zero. Also some extractive agents like resins, terpene and formaldehydes extract from wood along with water when lignin starts to crack. Because wood easily splits when it is dry, steam used in heating process also prevents unnecessary splitting. (18, 20)

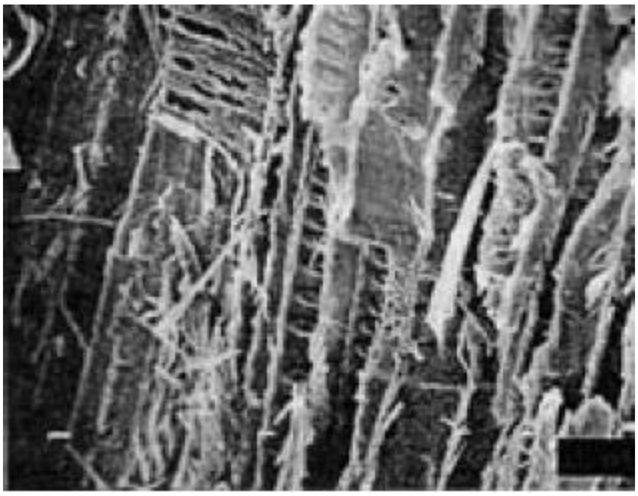
Second phase consists of actual thermal treatment, depending on the degree of treatment, when the temperature is let to rise above 185 °C and is kept there for 2-4 hours depending on wood. During this second phase when high temperature is used the wood is sprayed with water which protects the wood from igniting and from other influences like chemical changes. In the final phase the temperature is finally reduced by using the same water spray method. During this three phased process final product’s moisture content stabilizes at over four percent. (18, 20)



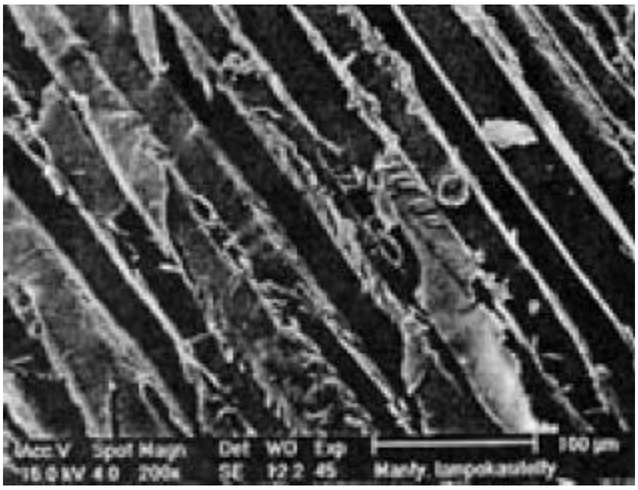
Picture 8 ThermoWood process phases (19)

When raw wood is treated with thermal treatment the wood structure will be re-formed to ensure specific properties characteristic for ThermoWood. Thermal treatment re-forms wood permanently and chemical and physical properties change in the final product. When the wood is heated it causes hemicelluloses in the wood to degrade and this is basically the reason why treatment produces ThermoWood. First structural changes starts to appear in raw wood in 150 °C temperature and structural changes continue during increasing thermal treatment after that specific temperature. Structural changes will settle down in phase 3 when the process is let to cool down.

As mentioned swelling and shrinkage because of moisture is decreased, biological durability is improved in high temperatures, colour darkens, several extractives flow from the wood during the process, pH decreases and thermal insulation properties are improved. However also wood’s rigidity and strength properties change during the thermal treatment. Following pictures show how the structure of pine wood changes after thermal treatment.



Picture 9 Untreated pine (21)



Picture 10 Pine after thermal treatment (21)

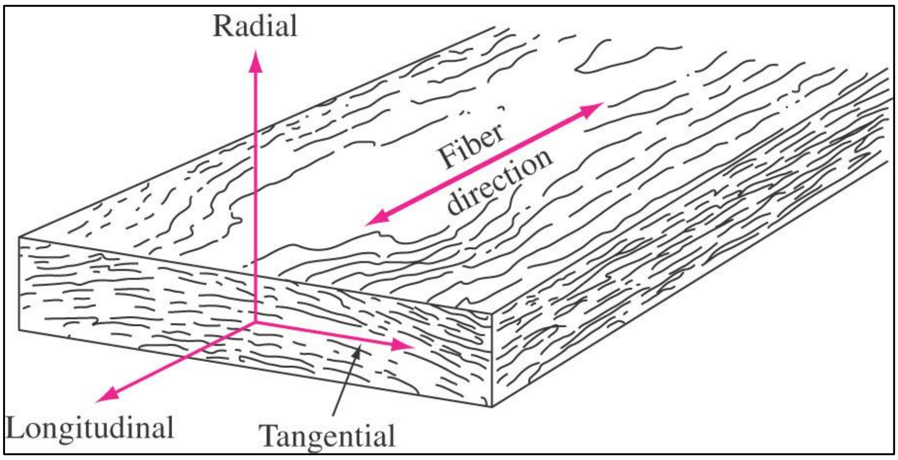
7.2 Thermo-S

Thermo-S term comes from “stability” where wood materials are modified by using lower temperatures than in Thermo-D products. Typically process temperatures are little bit over 185 °C but not over 200 °C. Alongside with stability, Thermo-S product’s appearance is slightly different than Thermo-D product’s. Where Thermo-D is darker when the thermal treatment is finished, the Thermo-S products are lighter coloured. The average tangential swelling and shrinkage because of moisture for Thermo-S class wood is 6-8 %. Thermo-S can be produced from softwood or hardwood.

When classified in standard SFS EN 350-1, the Thermo-S products are quite durable. Thermo-S products are in decay resistance class 3 when the scale is 1 very durable – 5 not durable. Thermo-S is not biologically very durable so main usage for this class is for example in indoor applications such as building components, furniture, flooring, fixtures in dry conditions, sauna benches, door and window components. Thermo-S can be also used in protected outdoor areas such as glazed balconies or in greenhouses. (16, 19, 20, 22, 24)

7.3 Thermo-D

Thermo-D term comes from “durability” where wood materials are modified by using higher temperatures than in Thermo-S products. Normal process temperatures for Themo-D class is above 200 °C which is much higher than in Thermo-S class. The average tangential swelling and shrinkage because of moisture for Thermo-S class wood is 5-6 %. When classified in the same standard EN 350-1 as Thermo-S, Thermo-D is classified to decay resistance class 1 or 2 which means very durable material. Class 1 materials can endure contact with ground roughly 25 years depending on moisture content of the soil. Thermo-D is after thermal treatment much darker than Thermo-S products and it has significantly better biological durability. Therefore Thermo-D class ThermoWood is more suitable for outdoor use but it can be also utilized in indoor use. Typical applications were Thermo-D is used are for example cladding, outer doors, shutters, flooring, garden furniture, sauna and bathroom furnishing. (16, 19, 20, 22, 24)



Picture 11 Lumber’s Gheometry (7)

8 CARBON FOOTPRINT

Carbon footprint is historically defined as “the total sets of greenhouse gas emissions caused by an organization, event, product or person”. However, in this research we were only interested in carbon dioxide (CO_2) emissions from manufacturing ThermoWood. Carbon footprint means total CO_2 amount produced from whole manufacturing and logistical cycle in one specific product. In this research the total CO_2 amount from ThermoWood’s whole production and logistical cycle in kilograms per one solid cubic meter of final product (kg [CO_2]/s-m^3 [ThermoWood]) was calculated. (24, 25)

9 CARBON FOOTPRINT CALCULATIONS

9.1 Combustion of Fuel Materials

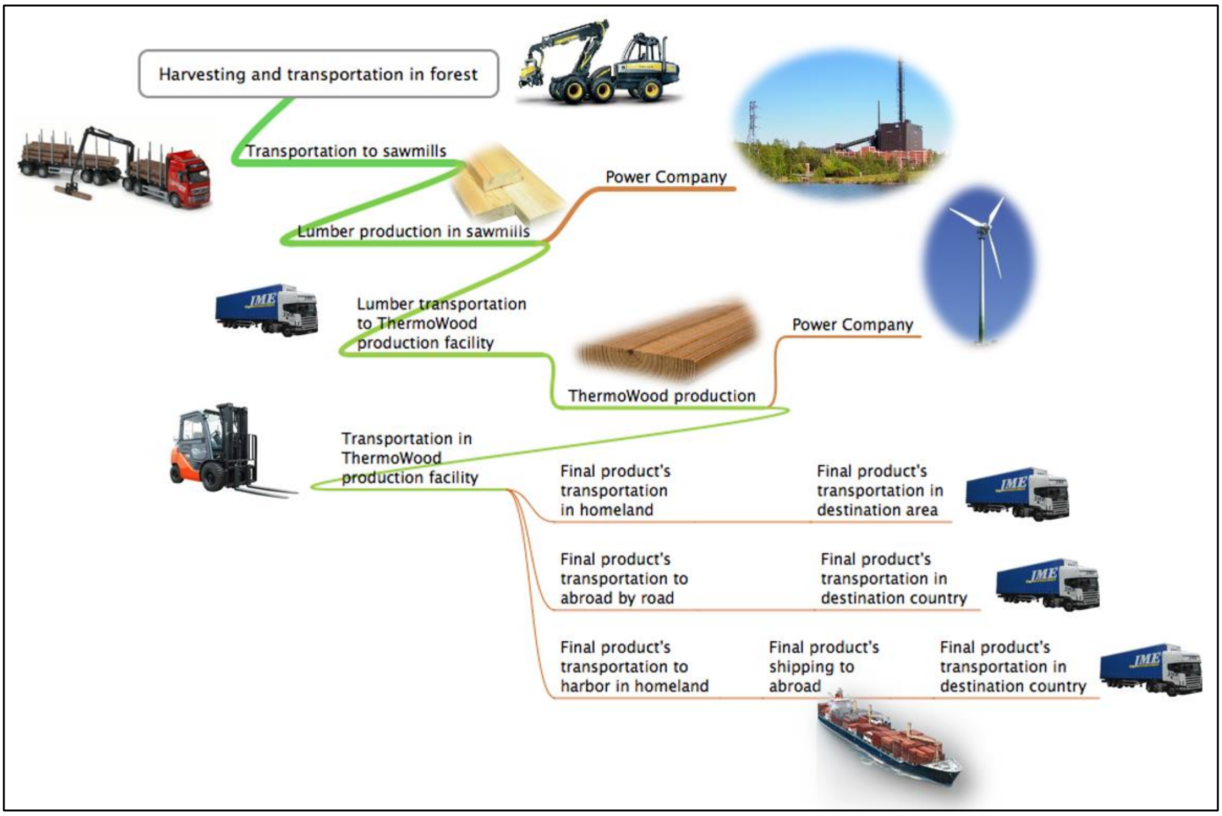
Carbon footprint was generally calculated by following the elemental carbon used in different kind of fuel materials in manufacturing process. Different kinds of materials like heavy oil, peat or liquefied petroleum gas (LPG) used in manufacturing process were thought through elemental carbon that those materials contain. That specific carbon amount was thought to be combusted and end up in carbon dioxide, so one specific amount of fuel used in ThermoWood or energy production related to ThermoWood process would create one specific amount of carbon dioxide. Final carbon dioxide was calculated by taking into account molecular factor in different kind of reaction formulas. For example when diesel oil is combusted, one mole corresponds 12 moles of CO_2 (see the reaction formula 1). Average chemical composition of diesel oil is considered to be $C_{12}H_{23}$.

$$\begin{array}{l} C_{12}H_{23} + 17{,}75\ O_2 \rightarrow 12\ CO_2 + 11{,}5\ H_2O \\ \quad 1\ mol \qquad\qquad\qquad 12\ mol \end{array} \tag{1}$$

Every calculation in this research follows this same idea to determine basic carbon amount used in specific process by using fuel which forms CO_2 while it is combusted. In some cases the final CO_2 amount is calculated by taking into account the heat values and how much CO_2 will that specific amount of heat or energy finally generate from the specific fuel. Material heat values were used when CO_2 amounts were calculated from saw mills but also in some cases in CO_2 emission determination from transportation.

9.2 Logistical Steps of ThermoWood

Data collection was done from companies producing ThermoWood, but also companies related to ThermoWood production, for calculations used in thirteen different sections shown below in Picture 12: Logistical cycle of ThermoWood product. The goal was to calculate enough accurate CO_2 emissions caused from these thirteen different steps from ThermoWood’s lifecycle from forest to final destination area before customer. These followed and calculated steps give enough accurate picture of the total CO_2 emission, which is released into the atmosphere when one solid cubic meter of ThermoWood product is produced and transported. Transportations and shipping emissions are the largest source of CO_2 in ThermoWood production. Almost in every calculated case in this report the emissions from transportation were over 40% from total CO_2 emissions.



Picture 12 Logistical cycle of ThermoWood product

9.3 PAS 2050:2011

Publically Available Specification (PAS) 2050 is a specification for the measurement and assessment of the life cycle greenhouse gas emissions of goods and services. It was first published by British Standards Institution (BSI) in 2008 and it was the first carbon footprint standard which was available to help companies or organizations measure the CO_2 impact from their goods and services.

Development of this standard was co-sponsored by Defra (Department for Environment, Food and Rural Affairs, UK), DECC (Department of Energy and Climate Change, UK) and BIS (Department for Business, Innovation and Skills, UK).

PAS 2050 gathers existing life cycle assessment methods from BS EN ISO 14040 and BS EN ISO 14044 and it gives requirements especially for the assessment of greenhouse gas emissions within the life or logistical cycle of goods and services. (26, 27)

10 CARBON DIOXIDE EMISSION CALCULATIONS

Every calculation in this final thesis is presented with imaginary values because confidential values from ThermoWood production or transportation cannot be used. Therefore calculations should read only as examples of how final values have been achieved.

10.1 Harvesting and Transportation in Forest

ThermoWood's calculation starts from the forest where raw wood is sawed down and transported to a road bank with heavy machinery. In this section it is assumed that logger operates in eight hour's shift. Breaks in shift are not taken into account. Fuel consumption for harvester is assumed to be 15 liters diesel oil per one hour and for the loader little bit less, 11 liters diesel oil per hour. Fuel consumptions values for harvester and loader were provided by the Forest institute in Kullaa. It is also assumed that loggers harvest wood approximately 250 solid cubic meters (s-m^3) in this eight hour shift which corresponds 31,25 s-m^3/h. From these assumptions and values we can calculate the CO_2 amount from harvesting and transportation in forest. (35)

Specific Diesel Consumption (SDC) for a harvester:

$$SDC = \frac{15\ L/h}{31{,}25\ (s{-}m^3)/h} = 0{,}48\frac{L}{s{-}m^3} \qquad (2)$$

Real diesel amount when diesel's density is taken into account:

$$0{,}48\frac{L}{s{-}m^3} * 0{,}85\frac{kg}{m^3} = 0{,}408\frac{kg}{s{-}m^3} \qquad (3)$$

Now diesel amount used in harvesting process when one s-m^3 of raw wood is treated in one hour is known. From this amount molar mass is determined for diesel oil:

$$n(diesel, C_{12}H_{23}) = \frac{m\ (g)}{M(\frac{g}{mol})} = \frac{408\ g}{167\ g/mol} = 2{,}44\ mol \qquad (4)$$

When the reaction formula (1) is used, the final CO_2 amount in moles is 12 times higher than diesel's →$12 * 2{,}44 mol = 29{,}32\ mol\ (CO_2)$, because 1 mole of diesel corresponds 12 moles of CO_2. From this molar amount the final amount of CO_2 in kilos is calculated:

$$m(kg[CO_2]) = \frac{n(CO_2)*M(CO_2)}{1000} = 1{,}29\ \frac{kg(CO_2)}{s{-}m^3(raw\ wood)} \qquad (5)$$

CO_2 amount for the loader is calculated in the same way. First the SDC is calculated and when the correct amount of diesel by using diesel's density is determined, diesel's molar amount can be calculated. Using same molecular factor (12) and calculating the final CO_2 amount through molar masses, the final CO_2 amount for loaders is 0,95 kg(CO_2)/s-m^3.

Total carbon dioxide load from harvesting raw wood and transport it to road bank for further transportation is **2,24 kg (CO_2)/s-m^3(raw wood)**, when CO_2 emissions from harvester and loader are took into account. In this research this value is used in all cases when referred to harvesting and transportation in forest. Results start to differ in transportation to sawmill, where the distances are not same.

10.2 Transportation to Sawmills

Truck transportation is calculated in the same way as harvesting process with harvester. Final CO_2 amount depends on how far the raw wood is transported to sawmill, how much raw wood truck can carry and how much truck consumes diesel oil in one hour. It was assumed that fulltrailer consumes diesel 55 liters when 100 km is travelled. This corresponds 0, 55 L/km. Truck loads in Finland are normally 50 s-m^3 raw wood when the truck is full.

Values for truck loads and consumptions were provided by Forest institute in Kullaa. CO_2 amount for the transportation to sawmill was calculated in the same way as with harvester previously. Average distances from forest to sawmill were asked directly from sawmills that were listed in the questionnaire sent back from the ThermoWood producers. (35)

For example, if distance between forest and sawmill is 135km, the diesel consumption can be calculated:

$$diesel\ consumption = 135\ km * 0{,}55 \frac{L}{km} = 74{,}25\ L \qquad (6)$$

Specific Diesel Consumption (SDC):

$$SDC = \frac{74{,}25\ L}{50\ s{-}m^3} = 1{,}485\ \mathrm{L/s\text{-}m^3} \qquad (7)$$

When diesel's density is taken into account the correct amount of diesel fuel is 1,26 kg/s-m^3. From this value calculated substance amount n(diesel) is 7,56 moles and finally, when molecular factor is took into account, the final CO_2 amount is **3,99 kg (CO_2)/s-m^3(raw wood),** when the truck transport equals 135km. Same calculation method is used with every sawmill which transportation distance is known. The variable in this section is the distance between forests and sawmill.

However, if there are several transportation routes, the final CO_2 emission from one specific transportation must be multiplied with weighted average values calculated from total transportation distance. For example if there are two different transportation distances, 135 km and 200 km, the weighted average is calculated by using total transportation distance which in this case is 335 km. From these values the percentage from total distance can be calculated and used in weighted average calculation for the first transportation:

$$\frac{135\ km}{335\ km} * 3{,}99\ \frac{kg(CO_2)}{s{-}m^3} = 1{,}61\ kg(CO_2)/s - m^3(raw\ wood) \qquad (8)$$

Second transportation emission is calculated in the same way as the first one and then multiplied with percentage from total distance to get the final weighted average value for the transportation. When values for both transportations are calculated by using percentage from total transportation distance, the final total CO_2 emission can be calculated by summing up all weighted average values.

10.3 Lumber Production in Sawmills

Carbon footprint from sawmills is calculated by taking into account sawmill’s annual lumber production, heat and electricity consumptions and also heat and electricity production’s fuel materials. Sawmills received an e-mail were those numbers and fuel materials were asked. Question like how far sawmills receive their raw materials averagely was also asked directly from sawmills that were listed in questionnaire sent back from the ThermoWood producers.

Annual production is needed to calculate the total CO_2 amount from sawmill to unit kg $(CO_2)/s\text{-}m^3$. Heat and electricity consumptions are needed to determine CO_2 which is caused from making heat and electricity. Heat values from different fuel materials are used in this section in CO_2 calculations, so the heat and electricity materials are also needed from sawmill.

Only non-renewable sources of energy and fuel materials are taken into account in CO_2 calculations. Materials like bark, wood chips or sawdust, if used in heat and electricity production, are not taken into account, because these are renewable energy materials, which eventually absorb CO_2 back to nature. Most sawmills produced own heat locally from renewable materials like bark, wood chips and sawdust. Some sawmills used oil in heat production to equalize suddenly grown lumber production. Major CO_2 emissions in lumber production how ever came from electricity consumption and used non-renewable fuel materials like coal, peat, oil and LPG (liquefied petroleum gas).

Usually electricity was bought from outside but in some cases sawmills produced their own electricity. Those companies which produced electricity to sawmill were studied to list all the materials they use in electricity production. If electricity was bought from stock market, the CO_2 amount was later estimated from results received from other companies.

For example, if sawmill used heat 45 MWh/a (produced 100% bark, wood chips and sawdust from sawmill) and electricity 5000 MWh/a (bought from company X) and annual production is 100.000 m^3, the CO_2 emissions were calculated in a following way:

Heat, which is produced from 100% bark, wood chips and sawdust, CO_2 emissions are **0 kg (CO_2)/s-m^3** because materials used in heat production are **renewable** and CO_2 will eventually absorb back to ecosystem.

Electricity bought from company X is produced from 45% peat, 46% wood and side products from sawmills, 5% from LPG and 4% from heavy oil. Only non-renewable materials are taken into account.

First the Specific Energy Consumption to one s-m^3 of final lumber is calculated:

$$SEC = \frac{1000*5000\ MWh}{100000\ m^3} = 50\ kWh/m^3 \qquad (9)$$

Only peat, LPG and heavy oil is taken into account:

$$PEAT\quad 0{,}45 * 50\frac{kWh}{m^3} = 22{,}5\ \frac{kWh}{m^3} \qquad (10)$$

$$LPG\quad 0{,}05 * 50\frac{kWh}{m^3} = 2{,}5\ \frac{kWh}{m^3} \qquad (11)$$

$$HEAVY\ OIL\quad 0{,}04 * 50\ \frac{kWh}{m^3} = 2\frac{kWh}{m^3} \qquad (12)$$

Total amount of fossil based electricity is 27 kWh/m^3. Fuel materials release specific amount of CO_2 when combusted, see table 1 below. Heat loss in power generation is not taken into account.

Table 4: Fuel materials specific CO2 emissions (28)

Fuel material	Specific CO_2 emission (kg[CO_2]/kWh)
Peat	0,38
LPG	0,24
Heavy oil	0,28

It is assumed that efficiency of back-pressure power plant is 80%. This means when 1 kWh electricity is produced, it consumes 1,25 kWh heat produced from a specific fuel material.

Now the CO_2 emission from different kind of fuel materials can be calculated:

$$PEAT \quad \frac{100\%}{80\%} * 0{,}38 \frac{kg(CO_2)}{kWh} * 22{,}5 \frac{kWh}{s{-}m^3} = 10{,}687\ kg(CO_2)/kWh \tag{13}$$

$$LPG \quad \frac{100\%}{80\%} * 0{,}24 \frac{kg(CO_2)}{kWh} * 2{,}5 \frac{kWh}{s{-}m^3} = 0{,}75\ kg(CO_2)/kWh \tag{14}$$

$$OIL \quad \frac{100\%}{80\%} * 0{,}28 \frac{kg(CO_2)}{kWh} * 2 \frac{kWh}{s{-}m^3} = 0{,}7\ kg(CO_2)/kWh \tag{15}$$

Company X's specific CO_2 emission is **12,14 kg (CO_2)/s-m^3 (lumber)**. Produced heat was calculated in the same way as produced electricity if non-renewable materials were used in production.

10.4 Lumber Transportation to ThermoWood Production Facility

This section was calculated in the same way as section 9.2 Transportation to sawmill. Final CO_2 amount depends on how far lumber is transported to ThermoWood production plant, how much lumber truck can carry and how much truck consumes diesel oil in one hour. It was assumed that fulltrailer consumes diesel 55 liters when 100 km is travelled. Also truck loads were assumed to be 50 s-m^3. Values for truck loads and consumptions were provided by Forest institute in Kullaa. Average distances from sawmill to ThermoWood production facility were asked from the ThermoWood producers in questionnaire or estimated by using map services founded from the internet. If there were several transportation routes from sawmills to ThermoWood production facility, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances. (35)

10.5 ThermoWood Production

CO_2 emission caused by ThermoWood production is calculated in a very similar way than lumber production's electricity and heat production from specific fuel materials. In questionnaire were asked how much electricity and heat will ThermoWood production take annually and from what fuel materials that electricity and heat is produced. Similarly when calculating CO_2 values from lumber production also this section were only non-renewable fuel materials taken into account.

If ThermoWood producer announced for example that they used for example 400000 liters of LPG annually to produce heat for production, the CO_2 emission was calculated in the following way:

First the right LPG mass was calculated by using LPG's density:

$$m(LPG, real) = m(LPG) * \rho(LPG) = 400000\ L * 0{,}51 \frac{kg}{L} = 204000\ kg \qquad (16)$$

When the right LPG mass was determined the Specific Fuel Consumption (SFC) could be calculated by dividing real LPG mass with annual production amount of ThermoWood:

$$SFC = \frac{204000kg(LPG)}{16000s{-}m^3} = 12{,}75\,\frac{kg(LPG)}{s{-}m^3} \qquad (17)$$

By using specific CO_2-emission for LPG the final CO_2-emission from using LPG in ThermoWood production can be calculated:

$$m(CO_2) = 3{,}0\,\frac{kg(CO_2)}{kg(LPG)} * 12{,}75\,\frac{kg(LPG)}{s{-}m^3} = 38{,}25\,\frac{kg(CO_2)}{s{-}m^3} \qquad (18)$$

When 400000 liters LPG is used to produce heat to ThermoWood production it will release **38,25 kg(CO_2)** into atmosphere when one solid cubic meter of ThermoWood is produced.

10.6 Transportation Inside ThermoWood Production Facility

In this section CO_2 emission caused by forklifts or any other machinery that are used in production facility related to ThermoWood production is calculated. In questionnaire it was asked how much non-renewable fuel materials, like LPG or oil, is annually used for example in forklifts.

CO_2 emission from forklifts is calculated similar way than CO_2 emission in ThermoWood production if only total mass of LPG or oil used in machinery was told in questionnaire. First the real density of used fuel material was calculated by using fuel’s density (calc. 15). When the mass of fuel was calculated, the SFC was calculated by dividing fuel’s real mass with annual production amount of thermowood (calc. 16). Total CO_2 amount is then calculated from SFC value by using specific fuel CO_2-emission values (calc. 17). Final CO_2-emission amount depends on used fuel materials and amount of fuel materials.

10.7 Product Domestic Transportation

Following sections related to transportation was calculated in a same way like in section 3.2 by using values for truck loads and consumptions provided by Forest institute in Kullaa. Calculation method is the same as in section 3.2 where only transportation distances will increase or decrease final CO_2 emission amount. SDC (specific diesel consumption) is divided by truck's total transportation capacity and not with the annual ThermoWood amount. Travel distances were only calculated between ThermoWood production facility and destination town or city and used in CO_2-emission calculations. If there were several transportation routes between ThermoWood production facility and destination areas, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances. (35)

10.8 Product Transportation in Destination Area

When the final product is transported by road to its destination town or city, the CO_2-emission from town's or city's local transportation was also calculated by using same values for truck loads and consumptions provided by Forest institute in Kullaa. Local transportation was estimated from maps from center of the town or city to its near outskirts. Overall transportation emissions from destination areas were quite small because transportation capacity is relatively big compared to transportation distances. If there were several transportations in various destination areas, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances. (35)

10.9 Product Transportation to Abroad by Road

Transportation to abroad by road was calculated same way as section 3.2 by using estimated shortest distances from given final stops that were listed in returned questionnaires. All transportation distances were estimated by fastest and shortest routes by land. If transportation included short ferry transportations those were not included in this survey.

CO_2 emissions from transportation to abroad by road was calculated similar way like in section 3.2. Travel distances were only calculated between ThermoWood production facility and destination town or city and used in CO_2-emission calculations. SDC (specific diesel consumption) was divided by truck's total transportation capacity and not with the annual ThermoWood amount. If there were several transportation routes between ThermoWood facility and destination countries, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances.

10.10 Product Transportation in Destination Country

This sections CO_2 emissions were calculated and estimated same way as section 3.8 where final product is transported to the nearby areas of final destination city or town. Transportation emissions were calculated by using same values for truck loads and consumptions provided by Forest institute in Kullaa. Local transportation was estimated from maps from center of the town or city to its near outskirts. Overall transportation emissions from destination areas were quite small because transportation capacity is relatively big compared to transportation distances. If there were several transportations in various destination areas, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances. (35)

10.11 Product Transportation to Harbor in Homeland

If final ThermoWood product was transported abroad by sea, the first step was to calculate the transportation to harbor. Like previous section, all transportation distances to harbor from ThermoWood production facility were estimated by fastest and shortest routes by land. CO_2 emissions from transportation to abroad by road was calculated similar way like in section 3.2. SDC (specific diesel consumption) was divided by truck's total transportation capacity and not with the annual ThermoWood amount.

If there were several transportations in various harbors, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances.

10.12 Product Shipping to Abroad

CO_2 emissions from shipping was estimated and calculated by using the website Sea-distances.org and given information about departure and arrival harbors from questionnaire sent to the ThermoWood producers. CO_2 emissions from shipping were calculated by using estimated engine power, cruising speed, heavy oil (fuel) consumption and cargo load. Ships differ a lot between sizes, cruising speed and cargo load so detailed emissions from shipping to abroad are difficult to calculate. In this section's calculations estimated values from various sources was used to achieve enough detailed CO_2 emissions values. (30)

For example if the departure harbor was Rauma and arrival harbor was in Dubai, the website given above calculated shipping distance to be 7262 nautical miles (NM) from shortest road through Suez Canal. This corresponds 13449 km when one NM is 1,852 km. It is estimated that ship's engine power is 9500 kW, cruising speed 35 km/h, heavy oil consumption 200 g/kWh and payload 80% from maximum which is 8000 bwt (brutto weight ton).

When calculating the fuel consumption in one hour the fuel consumption in one kilometer can be calculated:

$$fuel\ consumption = 200\,\frac{g}{kWh} * 9500\ kW = 1900\,\frac{kg}{h} \qquad (19)$$

$$\frac{fuel\ consumption}{km} = \frac{1900\ kg/h}{35\ km/h} = 54{,}29\ kg/km \qquad (20)$$

If oil's carbon content is 80 mass-%:

$$\frac{carbon\ amount}{km} = 0{,}80 * 54{,}29\frac{kg}{km} = 43{,}43\ kg(C)/km \qquad (21)$$

When that carbon is combusted in the following reaction formula (22), we get total CO_2 amount per one kilometer:

$$\begin{gathered} C + O_2 \rightarrow CO_2 \qquad (22) \\ 1mol + 1mol \rightarrow 1mol \end{gathered}$$

When one mole elemental carbon is combusted it will bind one mole oxygen and form one mole of carbon dioxide.

$$n(C) = \frac{m(C)}{M(C)} = \frac{43430\ g(C)}{12{,}01\frac{g(C)}{mol}} = 3616{,}15\ mol \qquad (23)$$

$$m(CO_2) = 3616{,}15\ mol * (32{,}0 + 12{,}01)\frac{g}{mol} = 159{,}2\ kg(CO_2)/km \quad (24)$$

$$\rightarrow \frac{159{,}2\ kg(CO_2)/km}{8000\ bwt} = 0{,}0199\frac{kg(CO_2)}{bwt * km} \qquad (25)$$

In other words one ton of final ThermoWood product corresponds **19, 9 g (CO_2)/km**. CO_2 emissions from shipping depends greatly on ship's cruising speed and how much cargo it can carry. When the distance from Rauma to Dubai via Suez Canal was 13449 km the total CO_2 emission will be **267, 63 kg (CO_2)/s-m^3(ThermoWood)** for this specific freight.

However these emissions from specific freights need to be calculated with weighted average values by taking percentage numbers of total amount of shipped ThermoWood from all freights. For example if ThermoWood is shipped to five different locations and total shipped amount of ThermoWood from all these transportations is 6000 s-m^3, the weighted average emission is calculated in the following way:

Shipped amount	%-fraction from total shipped ThermoWood
Transportation 1: 1000 s-m^3	16,67 %
Transportation 2: 500 s-m^3	8,33 %
Transportation 3: 250 s-m^3	4,16 %
Transportation 4: 1250 s-m^3	20,83 %
Transportation 5: 3000 s-m^3	50,00 %
Total 6000 s-m^3	Total 100 %

When percentage number is calculated it can be used to calculate weighted average value to first freight which CO_2 emission was 267,93 kg (CO_2)/s-m^3(ThermoWood):

$$0{,}1667 * 267{,}93\,\frac{\mathrm{kg}(CO_2)}{s-m^3} = 60{,}01\,\frac{\mathrm{kg}(CO_2)}{s-m^3} \qquad (26)$$

When finally every shipping emissions are calculated with weighted average the total CO_2 emission caused by shipping in kg(CO_2)/s-m^3(ThermoWood) can be calculated by summing up all weighted average values.

10.13 Product Transportation in Destination Country

This sections CO_2 emissions were calculated and estimated same way as section 3.8 where final product is transported to the nearby areas of final destination city or town. Transportation emissions were calculated by using same values for truck loads and consumptions provided by Forest institute in Kullaa. Local transportation was estimated from maps from center of the town or city to its near outskirts. Overall transportation emissions from destination areas were quite small because transportation capacity is relatively big compared to transportation distances. If there were several transportations in various destination areas, the final CO_2 emission was calculated with weighted average value similarly as in section 3.2. Weighted average values were calculated from total transported distances. (35)

10.14 Correction to Small Transportation Amounts

Some ThermoWood producers had only small amount to transport abroad from the whole annual production amount. Therefore also this had to be taken into account in calculations. When the total CO_2 emission was calculated in previous section with weighted average values, this final CO_2 emission value needed to be multiplied with percentage number of transported amount from whole ThermoWood production.

For example if company produces TerhmoWood annually 45000 m^3 but only 500 m^3 is transported to abroad by ship and 1500 m^3 by road from that amount. This means that transportation to abroad is only 2000 m^3. If the CO_2 emissions were for ship 150 kg(CO_2)/s-m^3(ThermoWood) and for road transportation 60 kg(CO_2)/s-m^3(ThermoWood) the final CO_2 is calculated in a following way:

$$\frac{500\,m^3}{2000\,m^3} * 150\,\frac{\mathrm{kg(CO_2)}}{s-m^3} = 37{,}5\ \mathrm{kg}(CO_2)/s - m^3(\mathrm{ThermoWood}) \tag{27}$$

$$\frac{1500\,m^3}{2000\,m^3} * 60\,\frac{\mathrm{kg(CO_2)}}{s-m^3} = 45{,}0\ \mathrm{kg}(CO_2)/s - m^3(\mathrm{ThermoWood}) \tag{28}$$

If however the transportation amounts to abroad were almost as high as the annual ThermoWood production, the final CO_2 emission calculated from transportation or shipping does not really change when taking into account the transportation ratio. This is because the ratio, which is calculated from transported amount divided with whole production, is almost one.

10.15 Summary from Calculation Results

ThermoWood producer	**A**	**B**	**C**	**D**	**E**	**F**
Harvesting and Transportation in Forest	2,24	2,24	2,24	2,24	2,24	2,24
Transportation to Sawmills	3,0	2,94	1,75	2,97	2,44	2,96
Lumber Production in Sawmills	36,97	0	39,71	127,50	121,62	8,30
Lumber Transportation to ThermoWood Production Facility	10,97	3,22	4,54	10,97	14,46	3,49
ThermoWood Production	0	0	68,46	63,63	78,45	0
Transportation Inside ThermoWood Production Facility	2,46	60,89	0,66	4,74	0,06	0
Product Domestic Transportation	8,99	6,96	1,34	5,37	10,17	14,49
Product Transportation in Destination Area	0,57	0,35	0	0	0,43	0,80
Product Transportation to Abroad by Road	45,79	32,48	21,22	61,20	61,13	43,62
Product Transportation in Destination Country	1,05	0,83	-	0,80	0,60	0,84
Product Transportation to Harbor in Homeland	3,89	9,27	6,32	4,84	8,65	-
Product Shipping to Abroad	15,59	58,90	20,0	15,02	16,02	-
Product Transportation in Destination Country	6,28	7,0	0,88	16,12	7,02	-

ThermoWood producer	**A**	**B**	**C**	**D**	**E**	**F**
TOTAL CO_2 (kg/s-m^3[ThermoWood])	158,18	185,08	163,52	315,31	323,31	76,74

AVERAGE CO_2 (kg/s-m^3[ThermoWood])	**203,69**

11 HOW TO REDUCE CARBON DIOXIDE EMISSIONS

As we can see from 10.15 Summary from Calculation Results, the biggest CO_2 source is transportation and shipping but also in some cases the manufacturing process if non-renewable fuel materials are used. These emissions can be however decreased by using renewable fuel materials and more environmentally friendly solutions in transportation methods. It is much more efficient when bigger amounts of product is transported at a time. Several smaller transportations increase overall CO_2 amount in a long run. This is challenging in road transportations where truck loads are controlled and cargo loads are significantly smaller than in ships. However if more aerodynamic trucks are used, it would decrease diesel consumption and eventually also CO_2 emissions. Also so called “super trucks” with one additional trailer could help decreasing emission loads when larger cargo loads would transport same amount of product with fewer transportations. However these larger trucks also need some change in the road network because only part of the whole road network is capable to handle the weight of these trucks.

11.1 Larger Truck Combinations and Air Resistance

If we compare how much difference there is between a normal fulltrailer and super truck with one additional trailer, we can calculate the diesel consumption in different speeds and how much force these trucks need to win in order to run. Full truck loads in Finland, considering cargo and truck's own weight, are approximately 55 tons but we can compare it to trucks that could carry up to 75 tons of mass. (31, 32)

Comparing cruising speeds 80 km/h and 70 km/h, we can determine force that truck needs to win in order to go forward. Forces that truck needs to win are friction force and air resistance. We can assume trucks surface area in front to be 9,46 m^2, when the height is 3,8 m and the width 2,49 m (32). Force is calculated in the following formula:

$$F = F_\mu + F_D = \mu_R m g + \frac{1}{2}\rho C_D A v^2 \tag{29}$$

Where μ_R= Friction coefficient
m = Truck combination's whole mass with cargo (kg)
g = Acceleration of gravity (m/s^2)
ρ = Density of air (kg/m^2)
C_D = Coefficient of resistance
A = Surface area of truck head (m^2)
v^2 = Truck speed (m/s)
F_μ = Friction force
F_D = Air resistance

When using coefficient of resistance value C_D = 0,7 and friction coefficient value μ_R = 0,08 (33) we can calculate forces to win for both transportations:

$$F_1 = 0{,}08 * 55000kg * 9{,}81\frac{m}{s^2} + \frac{1}{2} * 1{,}2\frac{kg}{m^2} * 0{,}7 * 9{,}46m^2 * (22{,}2\ m/s)^2 \tag{30}$$

$$F_2 = 0{,}08 * 75000kg * 9{,}81\frac{m}{s^2} + \frac{1}{2} * 1{,}2\frac{kg}{m^2} * 0{,}7 * 9{,}46m^2 * (22{,}2\ m/s)^2 \tag{31}$$

For 80 km/h cruising speed we get for normal truck F_1 = 45122 N and for the larger super truck F_2 = 60818 N. In other words, the larger truck needs to win 15,7 kN larger counter force than the smaller, conventional fulltrailer. However, the larger truck can carry 20 tons more cargo than its competitor. When the truck speed is decreased to 70 km/h the counter forces for both trucks are F_1 = 44666 N and F_2 = 60361 N. When the speed is dropped from 80 km/h to 70 km/h the counter forces are also decreased for smaller truck 456 N and for the bigger 457 N, which means force drop is basically the same for both truck combinations.

From these forces the diesel consumption can be calculated by using following formula:

$$W = F * s \qquad (32)$$

Where W = Work (J)
F = Force (N)
s = Distance (m)

When calculating work for 100 km transportation in 80 km/h cruising speed, work is:

$$W_1 = F_1 * s = 45122\,N * 100000\,m = 4512{,}2\,MJ = 1253{,}39\text{ kWh} \qquad (33)$$

$$W_2 = F_2 * s = 60818\,N * 100000\,m = 6081{,}8\,MJ = 1689{,}39\text{ kWh} \qquad (34)$$

Diesel oils specific energy content is 11,8 kWh/kg_{fuel} (28) and using this value the used diesel for 100 km transportation in 80 km/h cruising speed can be calculated:

$$Conventional\ fulltrailer = \frac{1253{,}39\,kWh}{11{,}8\,kWh/kg_{fuel}} = 106{,}22\,kg\ (Diesel) \qquad (35)$$

$$Larger\ fulltrailer = \frac{1639{,}39\,kWh}{11{,}8\,kWh/kg_{fuel}} = 143{,}16\,kg\ (Diesel) \qquad (36)$$

SDC in 80 km/h for both truck combinations are:

$$SDC_1 = \frac{106{,}22\ kg(diesel)}{50\ s{-}m^3} = 2{,}1244\frac{kg(diesel)}{s{-}m^3} \tag{37}$$

$$SDC_2 = \frac{143{,}16\ kg(diesel)}{70\ s{-}m^3} = 2{,}0451\frac{kg(diesel)}{s{-}m^3} \tag{38}$$

Diesel’s density is already took into account in specific energy content value. Calculating substance amount n(diesel) from both values above and when molecular factor is taken into account the final CO_2 amount for both truck combinations are **$m_1(CO_2)$ = 6,72 kg** and **$m_2(CO_2)$ = 6,47 kg**. These CO_2 emission amounts are per one cubic meter of transported product when operating efficiency is not taken into account. If operating efficiency is taken into account the final diesel and CO_2 amounts would be much higher because all energy from oil is not converted to kinetic energy. Roughly 25 % from energy which is produced with diesel oil is converted to kinetic energy. This means that final diesel amount and CO_2 amount is almost four times higher.

In other words, when these truck travel with 80 km/h speed one hundred kilometers, and when the resistance forces are taken into account, the larger truck is more efficient because it releases less CO_2 into atmosphere than the conventional truck. Truck emissions decreases slightly when larger trucks are used and more cargo can be transported at the same time. When the cruising speed is dropped to 70 km/h, the resistance force also drops in both cases almost the same amount. Final CO_2 emissions in that speed would be theoretically same as in 80 km/h speed but just smaller.

11.2 Cargo Ships

Cargo Ships are one of the biggest CO_2 emitters in transportation cycle, because distances are very long and fuel used in cargo ships are often oil based. However, fuel material can be also LPG which is less polluting solution comparing to oil. Fuel materials are not the only thing that will effect on the final CO_2 emission. The total CO_2 emissions caused by cargo ships are very difficult to calculate because it requires enormous amount of data basically from every existing ship. The variety of ships is much bigger than trucks because every ship is designed separately.

Like trucks, also dynamic shapes play a big role in efficiency. Better shapes in ship hulls will cut down hydrodynamic and also aerodynamic losses. Hull design also includes factors like advanced engine controls which also effect on carbon footprint. Also the speed plays an important role in the final emission value. Similarly like with the trucks, when the cruising speed is slowed down the final emission amount of CO_2 will also decrease. In summary, cargo ships emissions can be decreased when these things are taken into account already in ship planning. The change for new, better ships is however very slow because ships that already exist have a long lifetime in use and they do not necessarily have the best solutions when talking environmentally aspects. (34)

12 CONCLUSIONS

ThermoWood production process comparing to transportation cycle does not produce considerable CO_2 emission. As calculated, the biggest CO_2 emission source is transportation by road and sea which is averagely 48 % from all emissions. Actual ThermoWood and lumber production are both quite efficient when studying total CO_2 emission because in those production phases, almost in every case, renewable fuel materials were used. In ThermoWood facilities and sawmills, the electricity was bought outside which increased slightly the final CO_2 emission if electric companies used non-renewable fuel materials like peat, oil or LPG. Side products, like bark, sawdust and wood chips, in ThermoWood facilities and sawmills were used efficiently to produce heat and steam. Because these fuel materials were renewable, the final CO_2 emission was considerably smaller comparing to transportation cycle's emissions.

ThermoWood is environmental product from its overall CO_2 emissions but also because how it is done. No chemicals are used in the manufacturing process and the final product can be burnt after use without additional toxic emissions. CO_2 emissions from combusting wood is absorbed back to ecosystem to growing trees and other flora. This means almost zero net CO_2 emission from ThermoWood production process. As mentioned in section 6, the annual drain of wood in Finland is much smaller than the annual growth. Therefore CO_2 emissions from producing ThermoWood absorb back to ecosystem eventually.

Thermally treated wood is also much more durable than normal untreated wood and it is easily used in applications like building and furnishing materials both indoor and outdoor use. As building material it is, depending on quality, much safer to use than untreated wood in conditions were biological threats are possible.

SOURCES

1. The International ThermoWood Association's www-pages. 2013. Referred 13.5.2015. http://www.thermowood.fi

2. PuuProffa – Supporting Skills with Information www-pages. 2015. Structure of Wood. Referred 13.5.2015. http://www.puuproffa.fi/PuuProffa_2012/en/puun-rakenne/structure-of-wood

3. Vancouver Architectural Doors www-pages. 2015. Sapwood, heartwood, springwood and summerwood. Referred 13.5.2015. http://vancouverdoorco.com/sapwood-heartwood-springwood-and-summerwood/

4. Alternative11, Wood and Modern Technology, Livejournal, 22.9.2012, Referred 13.5.2015, http://alternative11.livejournal.com/33423.html

5. Univesity of Cambridge www-pages. 2015. The Structure of Wood (II), Referred 13.5.2015. http://www.doitpoms.ac.uk/tlplib/wood/structure_wood_pt2.php

6. Metsätieteiden laitos www-pages. 2006. Pinus sylvestris – Metsämänty, mänty. Referred 13.5.2015. http://www.helsinki.fi/metsatieteet/arboretum/puulajit/pinus_sylvestris.html

7. Paulo Monteiro. Referred 13.5.2015. www.ce.berkeley.edu/~paulmont/CE60New/wood.pdf

8. Wolman www-pages. 2015. Anatomical Structure of Wood. Referred 13.5.2015. http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/holzanatomie/index.php?thisID=329

9. Wolman www-pages. 2015. Structure of Coniferous Wood. Referred 13.5.2015. http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_nadelhoelzer/index.php?thisID=330

10. Wolman www-pages. 2015. Cross-section of a Spruce. Referred 13.5.2015. http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_nadelhoelzer/index.php

11. Wolman www-pages. 2015. Structure of Deciduous Wood. Referred 13.5.2015. http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_laubhoelzer/index.php?thisID=331

12. Wolman www-pages. 2015. Cross-section of an Oak. Referred 13.5.2015. http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_laubhoelzer/index.php?thisID=331

13. Wolman www-pages. 2015. Durability of Different Wood Types. Referred 13.5.2015. http://www.wolman.de/en/infocenter_wood/from_tree_to_wood/wood_properties/dauerhaftigkeit/index.php?thisID=332

14. Findicator www-pages. 2015. Increment and Drain of the Growing Stock 1879-2013. Referred 19.5.2015. http://www.findikaattori.fi/en/49

15. PuuProffa – Supporting Skills with Infromation www-pages. 2015. The Growth of Trees. Referred 19.5.2015. http://www.puuproffa.fi/PuuProffa_2012/en/puun-kasvu/the-growth-of-trees

16. Lunawood www-pages. 2015. Referred 19.5.2015. http://www.lunawood.fi/en/industry-processing-windows-doors-rough-thermowood/

17. The International ThermoWood Association’s www-pages. 2013. Properties of ThermoWood. Referred 19.5.2015. http://www.thermowood.fi/properties

18. fi.wikipedia.org www-pages. 2015. ThermoWood. Referred 19.5.2015. http://fi.wikipedia.org/wiki/L%C3%A4mp%C3%B6puu

19. The International ThermoWood Association’s www-pages. 2013. ThermoWood Brochure. Referred 19.5.2015. http://www.thermowood.fi/files/en.thermowood.kotisivukone.com/tiedostot/thermo_eng.pdf

20. SLP Thermowood www-pages. 2015. Production Process and Raw Material. Referred 19.5.2015. http://www.suomenlampopuu.com/en/slp-thermowood/production-process-and-raw-material/

21. The International ThermoWood Association’s www-pages. 2013. ThermoWood Handbook. Referred 19.5.2015. http://www.thermowood.fi/files/en.thermowood.kotisivukone.com/tiedostot/tw_handbook_080813.pdf

22. The International ThermoWood Association’s www-pages. 2013. Standard ThermoWood Treatment Classification. Referred 19.5.2015. http://www.thermowood.fi/classification

23. BS EN 350-1:1994 Durability of wood and wood-based products. Natural durability of solid wood. Part 1: Guide to the principles of testing and classification of the natural durability of wood.

24. en.wikipedia.org www-pages. 2015. Carbon Footprint. Referred 19.5.2015. http://en.wikipedia.org/wiki/Carbon_footprint

25. Time for Change www-pages. 2015. What is a Carbon Footprint – Definition. Referred 19.5.2015. http://timeforchange.org/what-is-a-carbon-footprint-definition

26. PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.

27. Trada – the Leading Authority on Wood www-pages. 2015. PAS 2050:2011 assessing the lifecycle greenhouse gas emissions of goods and services - A summary of the Standard and its background (Version 2). Referred 19.5.2015. http://www.trada.co.uk/publications/download/?id=1093800D-BE2D-4E28-B3B2-9477915CB3AF

28. The Engineering Toolbox www-pages. 2015. Combustion Fuels – Carbon Dioxide Emission. Referred 19.5.2015. http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

29. Sea-Distances.org www-pages. 2015. Referred 19.5.2015. http://www.sea-distances.org/

30. apks blog www-pages. 2015. Ajoneuvojen mitat ja massat. Referred 19.5.2015. http://www.apks.fi/blogi/2013/ajoneuvon-mitat-ja-massat/

31. Volvo Trucks www-pages. 2015. Suurimmat sallitut kokonaismassat ja mitat. Referred 19.5.2015. http://www.volvotrucks.com/trucks/finland-market/fi-fi/PublishingImages/Trucks/Kokonaispainojuliste_web.jpg

32. Volvo Trucks www-pages. 2015. Volvo FH:n ohjaamoerittelyt. Referred 19.5.2015. http://www.volvotrucks.com/trucks/finland-market/fi-fi/trucks/volvo-fh-series/specifications/Pages/cab-specifications.aspx

33. Inkinen & Tuohi, 2009, Momentti 1: Insinöörifysiikka. Helsinki: Otawa

34. The International Council on Clean Transportation www-pages. 2015. Consumers, shipping and our carbon footprint. Referred 24.5.2015. http://www.theicct.org/blogs/staff/consumers-shipping-and-our-carbon-footprint

35. Hiltunen, P. 2015. Forest Institute Kullaa, Winnova. Kullaa. 26.2.2015. Referred 19.5.2015.