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DEVELOPMENT AND TESTING OF THE CALCULATION TOOL FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM FINNISH SAWMILLS

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ABSTRACT

Climate change is caused by anthropogenic emissions, and many countries in the European Union, including Finland, prepare strategies to reduce their greenhouse gas (GHG) emissions. Finnish sawmill industry, which is a significant part of the Finnish economy, aims to reduce its impact on climate change before 2035 by decreasing its emissions by half. One of the methods to determine the influence of Finnish sawmills' operations on climate change is to conduct carbon footprint inventory.

The commissioner of this thesis project had identified a need to develop a tool which enables Finnish sawmills to understand their CO_2-equivalent status, as there has yet been no solution tailored for Finnish sawmilling companies, one that may be used by sawmill managers unfamiliar with GHG emissions calculations.

The objective of this thesis project was to create a Microsoft Excel-based calculation model for estimating GHG emissions released from Finnish sawmills' activities in the year 2022. The GHG Protocol Corporate Accounting and Reporting Standard was taken as the basis for the calculation tool. Sawmill companies' sources of GHG emissions were identified from the literature, and from visiting and observing the operations of three sawmills located in different parts of Finland.

Additionally, the calculation tool was tested on a real sawmill in order to identify possible flaws and find suggestions for improving the calculation model. The pilot project was run on a middle-sized sawmill, located in the North Savo region of Finland.

Keywords: climate change, greenhouse gas inventory, carbon footprint, GHG Protocol, emission factor, sawmill

CONTENTS

APPENDICES

LIST OF ABBREVIATIONS

CSRD	Corporate Sustainability Reporting Directive
ESG	Environmental, Social, and corporate Governance
ESRS	European Sustainability Reporting Standards
EU	European Union
CH	Methane
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
GHG	Greenhouse gas
GWP	Global Warming Potential
N_2O	Nitrous oxide
IPCC	Intergovernmental Panel on Climate Change

1 INTRODUCTION

Climate change mitigation and reduction of greenhouse gas (GHG) emissions are the topics that dominate environmental policy discussions nowadays (Hanley et al. 2019, 265-266). In the last 20 years climate change has been assessed by International Panel on Climate Change (IPCC 2022a). One of the key findings in the latest IPCC Assessment Report was that anthropogenic emissions must be limited to a specific level to provide a safe environment for people and nature (IPCC 2022b, 9-11).

The countries of the European Union are now revising and implementing long-term strategies to reduce the GHG emissions (Regulation (EU) 2018/841). For example, Finland is aiming to reduce GHG emissions by 60% by 2030 and become carbon neutral by 2035 (Ministry of Economic Affairs and Employment of Finland 2022/55). Finnish sawmill industry, which is a significant part of the Finnish economy, aims to reduce its impact on climate change before 2035 by decreasing its emissions by half (Merivuori 2021). One of the methods to determine the influence of Finnish sawmills' operations on climate change is to conduct carbon footprint calculations (Una Europa 2022).

The commissioner of this work is 1point5 Oy, a Finnish consulting, equipment supplies and project management company for industrial wood processing businesses (1point5 Oy 2023). 1point5 Oy had identified a need to develop a tool which enables Finnish sawmills to understand their CO_2-equivalent (CO_2-eq) status and calculate their greenhouse gas emissions. There is yet no solution tailored for Finnish sawmilling companies, one that may be used by sawmill managers unfamiliar with GHG emissions calculations.

The aims of this thesis project were to create a calculation model for estimating GHG emissions released from Finnish sawmills' activities, and to test the tool on a real sawmill in order to identify possible flaws and find suggestions for improving the calculation tool. The pilot project was run on a middle-sized sawmill (production volume less than 200 m3 of sawn timber), located in the North Savo region of Finland. The research objective question is: what are the main sources of GHG emissions at Finnish sawmills, and how these emissions can be calculated?

2 THEORETICAL BACKGROUND

2.1 Greenhouse gases and their contribution to global warming

Climate change is undeniably one of the biggest challenges for humanity in the 21st century. Fluctuations in climate bring various ecological consequences, both direct and indirect, such as weather phenomena, ecosystems and biodiversity loss, and human health threats. Changes in climate happen because of the atmosphere's constantly increasing temperature. (Manahan 2010, 420-425; Hanley et al. 2019, 265-266.)

There are several infrared-absorbing gases that, when in excess, hold too much heat, trap the outward radiation, and by this cause “greenhouse” effect. The main greenhouse gases that are released from anthropogenic sources are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). (Global Carbon Project 2021.) The measure used to assess the influence of greenhouse gas emissions is radiative forcing, expressed in watts per square metre (W/m^2). Positive value of radiative forcing leads to the warming of the Earth's surface and contribute to global warming of climate. (IPCC 2013, 13-14.)

The total anthropogenic radiative forcing has been noticed to be rapidly increasing. As presented in Figure 1, the radiative forcing for 2011 relative to the value for 1750 is 2,29 W/m^2. (IPCC 2013, 13-14.) Overall, the concentrations of greenhouse gases in the atmosphere have increased by approximately 30% in the last 200 years and continue to grow. This growth is mainly caused by human activities, such as burning of fossil fuels, which must be regulated and reduced. (Hanley et al. 2019, 265-266.)

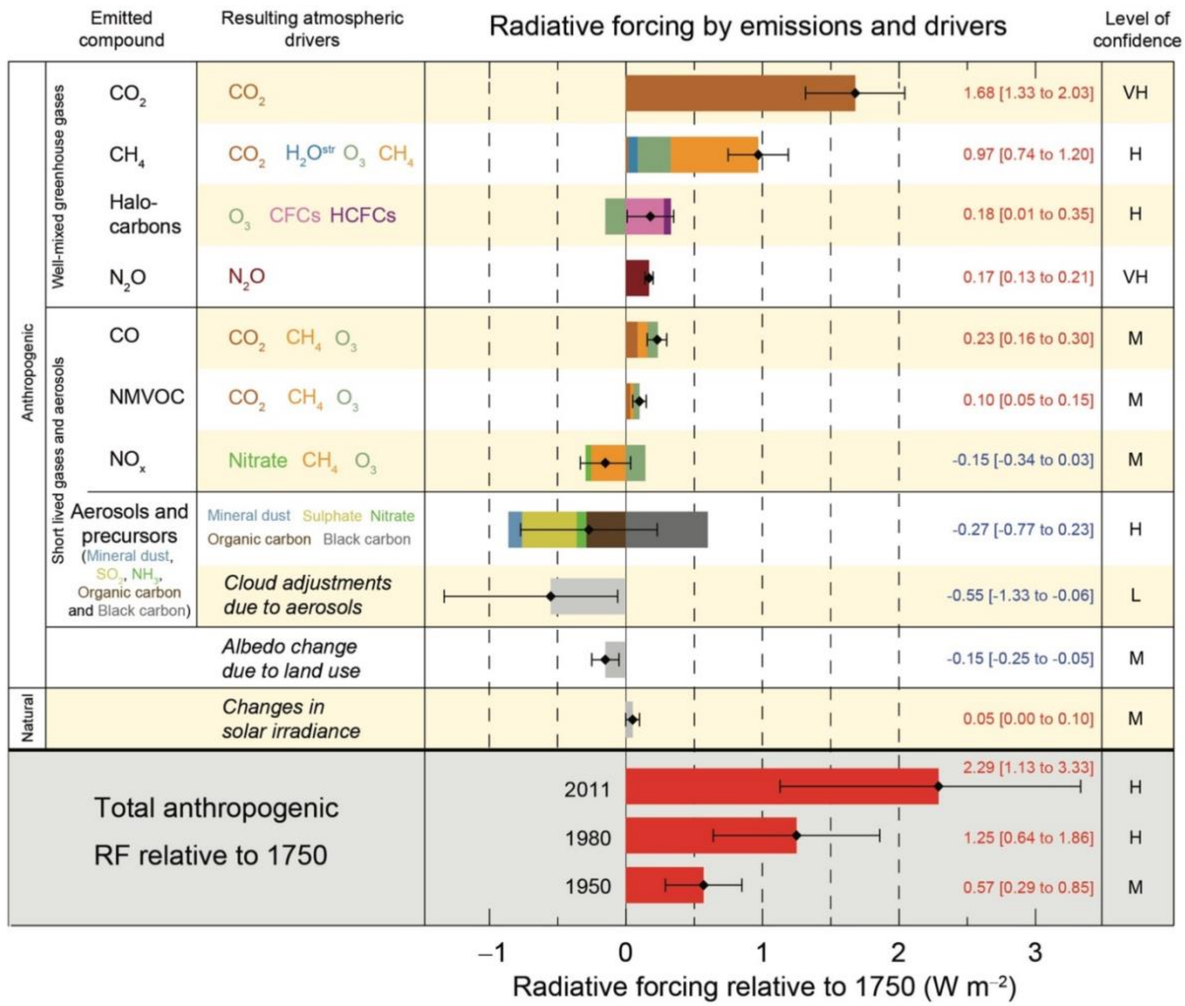

Figure 1. Radiative forcing in 2011 relative to 1750 (IPCC 2013, 13-14).

2.2 Corporate sustainability regulation in the European Union

The European Commission has recently published a Corporate Sustainability Reporting Directive (CSRD), which requires non-listed companies operating in the European Union to prepare non-financial reports that will disclose their environmental, social, and corporate governance (ESG) information. Many large sawmills fall under this new directive, and as large organizations will have to report their sustainability matters in 2026 for the financial year 2025. (European Commission 2023.)

Moreover, the European Sustainability Reporting Standards (ESRS), which are supporting the CSRD, were adopted by the European Commission at the end of July 2023. One of the sustainability topics covered by ESRS is climate. This section of sustainability reporting standards covers a company’s past, present, and future efforts toward climate change mitigation, of which the greenhouse gas emissions inventory is an indispensable part. (European Commission 2023.)

In addition to the legal requirements, there is also a high demand among organizations and companies to understand their CO_2-eq status by conducting carbon inventory, to reduce GHG emissions, to become more transparent and participate in the carbon and GHG emissions inventory disclosure. Apart from ethical and environmental concerns, there are financial reasons behind this will. Carbon disclosure may improve company image, and therefore, attract customers and investors conscious about climate change. Moreover, emissions disclosure leads to a better carbon management within a company and, consequently, energy consumption related costs are reduced. Nature and environmental regulatory risks are better estimated. (Hanh et al. 2015.)

2.3 Global warming potential

As mentioned above, there are various greenhouse gases contributing to global warming and climate change. To determine the effect of these gases, relative greenhouse gas emission metrics are used, one of which is the Global Warming Potential (GWP). GWP is an index quantifying the radiative forcing, in other words, the difference in the net radiative flux due to an increased concentration of a GHG, accumulated over a time horizon. In this study the time horizon of 100 years is chosen (Table 1). Thus, the GWP indicates cumulative effectiveness of the GHGs causing radiative forcing and the duration they remain in the atmosphere. (IPCC 2021, 109.)

Table 1. Global Warming Potential values of carbon dioxide, methane and nitrous oxide (IPCC 2013, 731).

	100-year time horizon
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous oxide (N_2O)	265

In the GWP metric, carbon dioxide is taken as a reference gas, and the emissions of the other non-carbon gases are expressed as “carbon dioxide equivalent” emissions, or CO_2-eq. Even though CO_2 covers most greenhouse gas emissions for sawmills (National Council for Air and Stream Improvement 2005, 11-12), methane and nitrous oxide emissions are also to be included in the calculation model in this thesis.

2.4 Fuel types

It is crucial to distinguish and calculate separately the emissions produced from combustion of fossil fuels and biofuels. Carbon dioxide emissions occurring from combustion of biofuels are classified as BIO and are not included in the total emissions amount. For example, wood fuels, such as chips, bark, and sawdust, are biofuels. Moreover, fuels used for industrial purposes are often blended, and may contain a certain biofuel share. (Statistics Finland 2022.)

2.5 Emission factor

To calculate the approximate amount of the GHGs emitted from an anthropogenic activity, an activity rate and a documented emission factor should be applied. The simplified Equation 1 (United States Environmental Protection Agency 2023) is used in this calculation approach.

$$E = A \cdot EF \tag{1}$$

where	*E*	emissions	[CO_2-eq]
	A	activity rate	[-]
	EF	emission factor	[-]

Activity rate is, for example, the amount of energy used, or fuel combusted per unit activity. Emission factor, or emission intensity, is a coefficient that evaluates the emissions of a gas per unit activity (IPCC 2021). Therefore, sawmills’ activities and emissions sources must be clearly determined when GHG inventory is conducted.

Emission factors for some fuels vary from year to year because their average biofuel share can change (Statistics Finland 2023). Moreover, the emission factor for the national electricity production fluctuates daily, as the ratio of renewable and fossil-based fuels used for energy production changes every day, depending on the demand and weather conditions. In Finland, fuels used in combustion plants for domestic energy production are natural gas, coal, oil, peat, biomass and indigenous waste fuels (Energiateollisuus 2023).

2.6 GHG Protocol

Based on IPCC reports, various carbon footprint calculation methodologies and frameworks have been created, one of which is the GHG Protocol Corporate Accounting and Reporting Standard. This protocol is mainly purposed for corporate usage and categorises companies' GHG emissions into 3 scopes: direct emissions, produced by company-owned equipment, machinery, and vehicles; indirect emissions from purchased electricity and heat; and all other indirect emissions that occur in a company's upstream and downstream value chain. The more detailed explanation of these scopes is presented in Table 2. (Greenhouse Gas Protocol 2023, World Resources Institute and World Business Council for Sustainable Development 2004.)

Table 2. GHG Protocol's 3 scopes (Greenhouse Gas Protocol 2023).

Scope 1	Direct emissions from company-owned activities, such as: • Onsite heat or electricity production • Fuel combustion by company-owned vehicles and equipment
Scope 2	Indirect emissions generated from purchased power production. These emissions are the consequence of a company's activities but generated by and purchased from a utility company.
Scope 3	All other indirect emissions that occur in a company's value chain. These emissions are generated from the indirect activities and listed in 15 categories.

It is important to note that the GHG emissions should be accounted for yearly, starting from the base year. It is required to define the base year, so the emissions could be compared over time. Moreover, the time period boundary should be set, because the emission factors for different fuels and energy sources change over time. (World Resources Institute and World Business Council for Sustainable Development 2004.)

3 METHODS

3.1 Development of a calculation tool

The GHG Protocol Corporate Accounting and Reporting Standard (World Resources Institute and World Business Council for Sustainable Development 2004) was taken as the basis for the calculation tool. Operational boundaries of a sawmill were set based on the GHG Protocol Corporate Accounting and Reporting Standard's recommendations (National Council for Air and Stream Improvement 2005).

Sawmill companies' sources of GHG emissions were identified from the Sawmill Industry handbook by the Association of Finnish Sawmillmen (2018). Additionally, three sawmills located in Finland were visited and observed. The aim of the observations was to become more familiar with sawmill operations and identify possible sources of GHG emissions, such as energy generation facilities and means of transportation combusting fuels.

The time period boundary was set: all the calculations were completed for activity performed in the year 2022. Based on the identified emission sources and time period boundary, the relevant emission factors were found. Also, the calculation methods (equations) to estimate the amount of emissions were developed. The equations that are used for GHG emissions calculations in this thesis were developed following the GHG Protocol Standard's guidance (National Council for Air and Stream Improvement 2005).

The calculation tool was created in Microsoft Excel. This software is widely accessible by sawmill managers, who are the target users of this calculation tool. Moreover, Microsoft Excel allows to set formulas and perform calculations.

3.2 Pilot project

The calculation tool was tested on a Finnish sawmill. A semi-structured interview with the sawmill's managing director was conducted, and the calculation model was filled in with the real data of the year 2022. A week prior to the interview, the list of questions was sent to the interviewee. The questionnaire is attached in Appendix 1.

4 RESULTS

4.1 GHG calculation tool

Operational boundaries were set: the calculation tool only includes GHG emissions generated from activities listed in scope 1 and scope 2 of the GHG Protocol Corporate Accounting and Reporting Standard. Only direct GHG emissions and electricity indirect GHG emissions are accounted. Due to time and resource limitations, it was challenging to also include scope 3 in the calculation model. Moreover, scope 3 activities vary from one sawmill to another, and to make precise calculations of emissions generated from other indirect emission sources case-by-case calculations would be required.

The emission sources were identified from the typical sawn timber production process in Finland described at the Sawmill Industry handbook by Association of Finnish Sawmillmen (2018), as well as from the observations. Three wood processing facilities located in different regions of Finland were visited and observed: Versowood Vierumäki in Päijät-Hame, Iisveden Metsä Oy in North Savo, and Tervolan Saha ja Höyläämo Oy in Lapland. The visited sawmills are all different in the size of their areas and production volumes. However, they have similar sources of GHG emissions, such as energy generation facilities and vehicles.

Typically, sawmilling involves such processes as log sorting and transportation, wood processing, drying of timber, and final product transportation. A heating or combined heat and power (CHP) plant is also often located on the premises of a Finnish sawmill. (Association of Finnish Sawmillmen 2018, 81). These processes generate GHG emissions from fuel combustion and electricity use.

The identified common direct emission sources at sawmills are energy generation facilities and transportation. Sawmills in Finland produce a significant number of combustible residues, such as bark and sawdust, and are self-sufficient in heat generation (Association of Finnish Sawmillmen 2018, 145). It was identified that the only purchased power is electricity. Therefore, purchased electricity is the only indirect emission source considered in this calculation model. In Table 3 the detailed list of Finnish sawmills' emission sources, used in the calculation tool, is presented.

Table 3. Emission sources and fuel types at sawmills in Finland.

Emission sources		**Fuel type [unit]**
Scope 1	Energy generation facilities: – Boilers – Combined heat and power plants (CHP)	Bark [cubic metres]
		Heating oil [litres]
		Sawdust [cubic metres]
		Wood chips [cubic metres]
	On-road vehicles: – Trucks – Passenger automobiles	Diesel [litres]
		Electricity [kWh]
		Petrol / gasoline [litres]

	Off-road vehicles: – Harvesters – Forwarders – Forklifts – Wheel loaders	Diesel [litres] Liquefied petroleum gas (LPG) [litres]
Scope 2	Purchased electricity	Electricity [MWh]

4.1.1 Calculating direct GHG emissions from energy generation facilities

Power generation plants that are located on sawmills' premises usually use fuel blends, the mixture of bio and fossil fuels. Depending on the type of fuel, whether it is in a liquid or solid form, litre or cubic metres units are used, respectively. Equation 2 is used for estimating fossil-based greenhouse gases (in CO_2-equivalent form) emitted during combustion of each fuel type. Total emissions by the company during the process of power generation can be calculated as a sum of these individual emission values.

$$GHG\ Emission_{fossil\ on-site\ energy} = \frac{V \cdot U \cdot (EF_{CO2} \cdot c_{fossil} + EF_{CH4} \cdot GWP_{CH4} + EF_{N2O} \cdot GWP_{N2O})}{1000} \quad (2)$$

where	$GHG\ Emission_{fossil\ on\text{-}site\ energy}$	total fossil-based GHG emissions from on-site energy production	[tCO_2-eq]
	V	volume of fuel combusted	[l] or [m^3]
	U	energy density of fuel	[GJ/l] or [GJ/m^3]
	EF_{CO2}	emission factor for carbon dioxide	[kg CO_2/GJ]
	c_{fossil}	fossil fuel share coefficient	[-]
	EF_{CH4}	emission factor for methane	[kg CH_4/GJ]
	GWP_{CH4}	global warming potential for methane	[-]
	EF_{N2O}	emission factor for nitrous oxide	[kg N_2O/GJ]
	GWP_{N2O}	global warming potential for nitrous oxide	[-]

According to GHG Protocol Corporate Accounting and Reporting Standard (2004), bio-based carbon dioxide emissions should be calculated and reported separately. Equation 3 is used for this purpose.

$$GHG\ Emission_{\ bio\ on-site\ energy} = \frac{V \cdot U \cdot EF_{CO2} \cdot c_{bio}}{1000} \quad (3)$$

where	*GHG Emission* *bio on-site energy*	total biobased GHG emissions from on-site energy production	[tCO_2-eq]
	V	volume of fuel combusted	[l] or [m^3]
	U	energy density of fuel	[GJ/l] or [GJ/m^3]
	EF_{CO2}	emission factor for carbon dioxide	[kg CO_2/GJ]
	c_{bio}	biofuel share coefficient	[-]

Emission factors for carbon dioxide are predefined in the Excel calculation tool, as well as the energy density of fuels and biofuel share. This data was obtained from Statistics Finland (2022) database. It is important to note that in Statistics Finland database the energy density is represented in *GJ/t* unit, while in this calculation tool the fuels are stated in m^3 and *l*. Cubic metres and litres are the units in which fuels are purchased and are more familiar to the end users of the calculation tool. Therefore, energy density values were converted to GJ/m^3 unit for wood residues and *GJ/l* unit for heating oil (Appendix 2). Emission factors for methane and nitrous oxide were obtained from Fortum Power and Heat Oy (2001) for biofuels, and from the report by National Council for Air and Stream Improvement (2005) for heating oil. All this data is summarized in Table 4.

Table 4. Fossil fuel and biofuel share coefficients, energy density and emission factors for fuels used in on-site energy production (Fortum Power and Heat Oy 2001, National Council for Air and Stream Improvement 2005, Statistics Finland 2022).

Fuel type [fuel unit]	**Fossil fuel share coefficient [-]**	**Biofuel share coefficient [-]**	**Energy density [GJ/fuel unit]**	**Emission factor for carbon dioxide [kg CO_2/GJ]**	**Emission factor for methane [kg CH_4/GJ]**	**Emission factor for nitrous oxide [kg N_2O/GJ]**
Bark [m^3]	0	1	3.38	112.00	0.030	0.004
Heating oil [l]	0.96	0.04	0.036	70.2	0.002	0.001
Sawdust [m^3]	0	1	2.17	112.00	0.030	0.004
Wood chips [m^3]	0	1	2.94	112.00	0.030	0.004

GWP coefficients (Table 1) are also set in the calculation model. Sawmill managers only insert the volume of combusted fuel in the year 2022 to get an estimation of total greenhouse emissions generated by power production. This information is usually available from the purchasing records of a company. Appendix 2 demonstrates how the calculation model for this scope is presented in Excel.

4.1.2 Calculating direct GHG emissions from transportation

It was assumed that sawmill managers do not have data of the total amount of fuel consumed by company-owned vehicles per year. Therefore, the calculation tool users need to insert the average fuel economy of a vehicle, the annual distance travelled by a vehicle, and a number of similar vehicles. The other parts of the equation are predefined in the Excel formula.

It is important to note that the fuel economy unit for on-road vehicles run on liquid fuels is *l/100 km*, and for electric vehicles it is *kWh/100 km*. For off-road vehicles the fuel economy unit is *l/hour*. Therefore, different equations should be used for calculating total fossil-based greenhouse gases emitted from on-road and off-road vehicles' exhaust pipes (Equation 4 and Equation 5 respectively).

$$GHG\ Emission_{fossil\ on-road} = \frac{\frac{FE \cdot d \cdot n}{100} \cdot U \cdot (EF_{CO2} \cdot c_{fossil} + EF_{CH4} \cdot GWP_{CH4} + EF_{N2O} \cdot GWP_{N2O})}{1000} \quad (4)$$

where	$GHG\ Emission_{fossil\ on\text{-}road}$	total fossil-based GHG emissions from on-road vehicles	[tCO_2-eq]
	FE	fuel economy of a vehicle	[l/100 km]
	d	average annual distance travelled by a vehicle	[km]
	n	number of similar vehicles	[-]
	U	energy density of fuel	[GJ/l]
	EF_{CO2}	emission factor for carbon dioxide	[kg CO_2/GJ]
	c_{fossil}	fossil fuel share coefficient	[-]
	EF_{CH4}	emission factor for methane	[kg CH_4/GJ]
	GWP_{CH4}	global warming potential for methane	[-]
	EF_{N2O}	emission factor for nitrous oxide	[kg N_2O/GJ]
	GWP_{N2O}	global warming potential for nitrous oxide	[-]

$$GHG\ Emission_{fossil\ off-road} = \frac{FE \cdot t \cdot n \cdot U \cdot (EF_{CO2} \cdot c_{fossil} + EF_{CH4} \cdot GWP_{CH4} + EF_{N2O} \cdot GWP_{N2O})}{1000} \quad (5)$$

where	$GHG\ Emission_{fossil\ off\text{-}road}$	total fossil-based GHG emissions from off-road vehicles	[tCO_2-eq]
	FE	fuel economy of a vehicle	[l/h]
	t	average annual operating hours of a vehicle	[h]
	n	number of similar vehicles	[-]
	U	energy density of fuel	[GJ/l]
	EF_{CO2}	emission factor for carbon dioxide	[kg CO_2/GJ]
	c_{fossil}	fossil fuel share coefficient	[-]
	EF_{CH4}	emission factor for methane	[kg CH_4/GJ]

GWP_{CH4}	global warming potential for methane	[-]
EF_{N2O}	emission factor for nitrous oxide	[kg N_2O/GJ]
GWP_{N2O}	global warming potential for nitrous oxide	[-]

To calculate bio-based carbon dioxide emissions, Equations 6 and 7 should be utilized for on-road and off-road vehicles respectively.

$$GHG\ Emission_{\ bio\ on-road} = \frac{\frac{FE \cdot d \cdot n}{100} \cdot U \cdot (EF_{CO2} \cdot c_{bio})}{1000} \quad (6)$$

where

GHG Emission bio on-road	total biobased GHG emissions from on-road vehicles	[tCO_2-eq]
FE	fuel economy of a vehicle	[l/100 km]
d	average annual distance travelled by a vehicle	[km]
n	number of similar vehicles	[-]
U	energy density of fuel	[GJ/l]
EF_{CO2}	emission factor for carbon dioxide	[kg CO_2/GJ]
c_{bio}	biofuel share coefficient	[-]

$$GHG\ Emission_{\ bio\ off-road} = \frac{FE \cdot t \cdot U \cdot (EF_{CO2} \cdot c_{bio})}{1000} \quad (7)$$

where

GHG Emission bio off-road	total biobased GHG emissions from off-road vehicles	[tCO_2-eq]
FE	fuel economy of a vehicle	[l/h]
d	average annual operating hours of a vehicle	[h]
n	number of similar vehicles	[-]
U	energy density of fuel	[GJ/l]
EF_{CO2}	emission factor for carbon dioxide	[kg CO_2/GJ]
c_{bio}	biofuel share coefficient	[-]

There are many liquid fuel blends available for vehicles. However, for now there are no specific carbon dioxide emission factors given for all of them. The average energy density and carbon dioxide emission factors for fuels purchased in Finland were obtained from Statistics Finland (2022) database, and the emission factors for methane and nitrous oxide were taken from the report by National Council for Air and Stream Improvement (2005). It is significant to note that electric vehicles have no tail-pipe emissions, therefore, the emission factors are zero. All this data is presented in Table 5.

Table 5. Fossil fuel and biofuel share coefficients, energy density and emission factors for fuels used for transportation (National Council for Air and Stream Improvement 2005, Statistics Finland 2022).

Fuel type [fuel unit]	**Fossil fuel share coefficient [-]**	**Biofuel share coefficient [-]**	**Energy density [GJ/fuel unit]**	**Emission factor for carbon dioxide [kg CO_2/GJ]**	**Emission factor for methane [kg CH_4/GJ]**	**Emission factor for nitrous oxide [kg N_2O/GJ]**
Diesel [l]	0.76	0.26	0.034	54.6	0.0040	0.0300
Electricity [kWh]	-	-	-	0.00	0.0000	0.0000
Liquefied petroleum gas (LPG) [l]	1	0	0.024	64.9	0.0050	0.0001
Petrol/gasoline [l]	0.885	0.115	0.031	65.6	0.0050	0.0002

4.1.3 Calculating indirect GHG emissions from purchased energy

Since emission factors for carbon dioxide emitted from electricity production fluctuate daily, in this calculation tool it was decided to take the average values for each quarter of 2022. The emission factors were obtained from Fingrid (2024) database and are summarized in Table 6.

Table 6. Average emission factor for carbon dioxide from electricity production, in every quarter of 2022 (Fingrid 2024).

	Q1 (1/1/22-31/3/22)	**Q2 (1/4/22 - 3/6/22)**	**Q3 (1/7/22 - 30/9/22)**	**Q4 (1/10/22 - 31/12/22)**
Emission factor [kg CO_2/MWh]	68	47	41	64

Equation 8 was used to calculate the carbon dioxide emissions from the total annual purchased electricity. The calculation tool users need to insert the amount of purchased electricity energy in every quarter of the year 2022.

$$GHG\ Emission_{\ purchased\ electricity} = \frac{E_1 \cdot EF_1 + E_2 \cdot EF_2 + E_3 \cdot EF_3 + E_4 \cdot EF_4}{1000} \qquad (8)$$

where	$GHG\ Emission_{purchased\ electricity}$	total GHG emissions from purchased electricity	[tCO_2-eq]
	E_1	energy imported in Q1	[MWh]
	EF_1	average emission factor for carbon dioxide from electricity production in Q1	[kg CO_2/MWh]
	E_2	energy imported in Q2	[MWh]
	EF_2	average emission factor for carbon dioxide from electricity production in Q2	[kg CO_2/MWh]
	E_3	energy imported in Q3	[MWh]
	EF_3	average emission factor for carbon dioxide from electricity production in Q3	[kg CO_2/MWh]
	E_4	energy imported in Q4	[MWh]
	EF_4	average emission factor for carbon dioxide from electricity production in Q4	[kg CO_2/MWh]

4.2 Testing the calculation tool

4.2.1 Calculating direct GHG emissions from energy generation facilities

For the on-site energy generation in boilers, the case sawmill combusted 37.4 m^3 of bark and 6.6 m^3 of wood chips. Because these fuels are entirely biobased, the total fossil CO_2-eq emissions are relatively low – 84 kg, which includes only methane and nitrous oxide. The biobased total emissions are 4.9 tCO_2-eq. The calculation table can be found in Appendix 7.

It is important to note that in purchasing records provided by the case sawmill's managing director there was no information about the quantity of combusted fuels. However, the total energy amount generated from each type of fuel was available. This data simplifies the initial equations used for calculating the company-owned total greenhouse gas emissions generated by power production (Equations 2 and 3), as the energy density multiplication was not required. The energy density values used in the calculation tool are average values taken from the Finnish national database and would not provide the exact amount of the energy generated.

Moreover, it was suggested that pellets, made of woody biomass, could be included as a possible fuel type to the list. Even though the case sawmill was not burning pellets for energy generation, in the interview with the sawmill manager it was found out that many other sawmills in Finland do that.

4.2.2 Calculating direct GHG emissions from transportation

The case company mostly exports the sawn timber (82% of total production) to Central Europe. The rest of the production is sold domestically. The deliveries are performed by trucks that use diesel fuel. Moreover, the company owns two passenger cars that also combust diesel fuel. Due to the long distances travelled, the on-road vehicles section of the calculation model demonstrates high emissions – 311.5 t of fossil-based CO_2-eq.

Off-road vehicles that belong to the case company and are used on mill site are one forklift and four wheel loaders. These vehicles also combust diesel fuel. The total fossil-based GHG emissions generated by off-road vehicles equal to 429.7 tCO_2-eq, and total bio-based emissions are 123 tCO_2-eq. Off-road vehicles is the source that generates the highest amount of GHG emissions in this calculation model. The total results of GHG emissions calculation from transportation of the case company are represented in Appendix 8.

4.2.3 Calculating indirect GHG emissions from purchased energy

Even though the case sawmill generates its own energy by combusting biobased by-products, it still purchases substantial amount of electricity. In 2022, the case company imported 7789 MWh of electricity, which caused emissions equal to approximately 438 tCO_2-eq. The results of GHG emissions generated from scope 2 source are presented in Appendix 9.

4.2.4 Summary of the case company's GHG emissions

The summary sheet (Appendix 10) presents the fossil-based and biobased GHG emissions, and allows the calculation tool users to compare the total emissions from each emission source group. In the case sawmill example, the fossil-based total GHG emissions are 1179.5 tCO_2-eq, and biobased total emissions are 217.2 tCO_2-eq. Transportation is the source producing the most GHG emissions in this case example.

The managing director of the case sawmill was satisfied with the obtained results and with testing this calculation model. The summary table clearly highlighted the source producing the highest amount of GHG emissions. The results demonstrated which emission source to pay attention to first and urged the management to think about the possible solutions for reducing their company's direct emissions.

5 DISCUSSION AND CONCLUSION

5.1 Uncertainties

Several uncertainties were detected during the development of the calculation tool. The emission factors for fuels are different in various databases and fluctuate yearly (Statistics Finland 2022). Moreover, fuels' fossil and bio shares fluctuate, and might not be true for the actual fuel used by the case company (Greenhouse Gas Protocol 2023). The emission factor for purchased electricity fluctuates daily (Fingrid 2024), and the mean values of each quarter of 2022 are taken. Also, the energy density values used in the calculation tool are average values taken from the Finnish national database (Statistics Finland 2022).

Overall, the values that are used in this thesis project are average national values and would not provide the exact amount of the energy or emissions generated. It is important to remember that the developed GHG emissions calculation tool provides an estimated value of scope 1 and scope 2 emissions.

5.2 Suggestions for improvement

This calculation tool can be used as a basis to start calculating GHG emissions at a sawmill in Finland. The model allows to calculate estimated emissions in the year 2022 and start yearly carbon footprint accounting from the base year. To perform calculation of GHG emission from the year 2023, emission factors should be updated.

To make more precise calculations, companies' operations should be analysed case-by-case. For example, the calculation of scope 2, purchased electricity, could be improved by taking the emission factor provided by the electricity supplier, instead of taking the national seasonal average value. The emission factors of electricity delivered by electricity suppliers vary, because the share of electricity produced from renewable energy sources in the production mix is different in every energy company (Fingrid 2024).

Sawmills significantly differ in their operation areas and production volumes (Association of Finnish Sawmillmen 2018). This was also proved by performing sawmills visits and observing them. Therefore, it is challenging to develop a tool that would include the calculation of GHG emissions produced by scope 3 sources, such as business travel, employee commuting, outsourced harvesting and upstream transportation of logs, packaging, and distribution of final products (World Resources Institute and World Business Council for Sustainable Development 2004). Scope 3 sources' emissions calculation may be included to this calculation tool when there is a demand for this data.

5.3 Conclusion

The research objective question was answered, and the main GHG emission sources at a typical Finnish sawmill were found from literature reviewing and mills visits. The calculation model was developed in Microsoft Excel based on the GHG Protocol Corporate Accounting and Reporting Standard (World Resources Institute and World Business Council for Sustainable Development 2004). The calculation tool includes pre-set equations for calculating GHG emissions generated from scope 1 and scope 2 activities. If there is a need to calculate emission from scope 3, then the calculation model can be improved, but this step would require a personalized approach and case-by-case analysis of sawmills operations.

The model was designed to account GHG emissions generated in the year 2022. It is important to remember that the emission factors must be updated in the model yearly to perform GHG emissions estimations over time. The emission factors are average values, and the calculation tool generates the estimated amount of GHG emissions.

The interview with the managing director of a Finnish sawmill demonstrated that the calculation tool is convenient to be used by a person unfamiliar with GHG emissions calculations. Moreover, suggestions for improving the tool were found during the interview. The developed calculation tool can be used as the starting point in GHG emissions accounting and allow Finnish sawmill management to understand their CO_2-eq status, to reduce GHG emissions, to become more transparent and participate in the carbon and GHG emissions inventory disclosure.

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Appendix 1/1

PRELIMINARY QUESTIONNAIRE FOR THE MANAGING DIRECTOR OF THE CASE SAWMILL

<table>
<tr><th></th><th>Question:</th><th>Answer:</th></tr>
<tr><td rowspan="4">Scope 1</td><td>1. What fuel type was consumed by your boilers / CHP and how much?
1.1. Bark [m³]?
1.2. Sawdust [m³]?
1.3. Wood chips [m³]
1.4. Heating oil [l]?
1.5. Other?</td><td></td></tr>
<tr><td>2. Do you produce any solar or wind electricity?
2.1. If yes, how much [kWh]?</td><td></td></tr>
<tr><td>3. How many of the following on-road vehicles do you own, and what is their average fuel economy?
3.1. Trucks?<table><tr><td>Diesel [l]</td><td>l/100 km</td></tr><tr><td>Electricity [kWh]</td><td>kWh/100 km</td></tr></table>3.2. Passenger cars?<table><tr><td>Petrol/gasoline [litres]</td><td>l/100 km</td></tr><tr><td>Electricity [kWh]</td><td>kWh/100 km</td></tr></table>3.3. Other?</td><td></td></tr>
<tr><td>4. What is the annual distance travelled by each on-road vehicle?</td><td></td></tr>
<tr><td></td><td>5. How many of the following off-road vehicles do you own, and what is their average fuel economy?
5.1. Forklifts?<table><tr><td>Diesel [litres]</td><td>litres/hour</td></tr><tr><td>Liquefied petroleum gas (LPG) [litres]</td><td>litres/hour</td></tr></table>5.2. Forwarders?<table><tr><td>Diesel [litres]</td><td>litres/hour</td></tr></table>5.3. Harvesters?<table><tr><td>Diesel [litres]</td><td>litres/hour</td></tr></table>5.4. Wheel loaders?<table><tr><td>Diesel [litres]</td><td>litres/hour</td></tr></table>5.5. Other?</td><td></td></tr>
</table>

	6. What are the annual operating hours of each off-road vehicle?	
Scope 2	7. What was the quantity of purchased electricity in each quarter (MWh)? 7.1. Q1 (Jan - Mar 2022) 7.2. Q2 (Apr - Jun 2022) 7.3. Q3 (Jul - Sep 2022) 7.4. Q4 (Oct - Dec 2022)	
	8. What power supply companies do you purchase from?	
	9. Do they share the information about their GHG emissions with you?	
Other	10. Does this tool give you a clear overview on the possible emissions of your company?	
	11. Do you have any suggestions how the tool may be improved?	

Appendix 2

FUEL DENSITY AND ENERGY DENSITY CONVERSIONS

	Fuel density		**Energy density**	
Fuel [fuel unit]	**Statistics Finland (2022) [t/m³]**	**[t/fuel unit]**	**Statistics Finland (2022) [GJ/t]**	**[GJ/fuel unit]**
Bark [m³]	0.45	0.45	7.5	3.38
Diesel [l]	0.804	0.000804	42.7	0.034
Heating oil [l]	0.834	0.000834	43.1	0.036
Liquefied petroleum gas (LPG) [l]	0.520	0.00052	46.3	0.024
Petrol/gasoline [l]	0.745	0.000745	41.6	0.031
Sawdust [m³]	0.31	0.31	7.0	2.17
Wood chips [m³]	0.28	0.28	10.5	2.94

The density of liquid fuels was converted to *t/l* unit assuming that 1 m^3 is equal to 1000 l.

The density of bark, sawdust and wood chips depends on the material's origin, moisture content, particle shape and homogeneity. The average values are considered in calculations. Bulk density of bark ranges from 0.19 t/m^3 to 0.7 t/m^3 (Kaderabek et al. 2016), therefore, in calculations the average of 0.45 is taken. The average density of sawdust is 0.31 t/m^3 (Stasiak et al. 2015). Bulk density of wood chips varies from 0.11 t/m^3 to 0.34 t/m^3; the average fuel density is 0.28 t/m^3 (Nurek at al. 2019, Stasiak et al. 2015).

Appendix 3

CALCULATION TOOL, SCOPE 1 – ENERGY GENERATION FACILITIES

Scope 1 - Direct emissions, company's own emissions

User entry field in yellow

Boilers / CHP

Please fill in the total fuel consumed or produced at facility.
This information can be determined from purchasing records.

Source	Fuel type SELECT FROM THE LIST	Quantity of fuel combusted (unit depends on the fuel type)	Energy Used (GJ)	Fossil-based CO_2 Emissions (metric tonnes)	CH_4 Emissions (metric tonnes)	N_2O Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalent (metric tonnes)	Biobased CO_2 Emissions (metric tonnes)
	Bark [m3]		0	0,000	0,000	0,000	0,000	0,000
	Heating oil [l]		0	0,000	0,000	0,000	0,000	0,000
	Sawdust [m3]		0	0,000	0,000	0,000	0,000	0,000
	Wood chips [m3]		0	0,000	0,000	0,000	0,000	0,000
							0,000	**0,000**

Appendix 4

CALCULATION TOOL, SCOPE 1 – TRANSPORTATION

Scope 1 - Direct emissions, company's own emissions

User entry field in yellow

Mobile and Transportation
Please fill in the total fuel consumed by **your company-owned** vehicles.
This information can be determined from purchasing records.

On-Road Vehicles

Source	Fuel type	Fuel economy unit	Fuel economy of a vehicle	Annual distance travelled by one vehicle (km)	Number of similar vehicles	Amount of fuel used per year	Energy Used (GJ)	Fossil-based CO_2 Emissions (metric tonnes)	CH_4 Emissions (metric tonnes)	N_2O Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalent (metric tonnes)	Biobased CO_2 Emissions (metric tonnes)	
Truck	Diesel [l]	litres/100 km				0	0	0,000	0,000	0,000	0,000	0,000	
Truck	Electricity [kWh]	kWh/100 km				0	0	0,000	0,000	0,000	0,000	0,000	*Electric vehicles have no tailpipe emissions
Passenger cars	Petrol/gasoline [l]	litres/100 km				0	0	0,000	0,000	0,000	0,000	0,000	
Passenger cars	Electricity [kWh]	kWh/100 km				0	0	0,000	0,000	0,000	0,000	0,000	*Electric vehicles have no tailpipe emissions
											0,000	**0,000**	

Off-Road Vehicles

Source	Fuel type	Fuel economy unit	Fuel consumption of a vehicle	Annual operating hours	Number of vehicles	Amount of fuel used per year	GJ Energy Used	Fossil-based CO_2 Emissions (metric tonnes)	CH_4 Emissions (metric tonnes)	N_2O Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalent (metric tonnes)	Biobased CO_2 Emissions (metric tonnes)
Forklift	Diesel [l]	litres/hour				0	0	0,000	0,000	0,000	0,000	0,000
Forklift	Liquefied petroleum gas (LPG) [	litres/hour				0	0	0,000	0,000	0,000	0,000	0,000
Forwarder	Diesel [l]	litres/hour				0	0	0,000	0,000	0,000	0,000	0,000
Harvester	Diesel [l]	litres/hour				0	0	0,000	0,000	0,000	0,000	0,000
Wheel loader	Diesel [l]	litres/hour				0	0	0,000	0,000	0,000	0,000	0,000
											0,000	**0,000**

Appendix 5

CALCULATION TOOL, SCOPE 2 – PURCHASED ELECTRICITY

Scope 2 - Indirect emissions, purchased electricity and heat energy

User entry field in yellow

Stream description	Quantity of energy imported (MWh)				CO_2 Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalents (metric tonnes)
	Q1 (Jan - Mar 2022)	Q2 (Apr - Jun 2022)	Q3 (Jul - Sep 2022)	Q4 (Oct - Dec 2022)		
Electricity (Finland)					0,000	0,000
						0,000

Appendix 6

CALCULATION TOOL, SUMMARY PAGE

Summary

	Total fossil-based emissions in terms of CO_2 equivalent (metric tonnes)	Total biobased emissions in terms of CO_2 equivalent (metric tonnes)
Scope 1. Company-owned energy generation facilities	0,000	0,000
Scope 1. Mobile and transportation.	0,000	0,000
Scope 2. Purchased energy.	0,000	
	0,000	**0,000**

Appendix 7

CASE COMPANY CALCULATION RESULTS, SCOPE 1 – ENERGY GENERATION FACILITIES

Scope 1 - Direct emissions, company's own emissions

User entry field in yellow

Boilers / CHP

Please fill in the total fuel consumed or produced at facility.
This information can be determined from purchasing records.

Source	Fuel type SELECT FROM THE LIST	Quantity of fuel combusted (unit depends on the fuel type)	Energy Used (GJ)	Fossil-based CO_2 Emissions (metric tonnes)	CH_4 Emissions (metric tonnes)	N_2O Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalent (metric tonnes)	Biobased CO_2 Emissions (metric tonnes)
	Bark [m3]		37,4	0,000	0,001	0,000	0,071	4,189
	Heating oil [l]		0	0,000	0,000	0,000	0,000	0,000
	Sawdust [m3]		0	0,000	0,000	0,000	0,000	0,000
	Wood chips [m3]		6,6	0,000	0,000	0,000	0,013	0,739
							0,084	**4,928**

Appendix 8

CASE COMPANY CALCULATION RESULTS, SCOPE 1 – TRANSPORTATION

Scope 1 - Direct emissions, company's own emissions

User entry field in yellow

Transportation

Please fill in the total fuel consumed by **your company-owned** vehicles.
This information can be determined from purchasing records.

On-Road Vehicles

Source	Fuel type	Fuel economy unit	Fuel economy of a vehicle	Annual distance travelled by one vehicle (km)	Number of similar vehicles	Amount of fuel used per year	Energy Used (GJ)	Fossil-based CO_2 Emissions (metric tonnes)	CH_4 Emissions (metric tonnes)	N_2O Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalent (metric tonnes)	Biobased CO_2 Emissions (metric tonnes)
Truck (international)	Diesel [l]	litres/100 km				181466,4523	6169,86	256,024	0,025	0,185	305,766	87,587
Truck (domestic)	Diesel [l]	litres/100 km	30	300	1	90	3,06	0,127	0,000	0,000	0,152	0,043
Truck	Electricity [kWh]	kWh/100 km				0	0	0,000	0,000	0,000	0,000	0,000
Passenger cars	Diesel [l]	litres/100 km	7	40000	1	2800	95,2	3,950	0,000	0,003	4,718	1,351
Passenger cars	Diesel [l]	kWh/100 km	10	5000	1	500	17	0,705	0,000	0,001	0,842	0,241
											311,478	**89,224**

*Electric vehicles have no tailpipe emissions

Off-Road Vehicles

Source	Fuel type	Fuel economy unit	Fuel consumption of a vehicle	Annual operating hours	Number of vehicles	Amount of fuel used per year	GJ Energy Used	Fossil-based CO_2 Emissions (metric tonnes)	CH_4 Emissions (metric tonnes)	N_2O Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalent (metric tonnes)	Biobased CO_2 Emissions (metric tonnes)
Forklift	Diesel [l]	litres/hour	6,25	4000	4	100000	3400	141,086	0,014	0,102	168,497	48,266
Wheel loader	Diesel [l]	litres/hour	17,5	2000	1	35000	1190	49,380	0,005	0,036	58,974	16,893
Wheel loader	Diesel [l]	litres/hour	13,75	4000	1	55000	1870	77,598	0,007	0,056	92,673	26,547
Wheel loader	Diesel [l]	litres/hour	13,75	4000	1	55000	1870	77,598	0,007	0,056	92,673	26,547
Wheel loader	Diesel [l]	litres/hour	10	1000	1	10000	340	14,109	0,001	0,010	16,850	4,827
											429,668	**123,079**

Appendix 9

CASE COMPANY CALCULATION RESULTS, SCOPE 2 – PURCHASED ELECTRICITY

Scope 2 - Indirect emissions, purchased electricity and heat energy

User entry field in yellow

Stream description	Quantity of energy imported (MWh)				CO_2 Emissions (metric tonnes)	Total emissions in terms of CO_2 equivalents (metric tonnes)
	Q1 (Jan - Mar 2022)	Q2 (Apr - Jun 2022)	Q3 (Jul - Sep 2022)	Q4 (Oct - Dec 2022)		
Electricity (Finland)	1865	1680	1729	2525	438,269	438,269
						438,269

Appendix 10

CASE COMPANY CALCULATION RESULTS, SUMMARY PAGE

Summary

	Total fossil-based emissions in terms of CO_2 equivalent (metric tonnes)	Total biobased emissions in terms of CO_2 equivalent (metric tonnes)
Scope 1. Company-owned energy generation facilities	0,084	4,928
Scope 1. Mobile and transportation.	741,146	212,303
Scope 2. Purchased energy.	438,269	
	1179,498	**217,231**