INCORPORATING FOREST CHIP COMBUSTION IN THE EMISSIONS TRADING SYSTEM AND ITS INFLUENCE ON ENERGY PRODUCTION IN SOUTH SAVO

A scenario-based impact assessment

Lappeenranta–Lahti University of Technology LUT

Master's programme in Bioenergy Systems, Master's thesis

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ABSTRACT

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Keywords: Bioenergy, Emissions, Emissions trading, Forest chips, Primary woody biomass

Forest chips are an important energy source in energy production in Finland, especially in district heat production. Finland and the South Savo region both have a target to achieve carbon neutrality by 2035. Forest chips are a renewable energy source, which has a significant role on reaching these targets. The consumption of forest chips in heat and power production has increased considerably in Finland since the beginning of 21st century and the increase of consumption is expected to remain for the next decade.

During the latest revision of the EU Renewable Energy Directive (RED), there have been proposals from the EU decision-making institutions about the status of primary woody biomass (PWB) as a renewable energy source. It has been decided that PWB will remain its status as a renewable energy source. However, it could be possible that at some point in the future the status of PWB will be questioned again. If forest chips, or some fractions of it, were to be considered as a non-renewable energy source, the combustion of it would require emission allowances in the plants that operate under the EU Emissions Trading System (EU ETS).

The aim of this thesis is to assess the impacts through different scenarios of the possible inclusion of forest chip combustion in the EU ETS in the region of South Savo and in Finland. This study is based on the predicted carbon dioxide emissions and the predicted consumptions of forest chips for coming years. In the maximum scenario, where all PWB is included in the ETS, the ETS sectors carbon dioxide emissions in 2035 would increase by 8,9 Mt CO_2 on the country level, while the increment would be 230 kt CO_2 in South Savo. Incorporating forest chip combustion in the ETS would hamper considerably Finland and South Savo to achieve their climate targets by 2035.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Energiajärjestelmät

Energiatekniikka

Jari-Pekka Johnson

Metsähakkeen polton sisällyttäminen osaksi päästökauppajärjestelmää ja sen vaikutukset energiantuotantoon Etelä-Savossa: Skenaariopohjainen vaikutusten arviointi

Energiatekniikan diplomityö

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Tarkastajat: Professori Tapio Ranta, Projektitutkija Mika Laihanen ja Projektitutkija Antti Karhunen

Avainsanat: Bioenergia, Metsähake, Primäärinen puubiomassa, Päästökauppa, Päästöt

Metsähake on Suomessa tärkeä energianlähde energiantuotannossa, erityisesti kaukolämmön tuotannossa. Sekä Suomen että Etelä-Savon maakunnan tavoite on olla hiilineutraaleja vuoteen 2035 mennessä. Metsähake on uusiutuva energianlähde, ja sillä on merkittävä rooli näiden tavoitteiden saavuttamisessa. Metsähakkeen käyttö lämmön ja sähkön tuotannossa on lisääntynyt Suomessa huomattavasti 2000-luvun alusta lähtien ja kasvun odotetaan jatkuvan seuraavalle vuosikymmenelle.

EU:n uusiutuvan energian direktiivin (RED) viimeisimmän tarkistuksen aikana EU:n päätöksentekoelimiltä on tullut esityksiä primäärisen puubiomassan (PWB) asemasta uusiutuvana energialähteenä. Primäärisen puubiomassan asema uusiutuvana energialähteenä on päätetty säilyttää, mutta on kuitenkin mahdollista, että jossain vaiheessa tulevaisuudessa sen asema kyseenalaistetaan uudelleen. Jos metsähaketta tai joitain sen jakeita pidettäisiin uusiutumattomana energianlähteenä, sen polttaminen edellyttäisi päästöoikeuksia EU:n päästökauppajärjestelmän (EU ETS) alaisuudessa toimivissa laitoksissa.

Tämän diplomityön tavoitteena on arvioida eri skenaarioiden avulla vaikutuksia metsähakkeen polton mahdollisesta sisällyttämisestä EU:n päästökauppajärjestelmään Etelä-Savossa sekä Suomessa. Tämä tutkimus pohjautuu tuleville vuosille ennustettuihin hiilidioksidipäästöihin sekä metsähakkeen kulutukseen. Maksimiskenaariossa, jossa kaikki primäärinen puubiomassa on mukana päästökauppajärjestelmässä, päästökauppasektorin hiilidioksidipäästöt vuonna 2035 kasvaisivat Suomessa 8,9 miljoonaa hiilidioksiditonnia, kun taas Etelä-Savossa lisäys olisi 230 000 hiilidioksiditonnia. Metsähakkeenpolton sisällyttäminen päästökauppajärjestelmään vaikeuttaisi huomattavasti Suomea ja Etelä-Savoa saavuttamaan vuoden 2035 ilmastotavoitteensa.

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Biggest thanks to my partner Janette for your invaluable support throughout my studies. Your belief in me, even when I doubted myself at times, has been extremely valuable. And of course, I must mention our dog Veeti, who is always happy and has cheered me up during my studies.

Kokkola, 25th of November 2023

Jari-Pekka Johnson

SYMBOLS AND ABBREVIATIONS

Roman characters

c	price	[€/MWh]
K	costs	[€/MWh]

Greek characters

η	efficiency	[-]

Subscripts

fix	fixed
fu	fuel
var	variable

Superscripts

*	Preliminary data

Abbreviations

BECCS	Bioenergy Carbon Capture and Storage
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture Utilization and Storage
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CHP	Combined Heat and Power
EA	Emission Allowance

EU	European Union
ELY	Elinkeino-, liikenne- ja ympäristö - Economic Development, Transport and the Environment
ESE	Etelä-Savon Energia Oy
ETS	Emissions Trading System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HOB	Heat Only Boiler
Luke	Luonnonvarakeskus - Natural Resources Institute Finland
LULUCF	Land use, Land-use change and Forestry
MSR	Market Stability Reserve
PWB	Primary Woody Biomass
RED	Renewable Energy Directive
SMR	Small Modular Reactor
UNFCCC	United Nations Framework on Climate Change
VRE	Variable Renewable Energy
WAM	With Additional Measures
WEM	With Existing Measures

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Appendices

1 Introduction

The purpose of this master's thesis is to carry out research on the impacts of different scenarios where combustion of forest chips, or some fractions of it, is incorporated into the EU Emissions Trading System (ETS). The aim of this study is to find out what the impacts of this would be for the energy production of South Savo and for Finland in general. The new EU Renewable Energy Directive (RED) is under revision and during the past couple of years there have been discussions that primary woody biomass (PWB), or some fractions of it, should not be considered as renewable energy.

The EU Council (2023) and the Parliament have reached a provisional agreement that all sustainably produced biomass will maintain its status as renewable energy. However, it is still possible that at some point in the future some kind of new regulations may come up again that might affect on the status of PWB as a renewable energy source. The main form of PWB in heat and power production in Finland is forest chips and therefore it has the principal role in this study as it is an important fuel for heat and power production in Finland.

During the last couple of years, the use of forest chips in heat and power generation has increased in Finland because the national climate policy aims to get rid of coal and decrease the use of peat (Ministry of Economic Affairs and Employment of Finland, 2022, 160). Russia's invasion of Ukraine in February 2022 increased the demand for domestic forest chips as importing forest chips from Russia was ceased later that year (Viitanen et al., 2022, 58-59). For the same reason natural gas and electricity imports from Russia have ended too, which is reflected in the demand of domestic fuels such as forest chips. Finland aims for carbon neutrality by 2035 and solid wood fuels have an important role in reaching this target.

Sweden, along with Finland, is one the biggest users of biomass in Europe. The Swedish Bioenergy Association has published a report which summarizes the impacts of the possible restrictions on primary woody biomasses on the Swedish energy use and on Swedish climate policies and targets (Svebio, 2022). The report concludes that if the use of PWB is restricted, it would be harder to replace fossil fuels with renewables. The reduced use of forest biomass would decrease the potential for negative emissions with bioenergy carbon capture and storage (BECCS). The restricted use of PWB would reduce the ability to reach climate targets in Sweden and in Europe as well. The report also discusses the current use of PWB in Sweden.

As the bioenergy use in Sweden is somewhat similar to the one of Finland's, most of the general level impacts of the restricted use of PWB presented in the report (Svebio, 2022) applies to Finland as well. However, this study provides more of a quantitative analysis of the impacts for energy production and climate targets on the country level for Finland and on the regional level for South Savo. This study focuses more on the issue of how much the carbon dioxide emissions would increase if the use of PWB is to be incorporated in the emissions trading system as a non-zero-emission fuel. South Savo acts more of a case study and the importance of forest chips in energy generation and the consequences of incorporating forest chips in the ETS are evaluated more broadly for the South Savo region.

One of the goals of this study is to highlight the importance of primary woody biomasses in energy generation in Finland. The consumption of forest chips in heat and power production accounted for about 6% of Finland's total energy consumption in 2022 (Natural Resources Institute Finland, 2023a; Statistics Finland, 2023a). Forest chips are the single most important fuel in district heat supply in Finland with a share of 27% (Finnish Energy, 2023a, 2). This thesis focuses more on heat than electricity production as most of the forest chips consumed in the ETS sector in South Savo are used for district heat production (Finnish Energy, 2023b).

This study assesses the role of forest chips in energy generation and the importance of forest chip combustion for Finland and South Savo to achieve their climate targets and carbon neutrality by 2035. Therefore, the objective of this study is to examine the carbon dioxide emissions from forest chip combustion as well as the consumption of forest chips of plants operating in the emissions trading sector. The climate targets of Finland are defined in the Climate Change Act, and therefore the climate targets guide the carbon dioxide emissions originating from energy production (Ministry of the Environment, 2023a).

The carbon dioxide emissions from the combustion of forest chips are determined from the predicted future consumption of forest chips. The WAM scenario is used to predict the future consumption of forest chips on the country level. The future consumption in South Savo is estimated by contacting the companies that operate the plants included in the ETS in South Savo that use forest chips as a fuel. Four different scenarios were created to predict the future

CO_2 emissions from the plants that are included in the emissions trading system. These four scenarios differ from each other in the way which fractions of PWB would be included in the emissions trading system.

This study focuses on the primary woody biomasses used in heat and power production, which is why the use of firewood in small-scale housing is excluded from this study, even though that is accounted as PWB as well. The aspect of whether the use of PWB is sustainable in Finland and South Savo is left out of the scope of this study. In the practical part, the possible free allocation of emission allowances is left out from the calculations. The predicted future emissions from the combustion of forest chips are calculated based on the predicted future consumptions. The calculations do not take into account the possible decrease of consumption if forest chip combustion were to be included in the ETS.

The thesis report consists of introduction, literature review, practical part, discussion and conclusions. The literature review in chapters 2 to 5 deals with the climate targets, energy use in Finland, the EU Emissions Trading System and wood utilization in Finland. Chapter six describes the consumption of forest chips in the ETS sector including calculated carbon dioxide emissions from the combustion. Chapter seven focuses on the constructed scenarios and the additional carbon dioxide emissions caused by these scenarios. It also includes an analysis of which plants would be added into the emissions trading system in South Savo and how much they would cause carbon dioxide emissions if the plants with a capacity of 5-20 MW would be added into the emissions trading system. The next chapter discusses the possible consequences of incorporating forest chip combustion in the emissions trading system with a focus on fuel price, energy production and climate targets. Possible solutions to decrease carbon dioxide emissions from forest chip combustion are briefly described for the South Savo region. Discussions and conclusions are the final chapters of this report.

1.1 South Savo

South Savo is located in eastern Finland and its regional centre is Mikkeli. It consists of 12 municipalities, three of which are cities: Mikkeli, Pieksämäki and Savonlinna. Other municipalities are Enonkoski, Hirvensalmi, Juva, Kangasniemi, Mäntyharju, Pertunmaa, Puumala, Rantasalmi and Sulkava. The total area of South Savo is 17 100 km^2 and the land area is 12 650 km^2. (South Savo Regional Council, 2023a) The location of each municipality is presented on map in Figure 1.

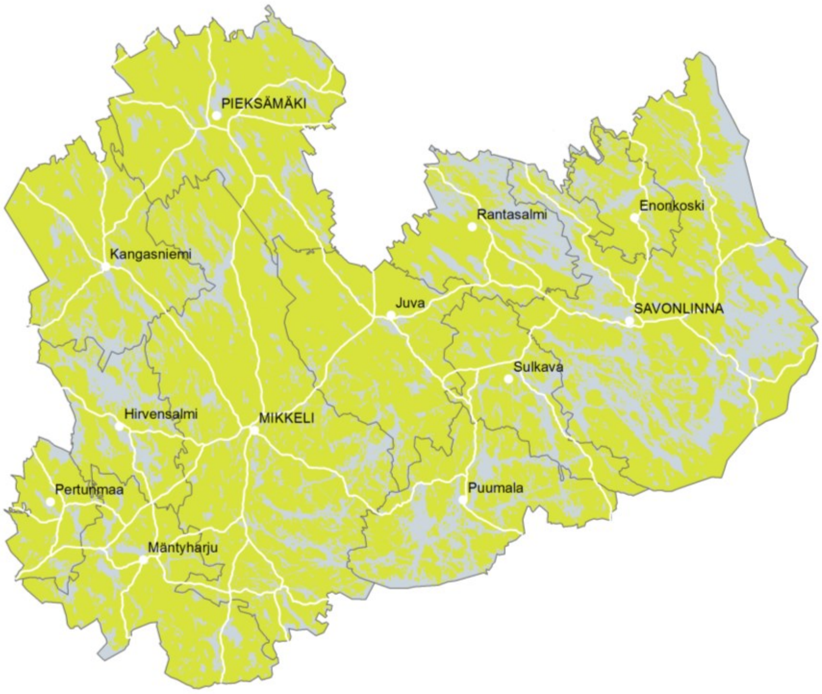


Figure 1. Map of the South Savo region. (South Savo Regional Council, 2021)

In May 2023 the population of South Savo was 130 171 persons, which is about 2% of the population of Finland. The age structure of population in South Savo is the highest in Finland, and it is estimated that the population will decrease to around 107 000 persons by 2040. The share of agriculture and forestry in South Savo is 8% of Finland's agriculture and forestry. The roundwood removals in South Savo accounts for 8% of Finland's roundwood removals. (South Savo Regional Council, 2023b)

South Savo has good forest resources and about 87% of the land area is forest land. Almost 10% of Finland's annual forest growth comes from South Savo. Forest lands in South Savo have better ability to produce wood compared to other regions in southern Finland, and the forest utilization rate is relatively high. The wood product industry accounts for 30% of the regions industry's turnover, which is among the highest numbers in Finland. (South Savo Regional Council, 2022)

2 Climate targets

This chapter discusses the main climate targets of the European Union as well as the Finnish national climate targets and the climate targets of the South Savo region. The climate targets are discussed especially from the perspective of renewable energy and the EU's Renewable Energy Directive is also explained.

2.1 Climate targets in the European Union

The member countries of the European Union are obliged to work for the commitments stated in the Paris Agreement to mitigate climate change. To reach these goals, the EU has its own strategy called the European Green Deal which is a set of policy initiatives published in 2019. Each of the 27 EU countries has signed it to commit to making Europe the first climate neutral continent by 2050. The climate targets in the European Green Deal are defined in the Fit for 55 package, which is a set of legislative proposals to revise and update EU legislation for reaching the climate targets. One of the most important milestones in the Fit for 55 package is to reduce the net greenhouse gas (GHG) emissions with at least 55% by 2030 compared to the 1990 levels. (European Council, 2022)

The climate targets in the European Union are divided between three different main sectors which are:

- The emissions trading system (ETS or EU ETS)
- effort sharing
- land use, land-use change and forestry (LULUCF).

Emission reductions in the EU are guided with the Emissions Trading Directive and Effort Sharing Regulation while the LULUCF regulation aims to strengthen carbon sinks. (Ministry of the Environment, 2023b)

Part of the Fit for 55 package is to increase the target for renewable energy in the EU energy mix from 32% to 40% by 2030. It also includes a tightened target for the ETS, which is to reduce the ETS sector emissions 62% by 2030 compared to the 2005. Fit for 55 also includes various other targets for reducing emissions such as a 40% emission reduction at the EU level for the effort sharing sector compared to 2005. (European Council, 2023)

As a result of Russia's invasion of Ukraine in 2022, the REPowerEU plan was introduced in May 2022. Its main purpose is to help the EU countries to rapidly reduce the use of Russian fossil fuels. The three pillars of the REPowerEU plan are:

- Saving energy
- Producing clean energy
- Diversifying energy supplies.

As a part of this plan, all EU countries have committed to decrease the use of natural gas consumption by at least 15%. The Renewable Energy Directive was revised as a part of the REPowerEU plan, and in March 2023 stronger legislation for renewable energy was agreed in the EU, and the binding target for 2030 was set to be a minimum of a 42,5% share, aiming to a 45% share of renewables in the EU energy mix. (European Commission, 2023a)

2.1.1 Renewable Energy Directive

The European Commission (2023b) describes the Renewable Energy Directive as follows:

> "The Renewable Energy Directive is the legal framework for the development of renewable energy across all sectors of the EU economy, supporting clean energy cooperation across EU countries."

According to the European Parliament (2023, 2-10), the first Renewable Energy Directive, (Directive 2009/28/EC) also known as the RED I, helped the EU to promote the use of renewable energy sources and to reach the target of 20% share of renewable energy by 2020. The revised Renewable Energy Directive (2018/2001/EU) (RED II) entered into force in 2018. It was a revision of the RED I and since June 2021, it has been legally binding. In July 2021, as part of the Fit for 55 package, another revision of the RED was proposed by the European Commission which would raise the target of renewables from 32% to 40%. In March 2023 a provisional agreement was reached to raise the target to 42,5% with an additional raise of 2,5%.

During the latest revision of the Renewable Energy Directive there have been various proposals about the sustainability of forest biomasses. The European Parliament (2022a) proposed in September 2022 that at first, the use of primary woody biomass would be limited to the average use of years 2017-2022 and the amount that goes above that level would not be counted as renewable energy. The Parliament also proposed a gradual phase down of the share of primary woody biomasses that counts as a renewable energy by 2030, based on an impact assessment of the EU Commission that would be performed later.

The EU Council (2023) and the Parliament reached a provisional agreement on the revision of the Renewable Energy Directive in March 2023. It is stated that all sustainably produced biomass will be counted as renewable energy. The requirements for sustainability of biomasses will be stricter and the cascading principle will be monitored more strictly. Cascade use of woody biomasses is described in section 5.2.1.

2.2 Climate targets in Finland

International climate policies such as the United Nations Framework on Climate Change (UNFCCC), Kyoto Protocol, Paris Agreement as well as the European Union’s climate policies set the boundaries for Finland’s own national targets. The last government of Finland (2019-2023), which was led by prime minister Sanna Marin, set a goal for Finland to be a carbon neutral country by 2035. The aforementioned government prepared a new Climate Change Act for Finland, which came into force in July 2022. This replaced the first Climate Change Act, which entered into force in 2015. (Ministry of Economic Affairs and Employment of Finland, 2022, 12-18)

In the Climate Change Act, it is mentioned that Finland’s target is to reduce net greenhouse gas emissions with 60% by 2030 compared to 1990 as presented in Figure 2. It can be seen from the figure that the emission reduction target for 2040 is 80% and the target for 2050 is at least 90%, aiming to 95%. (Ministry of the Environment, 2022a)

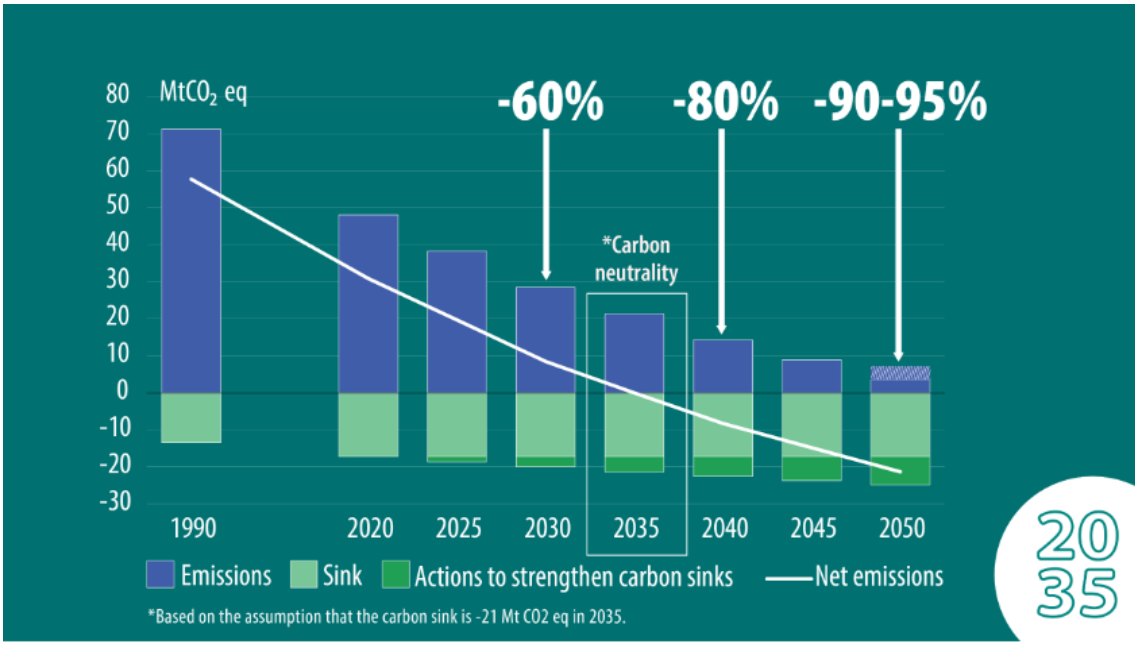


Figure 2. Finland's emission reduction targets from 2020 to 2050. (Ministry of the Environment, 2022a)

Other relevant targets for 2030 from the perspective of this study are the ETS sector emissions and the share of renewables in the energy mix. Finland’s goal for ETS sector emissions is the same as it is for EU that is a 62% reduction by 2030 compared to 2005. The target for renewables is at least a 51% share of the final energy consumption (Ministry of Economic Affairs and Employment of Finland, 2022, 15). Finland’s national target for effort sharing sector is 50% emission reduction by 2030 compared to 2005 (European Commission, 2023c).

2.2.1 Climate targets in South Savo

South Savo has a goal to be a climate neutral region by 2035 and to have the lowest CO_2 emissions per capita of all the Finnish regions by 2030 (South Savo Regional Council). South Savo also aims to increase its energy self-sufficiency to 60% and to increase the share of renewable energy from total energy consumption also to 60% by 2030 (South Savo Regional Council, 2020).

According to the South Savo ELY Centre (2023a, 5), the climate work in South Savo started in 2012 with the Savo climate program. Carbon free South Savo was the next major climate project, and its final report was presented in 2020. The aim of the Carbon free South Savo project, carried out by Laihanen et al. (2020, 4, 150), was to promote ways to reach carbon neutrality in South Savo. During the project, a climate working group was formed for South Savo region to implement the results of Carbon free South Savo project to the local level.

The Carbon Neutral South Savo project was started by the climate working group in 2021 and its goal was to update the Savo climate program to a regional level climate road map (Ministry of Economic Affairs and Employment of Finland, 2023). The South Savo climate road map was published in June 2023 and its main purpose is to outline the objectives and actions which help South Savo to become a carbon neutral region by 2035 (South Savo ELY Centre, 2023a).

The new Climate Change Act requires municipalities to have their own climate programs and the first climate program is obliged from the council period 2025-2029 (Ministry of the Environment, 2023c). In South Savo, already 11 out of the 12 municipalities have their own climate programs (South Savo ELY Centre, 2023a).

3 Energy use in Finland

According to Statistics Finland (2023a), the total energy consumption in Finland in 2022 was 360 TWh, based on the preliminary data. It decreased about five percent from the previous year. The total energy consumption has decreased about 14% from the peak year 2006, as it can be seen in Figure 3. Energy usage has shifted more from fossil fuel dominant to non-fossil fuel based during the years. The share of renewable energy in Finland's total energy consumption was 42% in 2022.

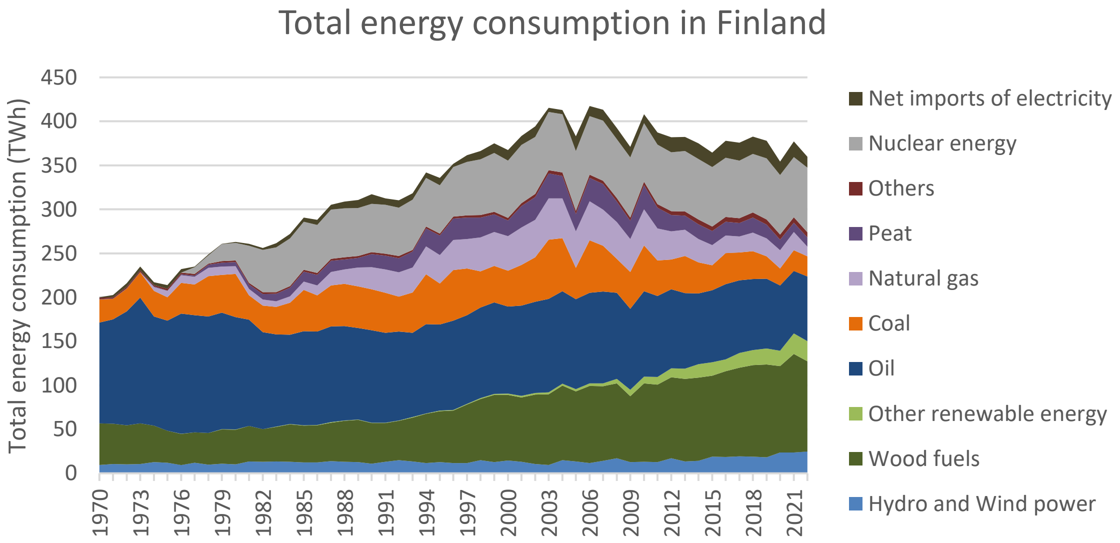


Figure 3. Total energy consumption in Finland by energy source from 1970 to 2022*. (Statistics Finland, 2023a)

Russia's invasion of Ukraine also had its impact on Finland's total energy consumption. Natural gas imports from Russia ceased in May 2022, which reflected in the usage of natural gas as it almost halved from 2021 to 2022. Russia's invasion increased electricity prices which reduced the use of electricity. The mild weather and the strike of the Paperworkers' Union in the beginning of the year also reduced the demand for electricity. Importing of electricity from Russia stopped in May 2022. This impacted the net imports of electricity, which decreased 30% from the previous year. The amount of nuclear energy increased 7%

as the new Olkiluoto 3 nuclear plant was connected to the grid in May 2022 for test runs. (Motiva, 2023)

The share of wood fuels in 2022 was 29% and it has the biggest share of Finland's total energy consumption as presented in Figure 4. Nuclear energy accounted for 20% of the consumption, but its share will increase as the Olkiluoto 3 nuclear plant is now producing electricity with full capacity and it will produce about 30% of Finland's electricity in coming years (TVO, 2023). Coal accounted for 6% of total energy consumption, but its use will decrease in coming years as its energy use will be phased out in Finland by 2029 (Ministry of Economic Affairs and Employment of Finland, 2022, 160).

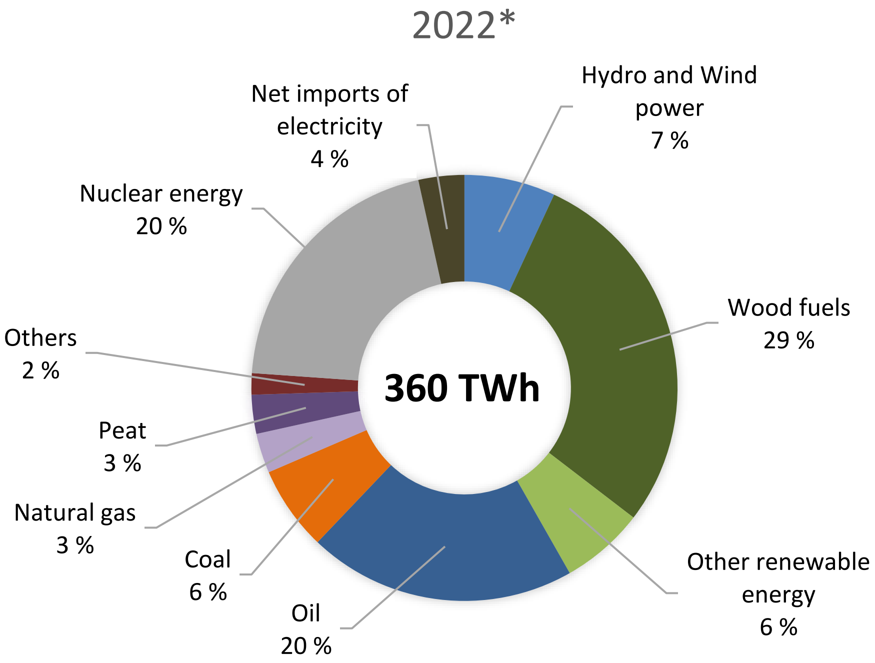


Figure 4. Total energy consumption by energy source in 2022*. (Statistics Finland, 2023a)

Wind power will play an important role in Finland's energy generation in the future as its amount is going to be multiplied in the coming years. At the end of 2022 the installed wind power capacity was 5677 MW (Finnish Wind Power Association, 2023a). The capacity of planned wind power investments in May 2023 was more than 120 GW, though only about 6900 MW of these projects are fully permitted or under construction (Finnish Wind Power Association, 2023b).

The previous government of Finland, led by prime minister Sanna Marin, had a government programme which stated that the energy use of peat should be halved by 2030. The energy use of peat has already decreased significantly during the past few years due to the high emission allowance prices. Peat is a domestic fuel so it does have an important role on the security of energy supply and therefore its use should not decrease too rapidly. (Ministry of Economic Affairs and Employment, 2021, 9)

3.1 Renewable energy in Finland

According to Motiva (2021), Finland has one of the highest shares of renewable energy sources in its energy mix in the EU. Sweden has the highest share of renewables of the total energy consumption, but a substantial amount of Sweden's renewable energy comes from hydro power whereas in Finland the most important renewable source is wood fuels. The consumption of renewable energy in Finland was 150 TWh according to the preliminary data of 2022 (Statistics Finland, 2023a). Wood fuels accounted for 68% of the renewable energy in 2022 as presented in Figure 5.

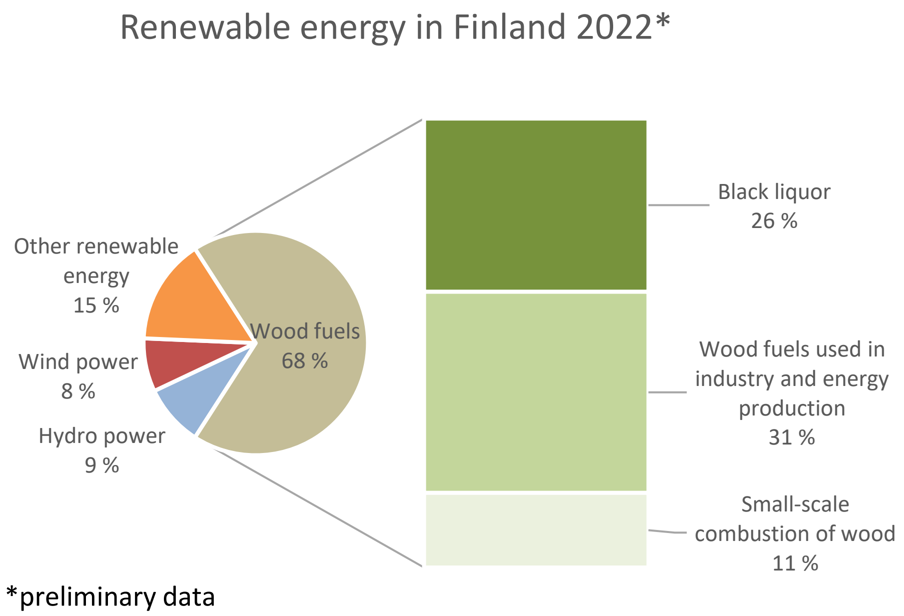


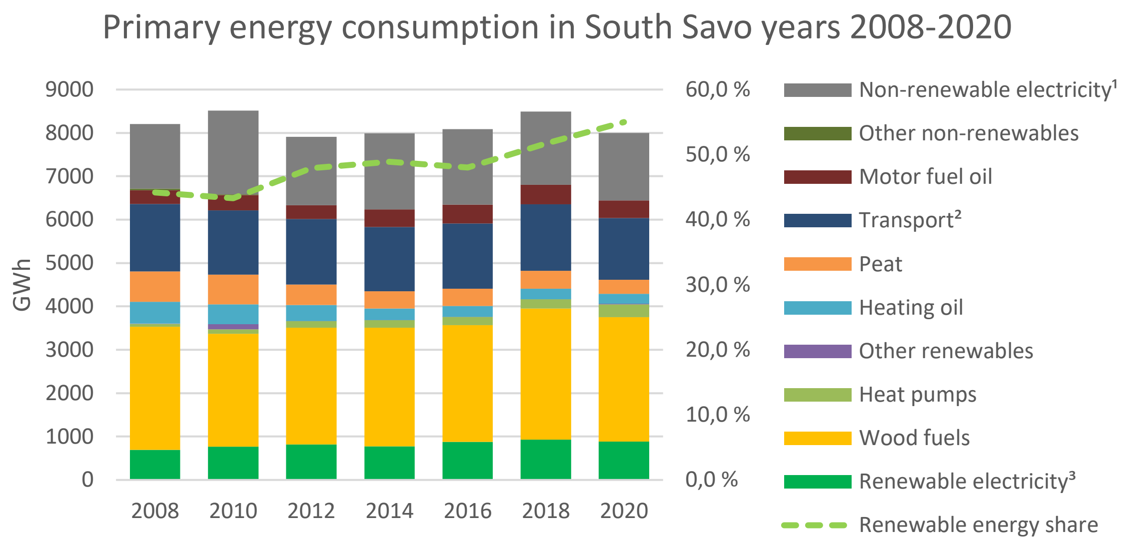
Figure 5. Renewable energy consumption in Finland 2022. (Statistics Finland, 2023a)

Finland has strong forest and pulp industries which explains the high number of wood-based fuels in energy generation. Most of the wood used for energy production are side streams of these industries. Black liquor comes as a side product of a cooking process in pulp industry, and it is the most significant wood fuel in energy production. Other important wood fuels are bark, sawdust, and forest chips. Bark and sawdust are side streams from wood processing and forest chips relate to wood chips made from stems, branches, stumps, and treetops which are collected during harvesting and silvicultural operations. (Ministry of Agriculture and Forestry, 2023a)

3.2 Energy use in South Savo

The consumption of primary energy in South Savo in 2020 was 7995 GWh. Comparing this to the total energy consumption of Finland presented in Figure 4, it can be said that South Savo's share is about 2% of the total energy consumption of Finland. The share of renewable energy in 2020 was 55% and it has increased quite steadily since 2010 as presented in Figure 6. The share of renewables in South Savo is well above the whole country's average. There are two main factors that have affected the increased share of renewable energy in South Savo since 2008: the increased share of renewable energy in electricity transferred from other regions and the decreased use of peat for energy production. (Itä-Suomen Energiatilasto 2020, 2021, 9)

Wood fuels accounted for 36% of primary energy consumption making it the most important source of energy in South Savo as presented in Figure 6. The high share of renewable energy is explained with the high amount of wood fuels and the minor use of coal and natural gas. Coal and natural gas are not directly used in South Savo, but they are included in the non-renewable electricity transferred from other regions (Itä-Suomen Energiatilasto 2020, 2021, 9-17).



¹The amount of imported non-renewable electricity
²Includes also the bio share of transportation fuels
³Includes the hydro power produced in South Savo and the imported renewable electricity

Figure 6. Primary energy consumption in South Savo from 2008 to 2020. (Itä-Suomen Energiatilasto 2020, 2021, 9)

At the end of 2022 there were no commercial windmills installed in South Savo (Finnish Wind Power Association, 2023a). Electricity production in South Savo is not sufficient to cover the region’s consumption, so a good amount of electricity must be transferred from other regions. Self-sufficiency in primary energy was 44% in 2020. The low amount of hydro power is one of the reasons for moderate self-sufficiency in energy. Also, the fact that there are no pulp mills in South Savo is another aspect leading to moderate self-sufficiency. (Itä-Suomen Energiatilasto 2020, 2021, 9-17)

3.3 District heat production

The most common heating form in Finland is district heating. District heat is commonly produced in combined heat and power plants or in heat only plants. Non-combustion based district heat production technologies, such as heat pumps and other hybrid solutions, are becoming more common. (Finnish Energy, 2023c)

According to Finnish Energy (2023a, 2), district heat supply in Finland was about 36 TWh in 2022 as presented in Figure 7. The share of renewables was 49% and the share of heat recovery from renewable sources was 12%. The rest of the production was covered with non-renewable energy sources. The single most important fuel used for district heat production was forest fuelwood, with a share of 27% from distric heat production. Forest fuelwood refers to forest chips, excluding short rotation coppices as those were not used for district heat production (Finnish Energy, 2023b). The impacts of ceasing natural gas imports from Russia can be seen in the figure as especially the consumption of coal and forest fuelwood has increased from 2021 to 2022.

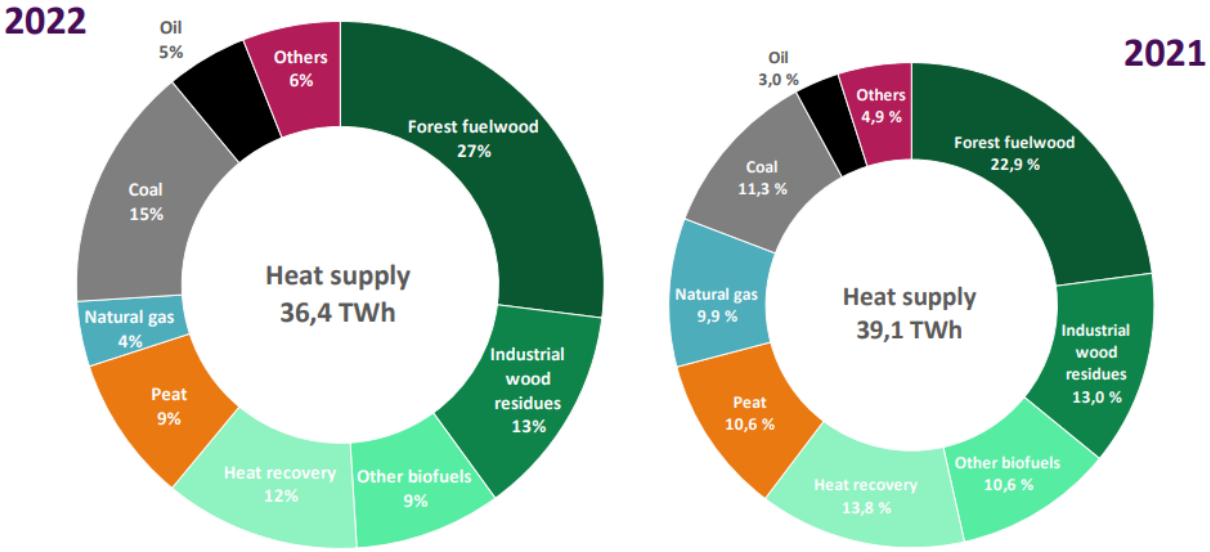


Figure 7. Energy sources of district heat supply in 2021 and 2022. (Finnish Energy, 2023a, 2)

District heat has earlier been typically produced in CHP and heat only plants, but during the past few years heat recovery has become a more common method in district heat production as it can be seen from Figure 8 (Statistics Finland, 2022, 39). According to Finnish Energy (2022, 3), in 2021 about 14% from the total supply of district heat was produced with heat recovery and heat pumps, 56% in CHP plants and 30% in heat only plants.

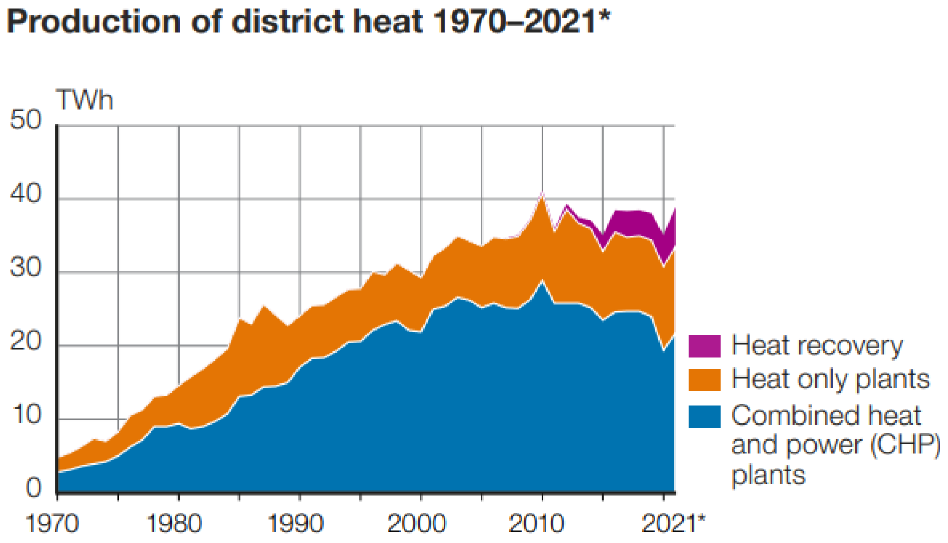


Figure 8. Production of district heat by production mode in Finland between 1970-2021. (Statistics Finland, 2022, 39)

According to Finnish Energy (2023d), the use of a CHP plant usually derives from the demand of district heat, and the plant is used with maximum capacity when the need for district heat is at its highest. During the coldest times, the consumption of electricity is normally at its highest, when the demand for heat is at its highest as well. The electricity production of a CHP plant can be adjusted, and for instance it can be reasonable to produce more electricity, if possible, when the market price of electricity is high. Electricity produced in district heat CHP plants has an important role in Finland and it accounted for about 10% of Finland's electricity production in 2022 (Finnish Energy, 2023e, 10).

According to the district heating statistics of Finnish Energy (2023b), district heat net production with fuels in South Savo was 904 GWh in 2021. The amount of district heat produced with heat recovery and heat pumps was 20 GWh. In 2021, 75% of the district heat was produced in CHP plants and 23% in heat only plants, as presented in Figure 9.

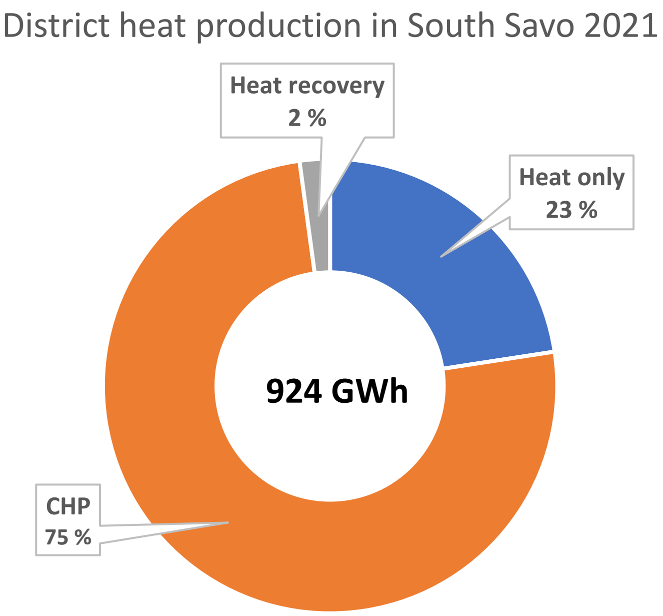


Figure 9. Production of district heat by production mode in South Savo in 2021. (Finnish Energy, 2023b)

According to Finnish Energy (2023b), the consumption of fuels for district heat production and electricity production in district heat CHP plants in South Savo was 1449 GWh in 2021. It can be seen from Figure 10 that wood fuels had a 76% share of the used fuels, and the single most important fuel was forest chips with a share of 47%. The net electricity production in district heat CHP plants in South Savo was 223 GWh in 2021.

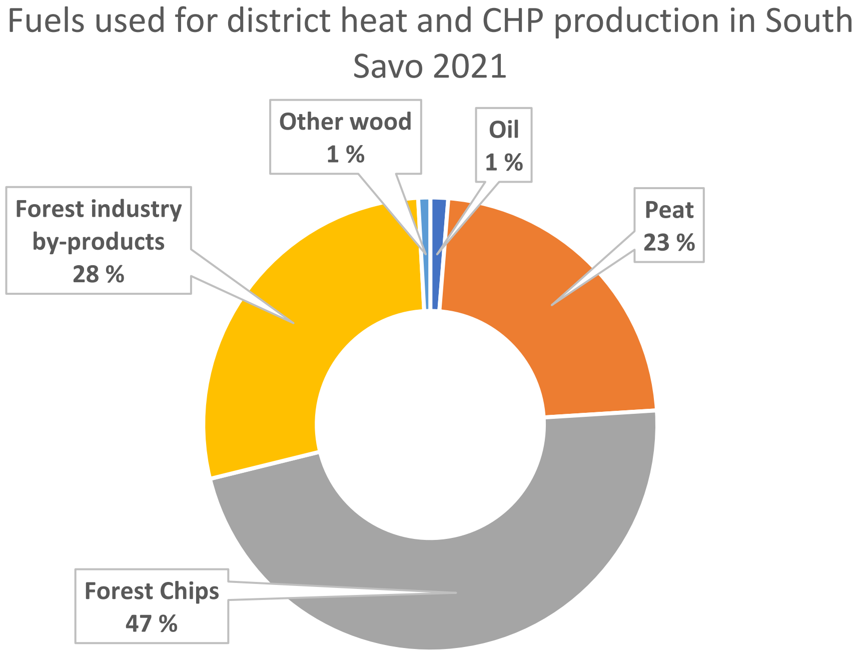


Figure 10. Fuels consumed for district heat production and CHP production in South Savo in 2021. (Finnish Energy, 2023b)

According to the district heat statistics of Finnish Energy (2023b), coal and natural gas were not used for district heat and CHP production in South Savo in 2021, despite covering a considerable share of used fuels on the country level. On the other hand, the share of peat is higher in South Savo than it is on the country level and the same applies to forest industry by-products and forest chips as well.

3.4 Greenhouse gas emissions in Finland

According to Statistics Finland (2023b; 2023c), greenhouse gas emissions excluding the LULUCF sector in Finland were 46 Mt CO_2 equivalents (CO_2-eq) in 2022. Emissions have reduced from 1990 to 2022 by 36% as presented in Figure 11. One of the next milestones in Finland's climate targets, as mentioned in section 2.2, is to achieve a 60% emission reduction by 2030, which means that the emissions must still be reduced by 29 Mt CO_2-eq by 2030. The CO_2 emissions from fuel combustion were about 32 Mt CO_2 in 2022. It can be seen from the figure that the emissions without LULUCF and CO_2 emission from fuel combustion pretty much follow each other. This means that most of the emission reductions have originated from the reduced emissions of fuel combustion, namely from the reduced use of fossil fuels and peat.

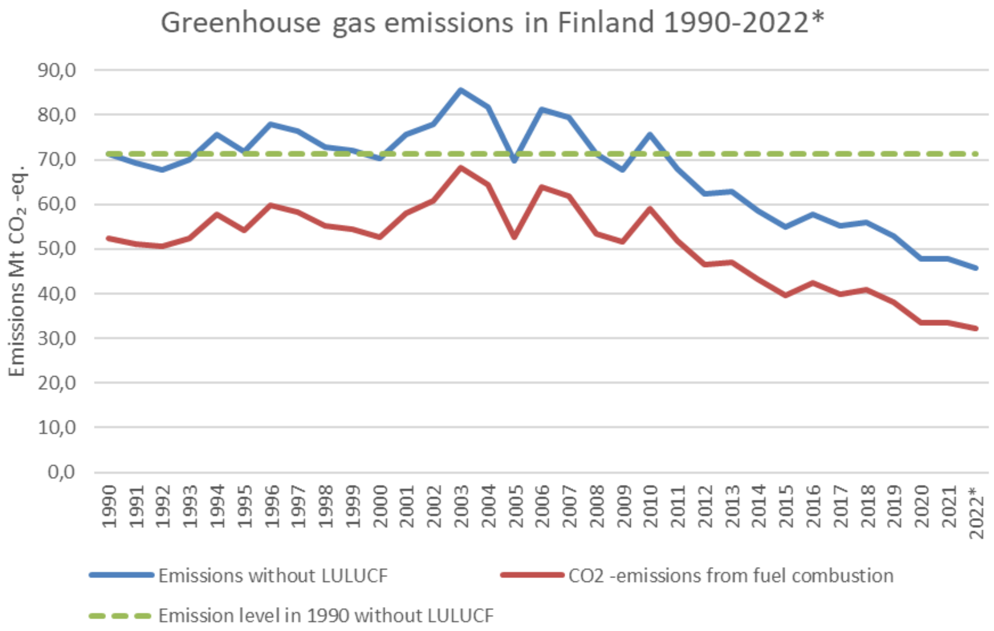


Figure 11. Greenhouse gas emissions in Finland from 1990 to 2022. (Statistics Finland, 2023b; Statistics Finland, 2023c)

The energy sector is the major source of greenhouse gas emissions in Finland with 34 Mt CO_2-eq, which is a 72% share of the total emissions (Statistics Finland, 2023d). The LULUCF sector has historically been a net sink of CO_2 emissions in Finland. However, in 2021 it became a net source of emissions for the first time with 0,5 Mt CO_2 equivalents. Forest land is the most important carbon sink in Finland. It accounted for -8 Mt CO_2-eq in 2021 which is the smallest amount since 1990. Forest lands carbon sink has decreased due to increased harvest rates, decreased tree biomass growth and increased emissions from drained peatlands in forest land. (Natural Resource Institute Finland, 2023)

According to Statistics Finland (2023e), the LULUCF sector’s carbon net sink has been almost 40 Mt CO_2-eq at its highest as presented in Figure 12. Carbon sinks play an important role for Finland to achieve its carbon neutrality by 2035 as it is projected to be more than 20 Mt CO_2-eq by that time as presented in Figure 2. The net emissions were 45 Mt CO_2-eq in 2021, which is almost the same as it was in 1990 as presented in Figure 12. This is because of the decreased carbon sinks. Between 1990 and 2021, the net emissions have varied between 30-59 Mt CO_2-eq even though the emissions have decreased from the highest level of 2003.

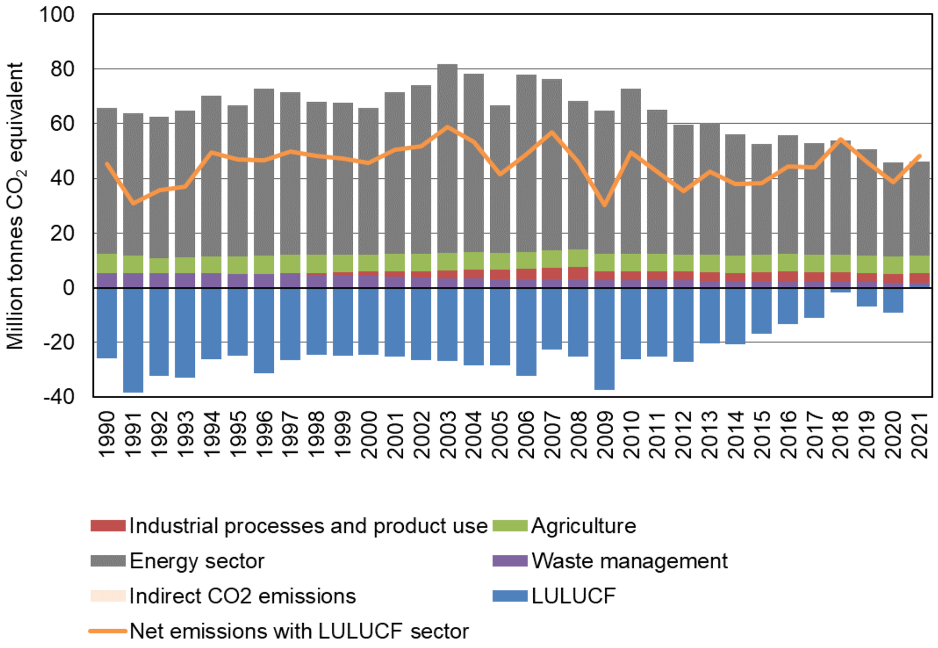


Figure 12. Greenhouse gas emissions and removals in Finland by sector 1990-2021. (Statistics Finland, 2023e)

Finland's greenhouse gas emissions from 2005 to 2021 divided between the ETS sector and non-ETS emissions are presented in Figure 13. It can be seen from the figure that especially emissions related to energy production in the ETS sector, since the beginning of emissions trading in 2005, have decreased significantly from the highest levels of 2006. In 2021 emissions from the ETS sector were 20,3 Mt CO_2-eq, of which 81% originated from energy sector, and the rest of the ETS sectors emissions came from industrial processes. The ETS sector covered 42% of Finland's total emissions in 2021. (Statistics Finland, 2023f)

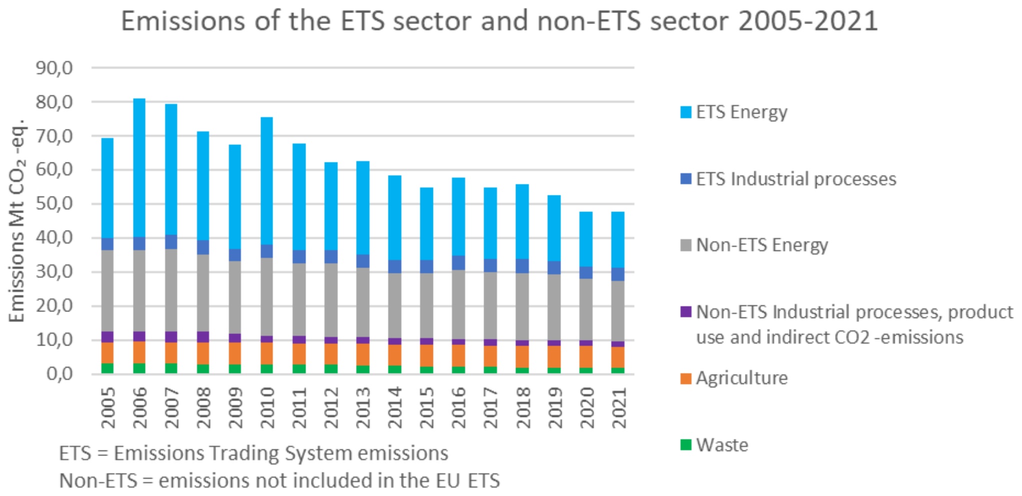
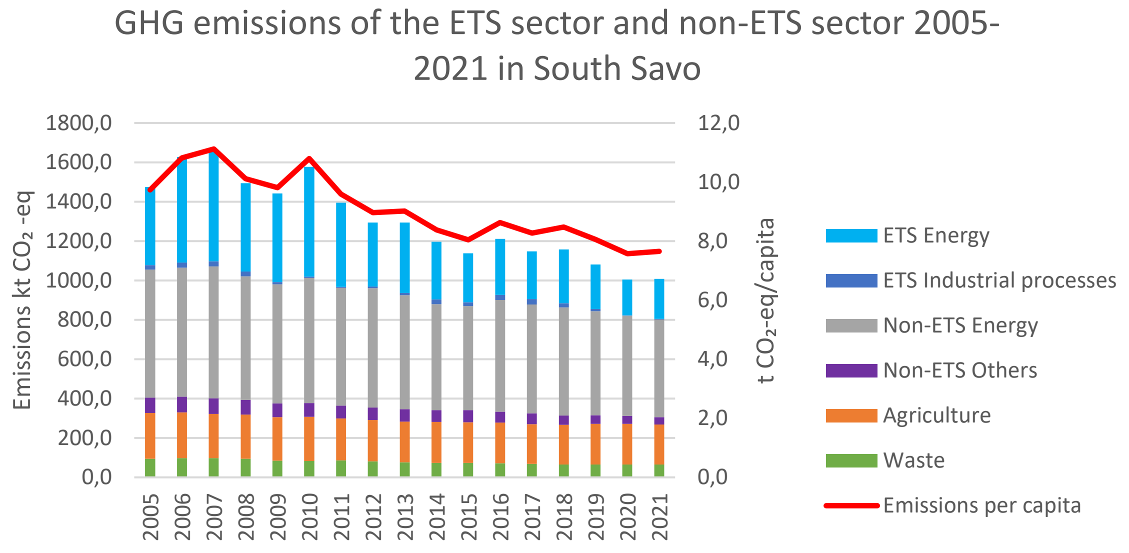


Figure 13. Finland's greenhouse gas emissions from ETS sector and non-ETS sector from 1990 to 2021. (Statistics Finland, 2023f)

Since the beginning of the emissions trading system in 2005, the ETS sector emissions have decreased by 15 Mt CO_2-eq which is about 42,5% when calculated with present-day coverage of the ETS, as stated in the report by Ministry of the Environment (2022b, 18-20). Emissions from the effort sharing sector have decreased by about 21% since 2005. The EU Emissions Trading System is described more detailed in chapter 4.

3.4.1 Greenhouse gas emissions in South Savo

The usage-based GHG emissions in South Savo were 1008 kt CO_2-eq in 2021 (Finnish Environment Institute, 2023a). In the usage-based emissions calculation method, emissions are calculated for the area where the consumption occurs, regardless of the geographical area of the origin of the emissions (Finnish Environment Institute, 2023b). Greenhouse gas emissions in South Savo from 2005 to 2021 divided between ETS sector and non-ETS emissions are presented in Figure 14. The biggest individual emission source is road transport with 28% share of the total emissions in 2021. Road transport is the main reason why the non-ETS energy has the highest share of the CO_2 emissions in South Savo accounting for 49%. Agriculture and energy produced at emissions trading sector both have a share of about 20% of the GHG emissions in South Savo. (Finnish Environment Institute, 2023a)



ETS = Emissions Trading System emissions
Non-ETS = Emissions not included in the EU ETS

Figure 14. Greenhouse gas emissions from the ETS sector and non-ETS sector in South Savo from 2005 to 2021. (Finnish Environment Institute, 2023a)

According to the Finnish Environment Institute (2023a), the greenhouse gas emissions have decreased for 466 kt CO_2-eq since 2005 in South Savo, which is a 32% reduction. Emissions from the emissions trading sector have decreased from 420 kt CO_2-eq to 207 kt CO_2-eq, which is a 51% reduction. Emission reductions, especially in the ETS sector, could be mainly explained with the rising trend of the renewable energy share in South Savo, which is presented in Figure 6. Emissions trading system covered 21% of South Savo’s total emissions in 2021. Emissions per capita have decreased since 2010 being 7,7 tonnes of CO_2 equivalents in 2021 as presented in Figure 14.

There is not much of emission-causing industry in South Savo, which is why there is basically no emissions from industrial processes in the ETS sector (South Savo Regional Council, 2022). Due to a small amount of emission-causing industry and a high share of renewables in energy production, agriculture and non-ETS sector energy are involved with higher shares in South Savo’s GHG emissions than they are in Finland’s GHG emissions.

4 EU Emissions Trading System

The EU Emissions Trading System (EU ETS or ETS) was introduced in 2005. It aims to work as a financial incentive for power plants and industries to reduce their greenhouse gas emissions. The companies operating under the ETS must pay for their emissions, so the less they pollute, the less they will pay for emission allowances (EA). The EU ETS acts in all EU countries and also in Iceland, Lichtenstein, and Norway. The ETS directive is the legislative framework of the EU ETS, and it has gone through several revisions during the existence of the emissions trading system. (European Commission, 2023d)

According to the European Commission (2023d), the EU ETS covers around 10 000 stationary installations among the energy sector and energy intensive industries as well as the emissions from aviation between the countries of the European economic area. The emissions trading system covers around 40% of the GHG emissions in the EU. There were 501 plants from around 140 operators involved in the EU ETS in Finland and it covered 42% of Finland’s total emissions in 2022 (Rautalin, 2023).

According to the European Commission (2023e), the EU ETS covers carbon dioxide emissions from energy intensive industries, heat and power production, aviation, and maritime transport. The EU ETS also covers perfluorocarbons from aluminium production and nitrous oxide from adipic and glyoxylic acids and glyoxal production. There are some exemptions according to the forementioned sectors as in some sectors plants under a certain size are excluded from the ETS. According to the Finnish Emissions Trading Act (Päästökauppalaki 2011/311), only plants above 20 MW of total rated thermal input are included in the ETS in heat and power production. Smaller plants operating in the same district heating network with a plant above 20 MW are also included in the ETS in Finland.

The emissions trading system works on a cap-and-trade principle, which means that there is a cap for the emissions in the system and all operators in the ETS must get along within the set cap. The emissions are regulated with emission allowances which the operators buy or receive for free. One emissions allowance is equal to one tonne of carbon dioxide equivalents. The operators operating in the system can buy and sell their emission allowances to other operators or save the allowances for coming years if they wish. Emission allowances are sold in auctions and the price depends on the demand and supply. The amount of emission allowances in the ETS reduces every year to gradually decrease the emissions originating from the ETS sector. (European Commission, 2023d)

4.1 Price development of emission allowance

The price of emission allowance was low for years until it started to increase in 2018 as presented in Figure 15. The price was low due to the surplus of emission allowances after the economic crisis in 2008. Emission allowances accumulated due to the low demand after 2008 that resulted as low prices for many years after that, which did not encourage the companies to reduce their emissions. (European Commission, 2023f)

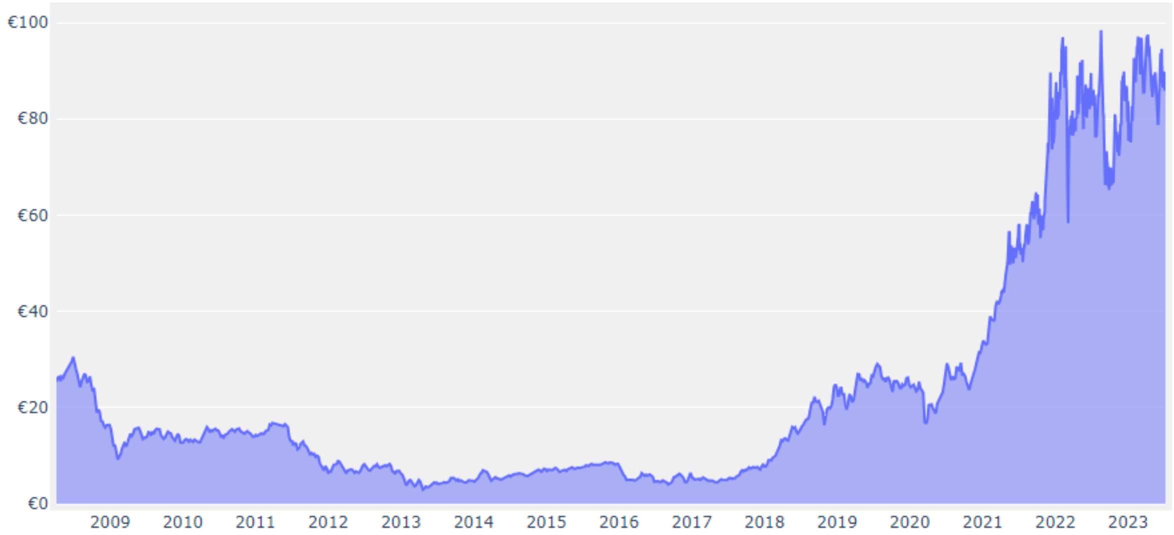


Figure 15. CO_2 emission allowance price development from 2008 to 2023 (€/CO_2 tonne). (Sandbag, 2023)

The price of carbon dioxide emissions started to increase heavily in 2021, especially because of the economic recovery after the Covid-19 pandemic, which led to an increased demand of natural gas and coal. The higher demand for these fossil fuels increased the demand of emission allowances which reflects to its price. The price of emission allowance has also increased because of the tightened climate targets in the EU with the Fit for 55 package and limitation of the amount of emission allowances in circulation. (Hiilamo, 2022)

4.1.1 Market Stability Reserve

The European Commission (2023f) postponed the auctioning of 900 million emission allowances between 2014-2020 to answer to the low emission allowance price as a short-term measure. The Market Stability Reserve (MSR) began in 2019, and it aims to work as the long-term solution for the surplus issue of emission allowances. Its idea is to adjust the amount of the emission allowances with pre-defined rules. Each year the amount of emission allowances in circulation are published, and based on that, it is decided whether allowances are put into the MSR or released from there. From 2019 to 2023 24% of the emission allowances in circulation are put into the MSR each year and from 2024 the annual amount will decrease back to the regular rate, which is 12% (European Commission, 2023g).

4.2 Phases of the EU Emissions Trading System

The emissions trading system is now on its fourth phase since the beginning of it in 2005. The periods can be divided as follows:

- First phase 2005-2007
- Second phase 2008-2012
- Third phase 2013-2020
- Fourth phase 2021-2030.

The first phase was more of a pilot for the upcoming second phase to see how the system would work and to form a price for carbon dioxide emissions. The ETS covered only carbon dioxide from power plants and energy intensive industries during the first phase, and almost all the allowances were given for free. The penalty for not being able to comply with the given allowances was 40 € per carbon dioxide tonne. (European Commission, 2023h)

Three countries outside of the EU, Iceland, Lichtenstein, and Norway, also joined the EU ETS for the second phase. The emission cap was lowered about 6,5%, the allocation of free allowances was decreased to around 90% and the penalty was increased to 100 €/CO_2 tonne. The aviation sector was also included in the ETS in 2012 covering the flights between European countries. (European Commission, 2023h)

For the third phase more gases and sectors were included in the ETS, which increased its coverage of the total emissions in the EU. Auctioning became the primary method for allocating emission allowances instead of free allocation. During the first and second phase each country had its own cap for emissions, but for the third phase a single cap for the whole EU took place. (European Commission, 2023h)

From the beginning of the fourth phase the amount of emission allowances will decrease by 2,2% annually, compared to 1,74 which it was before the fourth phase. The allocation of free emission allowances for sectors that have a risk for carbon leakage is prolonged. The phase-out of emission allowances for these sectors will begin in 2026 and end in 2034. The phase-in of the Carbon Border Adjustment Mechanism (CBAM) will take place over the same period. The CBAM will put a price for carbon intensive goods that are imported from outside of the EU. Allocation of free emission allowances for the sectors that are not exposed for carbon leakage will be phased out by 2030. (European Commission, 2023g; European Commission, 2023i)

To help the operators in energy intensive industries and energy production sectors to cut their emissions, two new funds were established: the innovation fund and the modernisation fund. The maritime sector and municipal waste incineration will also be included in the current ETS in the future. A separate emissions trading system ETS II will be established by 2027, and it will cover fuel for road transport and buildings as well as fuel for some other sectors such as manufacturing. If the energy prices are very high, the introduction of ETS II could be postponed to 2028. (European Parliament, 2022b)

5 Wood utilization in Finland

Finland is the most forested country in Europe with forest coverage of about 75% of the country's land area. The forests are the most important natural resource for Finland. The forest industry is one of the most significant industries, and it accounted for 17,5% of the value of the country's exported goods in 2021. The forest industry strengthens employment and business opportunities especially in the regions outside of the growth centres. (Finnish Forest Industries, 2022; Ministry of Agriculture and Forestry, 2022, 7).

61 000 persons worked in the forest sector in 2021, of which 25 000 persons worked in forestry and 36 000 persons worked in forest industry. Of those working in forest industry, 56% were employed in wood-products industries and 44% in pulp and paper industries. (Natural Resources Institute Finland, 2022a)

Finland's roundwood flows in 2021 are presented in Appendix 1. The volume of growing stock was reported as 2529 million cubic meters in stemwood, which means the part of tree above the stump including bark excluding branches. The annual growth of growing stock was 103 million cubic meters, which represents an average growth in a five-year period. The total drain was 92 million cubic meters and roundwood removals from Finnish forests were 76 million cubic meters in 2021. The domestic consumption of roundwood is calculated by adding the imports and deducting the exports to roundwood removals. The domestic consumption of roundwood was about 85 million cubic meters in 2021. The domestic roundwood remaining in Finland goes through roundwood inventories before it is taken into use. There are no statistics about the roundwood inventories in Finland. Roundwood is then used in wood-product industries, pulp industries, energy production or as a fuelwood for small-scale housing. (Kulju et al., 2023, 14-15)

The Natural Resources Institute Finland (2023b) estimates the annual maximum sustainable yield of roundwood total removals. There can be intensive variation in the felling volumes depending on the demand, so the annual maximum sustainable felling potential is designated over a period of several years. For 2016-2025 the annual sustainable felling potential is 80,5 million cubic meters. From the beginning of this present period, which begun in 2016, the felling volumes on the country level have been 91% of the felling potential on average. Six regions are above the maximum sustainable felling volume, and one of them is South Savo with an average felling volume of 103% from the maximum sustainable yield between 2016-2022 as presented in Figure 16.

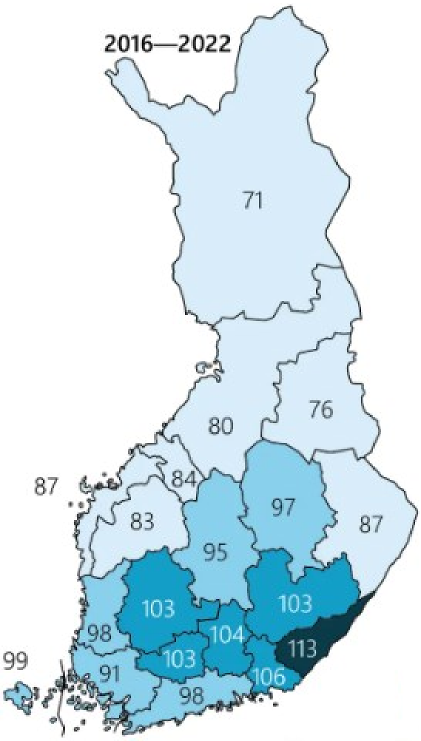


Figure 16. Felling percentage from the estimated sustainable maximum yield 2016-2022. (Natural Resources Institute Finland, 2023b)

In the southern regions of Finland, the average felling percentage is varying from 91% to 113%, so the best possibilities to increase the felling rates are in the northern Finland, especially in Lapland, as it can be seen in Figure 16. It is worth noting that five out of the six South Savo's neighbouring regions have felling rates of at least 95% of the maximum sustainable felling potential.

According to Viitanen et al. (2022, 55), the demand for wood from Finnish forests is likely to increase as there are some new investments in the forest industry, wood imports from Russia has ended, and the use of wood for energy production is increasing as well. The industrial roundwood loggings are expected to exceed 66 million cubic meters in 2023. Stora Enso's Kemi bioproduct mill is planned to start-up in the third quarter of 2023 which will add annual pulpwood demand by 4,5 million cubic meters. On the other hand, some older forest industry plants might and will get closed as the competition gets tougher. For example, Stora Enso (2023) announced that they are planning to permanently shut down the Sunila pulp mill as it is no more profitable as the competition of domestic pulpwood has increased and the wood imports from Russia are discontinued.

5.1 Carbon neutrality of wood combustion

Forest biomass is used for multiple purposes, which can be divided to three main categories: bioenergy, wood products and pulp production. Wood fuels for energy production are usually side streams from forest industry processes, but also residues and small diameter wood from forestry are used as a fuel as presented in the flowchart in Figure 17. To meet the needs of process energy in pulp mills and wood product manufacturing, wood is used internally at site for energy supply to meet the demand. In pulp mills black liquor is used as a fuel in recovery boilers, and sawmill by-products are used for drying in sawmills. (Berndes et al., 2016, 6)

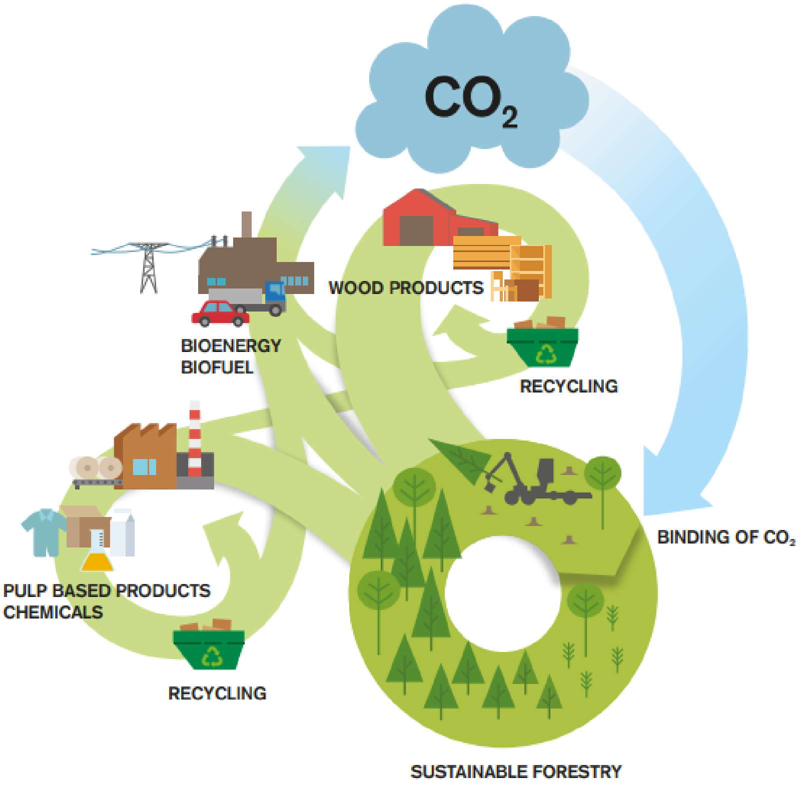


Figure 17. Forest bioenergy’s carbon cycle in the framework of forestry and forest industry. (Berndes et al., 2016, 6)

When biomass is combusted for energy production it is considered as a carbon neutral fuel in the EU Emissions Trading System if it meets the sustainability criteria of the present Renewable Energy Directive (RED II) (European Commission, 2022a, 10). Biomass is rated as carbon neutral fuel because biomass emits the same amount of carbon dioxide to the atmosphere when combusted which it absorbed from the atmosphere when it grew up (Berndes et al., 2016, 8).

According to the report by Berndes et al. (2022, 1-2), the emissions from biomass combustion are not included in the energy sector reporting in national greenhouse gas inventories. Instead of this, biomass use is reported in the LULUCF sector, simply to avoid double counting. This means that biomass usage is not defined as carbon neutral in the national greenhouse gas inventories. In case that biomass usage exceeds the growth rate, it will reflect in the national greenhouse gas inventory as the forest carbon stock is reduced.

When considering the supply chain, there are some carbon emissions in the supply chain of forest biomass as the machines and trucks used for harvesting and road transport normally uses diesel as a fuel. Depending on the method, chipping may also cause carbon emissions. The supply chain fossil fuel emissions account for less than 5% of the energy content of the biomass supplied, which could be considered as a relatively small fraction. (Berndes et al., 2016, 8-9)

There are also other views about the carbon neutrality of the combustion of woody biomasses and especially of the combustion of primary woody biomass. More than 500 scientists undersigned a letter which was addressed to EU Commission President, Ursula von der Leyen and European Council President Charles Michel and other world leaders. The scientists appeal that the burning of biomass must stop as the regrowth of trees takes more time than the world has time to solve the climate change. The letter also states that EU should not consider biomass combustion as carbon neutral in the renewable energy standards and in the ETS. (Raven, 2021)

5.2 Classification of wood fuels

According to Alakangas et al. (2016, 64), woody biomasses can be divided into three categories by their raw material classes following the standard SFS-EN ISO 17225-1 - Solid biofuels. Those three categories are:

- Forest, plantation, and other virgin wood (Primary woody biomass)
- By-products and residues from wood processing industry (Secondary woody biomass)
- Used wood (Tertiary woody biomass).

The classification of the categories in the list above is similar to Figure 18. The figure presents an overview of different types of woody biomasses and their flow within energy production, wood processing industry and the end use of wood products.

This study focuses on the primary woody biomasses excluding woody biomasses from woody energy crops and the use of firewood in small-scale housing. Most of the firewood used in small-scale housing is made from delimbed stems (Alakangas et al., 2016, 87).

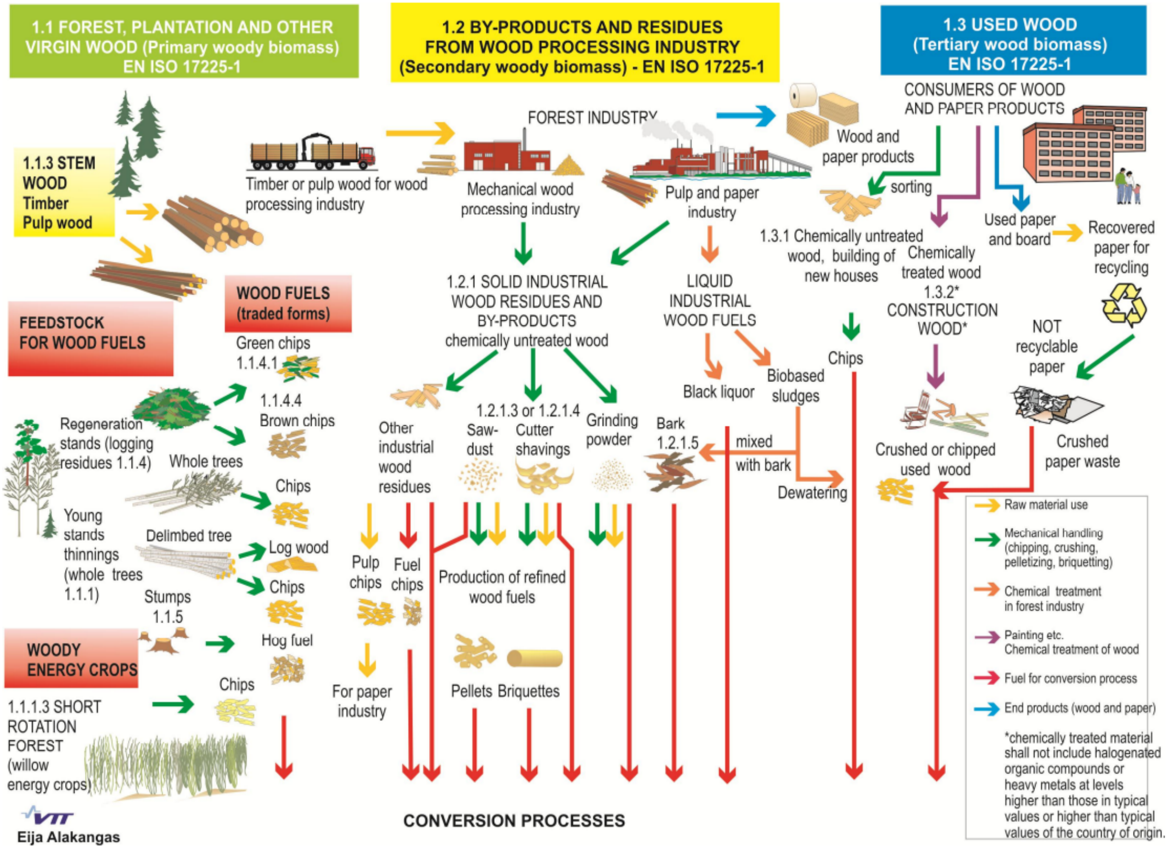


Figure 18. Example of classification of woody biomasses by their raw material class. (Alakangas et al., 2016, 65)

The Natural Resources Institute Finland (Luke) provides official statistics of wood consumption in Finland, which is why most of the data used in this study comes from Luke's database. Some of the data used in this study comes from Statistics Finland, which is the national statistics institute of Finland, providing impartial statistics. Luke uses the same fuel classification as Statistics Finland though there might be small differences in the names of the fuels. Therefore, the fuel classification of Statistics Finland is the one used in this study. Definitions for the classification of energy wood are provided in Appendix 2. Definitions in the appendix are from the definitions for fuel classification of 2020 updated with the present fuel codes (Statistics Finland, 2023g).

There are four different wood fuel categories that are the most relevant to this study:

- Chips from roundwood, small-sized trees
- Chips from roundwood, large-sized timber

- Forest residue chips
- Hog fuel from stumps.

The European Commission’s categorization of woody biomasses differs a little bit from the standard SFS-EN ISO 17225-1 as recovered wood (used wood in Figure 18) is counted as secondary woody biomass. European Commission (2021, 168) describes primary woody biomass as follows:

> “All roundwood felled or otherwise harvested and removed. It comprises all wood obtained from removals, i.e., the quantities removed from forests and from trees outside the forest, including wood recovered due to natural mortality and from felling and logging. It includes all wood removed with or without bark, including wood removed in its round form, or split, roughly squared or in other form, e.g., branches, roots, stumps and burls (where these are harvested) and wood that is roughly shaped or pointed.”

5.2.1 Cascade use of woody biomasses

According to Vis et al. (2016, i) cascade use means resource efficient using of available resources by using recycled materials or residues which in the context of this study means the resource efficient use of woody biomass. In the cascading principle woody biomass is first used for a product and after that it is used at least once more for a product or for energy production. Different parts of a tree are used for the purpose where the highest value is provided (Valkeapää & Soilampi, 2022). Cascade use is present in Figure 18 as the figure follows the cascading principle, but what cascading means when considering a full-grown tree is presented in Figure 19.

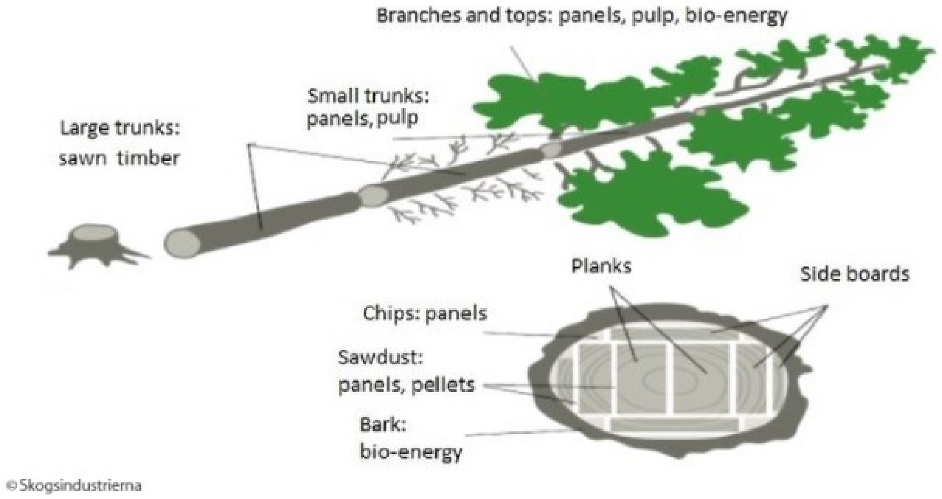


Figure 19. Different parts of a tree are used for different purposes. (European Commission, 2018, 25)

The lower part of the tree is used as logs to make sawn wood products such as timber and plywood. Pulp is produced from treetops and thinner trees. Pulp is then used to manufacture paper, board or other bioproducts such as cosmetics, textiles, and adhesives. (Valkeapää & Soilampi, 2022)

According to the Ministry of Agriculture and Forestry (2023b, 5-7), most of the solid wood fuels for energy and heat production originate as a side stream of forest industry such as bark and sawdust. Forest chips for energy generation are mainly produced from low-value biomasses such as branches, treetops and small-sized trees. Small-sized trees usually come from silvicultural operations of young forests. Treetops and branches are collected as logging residues from regeneration sites. Decayed or damaged parts of stems can also be used for energy production as they are not suitable for manufacturing of wood products (Ministry of Agriculture and Forestry, 2023c, 4).

When considering a full-grown tree, the highest added value comes from wood products as they can be used for many different purposes instead of fossil-based materials, and they can offer a long-term carbon storage for the carbon contained in the wood (European Commission, 2018, 25). A wood product can be used for energy use if its service life can't be extended or it is not suitable for re-use or recycling (Sokka et al., 2014, 5).

5.3 Trends of solid wood fuel consumption

According to Luke's statistics (Natural Resources Institute Finland, 2023a), the use of solid wood fuels in heat and power plants in Finland was 44,5 TWh in 2022 having a 5% decrease from the previous year when the consumption was the highest in record. The use of solid wood fuels in heat and power production in Finland and South Savo from 2010 to 2022 is presented in Appendix 3. The use of solid wood fuels in energy production has increased by 45% in Finland since 2010, but in South Savo the consumption of solid wood fuels has remained about the same for the mentioned period. According to the preliminary data of 2022, the use of forest chips in heat and power plants in Finland has increased from 12,5 TWh to 20,1 TWh since 2010, accounting for 45% of the consumption of solid wood fuels which is the highest share of all solid wood fuels in 2022. When compared to the total energy consumption of Finland (Statistics Finland, 2023a) it can be stated that forest chips accounted for about 6% of Finland's total energy consumption in 2022.

5.3.1 Consumption of forest chips in Finland

According to Luke (Natural Resources Institute Finland, 2023c), the use of forest chips in heat and power production in Finland was 10,2 million cubic meters in 2022. A total of 6,6 million cubic meters was used in combined heat and power (CHP) plants and the rest was used in heat production as presented in Figure 20. It can be seen from the figure that the use of forest chips in heat and power production has increased significantly since 2000, when the consumption of forest chips was only 0,8 million cubic meters.

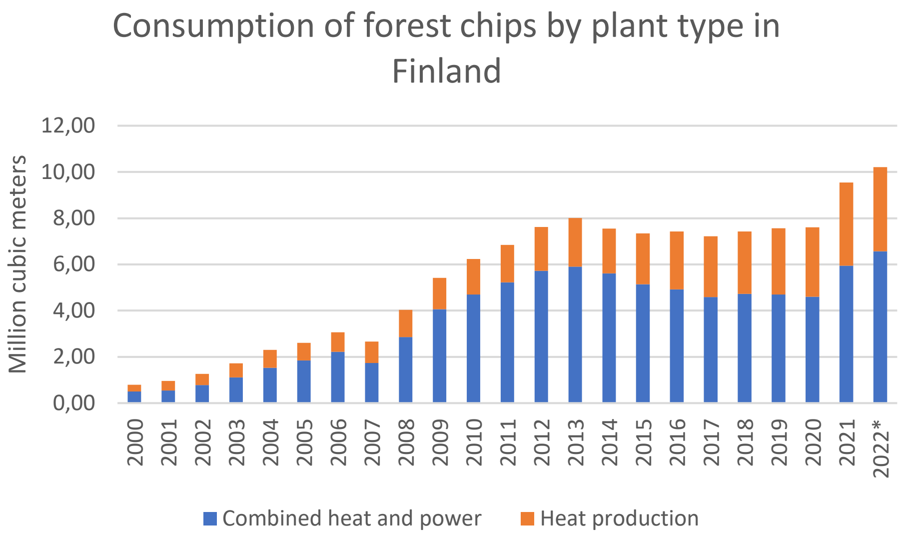


Figure 20. Consumption of forest chips by plant type in Finland from 2000 to 2022. (Natural Resources Institute Finland, 2023c)

In 2022, 6,4 million cubic meters of forest chips were produced from small-sized trees which is more than 60% of the total forest chip consumption as presented in Figure 21. Small-sized trees are whole trees, pruned stems and pulpwood. The second highest share is from logging residues accounting for 2,9 million cubic meters. The use of large-sized timber was about 0,6 million cubic meters. Most of the large-sized timber is usually from decayed trees that is unsuitable for other use. The rest of the forest chips, 0,3 million cubic meters, was produced from stumps. The biggest increase of forest chip raw materials has originated from the small-sized trees as its use has increased since 2010 from 2,5 million cubic meters to 6,4 million cubic meters. The use of stumps has decreased during the same period by more than 70%. (Natural Resources Institute Finland, 2023d)

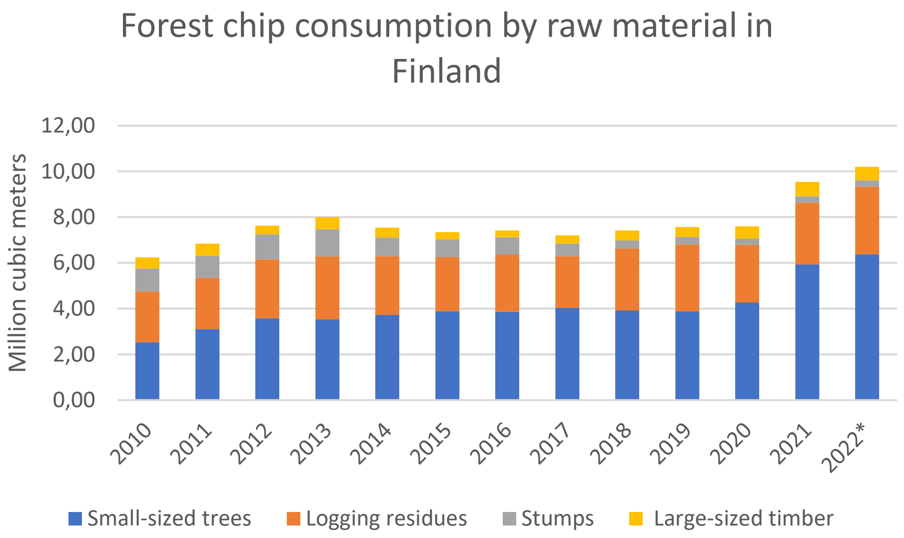


Figure 21. Forest chip consumption by raw material in Finland 2010-2022. (Natural Resources Institute Finland, 2023d)

The high demand for energy wood during the past year has led to a situation where some of the wood which is suitable for forest industry processes has been used for energy production. All energy wood is counted as energy wood in the statistics despite its suitability for other purposes. Therefore, it is not possible to find out from the statistics what is the share of suitable raw material for forest industry of the wood that was used as energy wood. (Natural Resources Institute Finland, 2023e)

The consumption of imported chips in heat and power plants collapsed to 0,5 million cubic meters in 2022, which equals to about 5% of the usage of forest chips in heat and power plants, as the forest chip imports from Russia ended. The share of imported chips was at its highest in 2020 accounting for 24% of the forest chips used for heat and power production as presented in Figure 22. However, the highest amount of imported chips used for the mentioned purpose was in 2021 when the amount was 1,9 million cubic meters. (Natural Resources Institute Finland, 2023f)

Luke’s quality report of wood consumption (Natural Resources Institute Finland, 2023g) mentions the following about the consumption of imported chips:

> “Estimates of the consumption of imported chips at heating and power plants are calculated as a difference between the volume of imported chips obtained from the forest industries’ foreign trade statistics and the volume of imported chips indicated in the statistics on forest industries’ wood consumption.”

It is estimated that any surplus volume has been used in energy generation as forest chips. Therefore, the imported chips used in heat and power production are accounted as forest chips and are also referred as imported forest chips in this work.

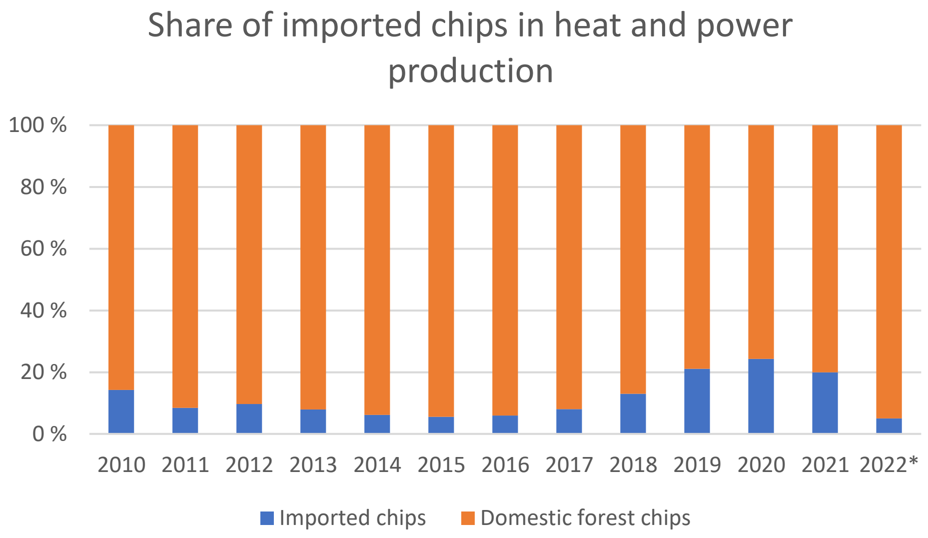


Figure 22. Share of imported chips and domestic forest chips of the total use of forest chips in heat and power production in Finland 2010-2022. (Natural Resources Institute Finland, 2023f)

As the share of imported chips was small in 2022 and at the same time the total use of forest chips for heat and power production was at a record high, the use of domestic forest chips was high, accounting for 9,7 million cubic meters. The same number for previous year was 7,6 million cubic meters so the increase from 2021 was about 27%. (Natural Resources Institute Finland, 2023f)

In order to support the preparation of Finland’s Climate and Energy Strategy and the Medium-term Climate Change Policy Plan, an extensive background study was carried out. The background study is called “Carbon neutral Finland 2035 – measures and impacts of the climate and energy policies” and it is abbreviated as the HIISI project. (Ministry of Economic Affairs and Employment of Finland, 2022, 11)

In the HIISI project two different scenarios were prepared: a scenario With Existing Measures (WEM), also known as the base scenario, and a scenario With Additional

Measures (WAM). The WEM scenario takes into account the policy measures that are already in place. The WAM scenario takes into account the policy measures in place and the planned policy measures that are not yet in force. (Hiisi2035, 2023)

The WAM scenario takes into account the greenhouse gas emission reduction targets, such as carbon neutrality by 2035, and the targets of the Finnish Climate Change Act for 2030, 2040 and 2050, unlike the WEM scenario (Lehtilä et al., 2021, 17). The WAM scenario is considered to be more relevant according to the scope of this study and therefore used as a base scenario in this study to predict the future consumption of forest chips in heat and power plants as well as predicting future CO_2 emissions later in this study.

The consumption of forest chips is predicted to increase until 2035 in the future in Finland as presented in Table 1. The consumption of forest chips is expected to turn into slight decrease after 2035 due to development of other energy production technologies and improvement of thermal insulation in buildings (Maanavilja et al., 2021, 51). In the WAM scenario, the predicted use of domestic forest chip distribution by raw materials is following the average consumption of 2015-2019 (Maanavilja et al., 2021, 77).

Table 1 presents the predicted total consumption of forest chips in million cubic meters and in terawatt hours. The amount of forest chips in cubic meters can be converted to megawatt hours by using the energy density of forest chips (2 MWh/m^3), which is used throughout this work in cases where the values are only available in cubic meters. In some of the Luke's statistics, where the amounts are reported in both units: GWh and m^3, there is some fluctuation due to the collecting method of the data and the numbers does not always match with 2 MWh/m^3. (Natural Resources Institute Finland, 2023g)

Table 1. Predicted consumption of domestic forest chips and imported chips for heat and power plants in Finland according to the WAM scenario. (Maanavilja et al., 2021, 52)

	2025	2030	2035	2040
Domestic forest chips (Mm^3)	9,9	11,5	11,9	11,3
Imported chips (Mm^3)	2,1	2,1	2,4	2,5
Total (Mm^3)	**12,0**	**13,6**	**14,3**	**13,8**
Total (TWh)	**24,0**	**27,1**	**28,5**	**27,7**

It should be noted that the predicted use for domestic forest chips is expected to be 9,9 million cubic meters in 2025 in the WAM scenario even though the use of domestic forest chips was already 9,7 million cubic meters in 2022. The HIISI project was carried out before Russia's invasion of Ukraine and the end of wood imports from Russia. Therefore, the estimated amount of imported chips for future is unsure. The imports from Russia accounted for 75% of all wood fuel imports in 2021 and the rest came mainly from Baltic countries. Therefore, it is assumed that the share is the same for the imported chips, since it is not possible to verify it from the statistics (Natural Resources Institute Finland, 2022b).

Imported forest biomass must fulfil the sustainability criteria, otherwise it would be treated the same way as fossil fuels according to the European Commission's (2022b) implementation regulation. The Finnish Energy Authority (2022) has listed countries which fulfil these criteria. Baltic countries, Sweden and Norway are on the list, but Russia is not included. In case where forest biomass would be imported from Russia, the fulfilment of sustainability criteria must be evaluated by the zone of supply.

Due to Russia's attack to Ukraine, Finnish Government appointed a Ministerial Working Group on Preparedness to guide preparedness related to the impacts of the war (Finnish Government, 2022a). As a part of ensuring the energy supply and availability, the working group set temporary measures to improve the availability of domestic forest chips as the imports of forest chips from Russia was ceased. The subsidies were increased for the management of young forests and collecting of small wood, which will increase the amount of collected small wood from forests. (Finnish Government, 2022b)

As the share of Russian forest chips is assumed to be 75% of the total amount of imported chips, in this study that share is expected to be replaced with domestic forest chips and imported chips from other countries. The total amount of forest chips, presented in Table 1, is used to find out the share of forest chips used in the ETS sector in section 6.1. The use of forest chips is not divided between domestic and imported further in this study as the carbon dioxide emissions from combustion would fall for Finland's account anyway, despite the origin of the fuel.

5.3.2 Consumption of forest chips in South Savo

According to Natural Resources Institute Finland (2023a; 2023d), the use of forest chips in heat and power plants in South Savo was 489 000 m^3 in 2022, which was reported as 964

GWh. This accounts for about 5% of the total amount of forest chips used in Finland in 2022. Small-sized trees have been the major source of forest chips in 2022, which accounted for 269 000 m^3 as presented in Figure 23. The consumption of logging residues was 211 000 m^3, large-sized timber accounted for 7 000 m^3, and stumps 2 000 m^3 in 2022. When comparing the forest chip consumption of 2020 (Natural Resources Institute Finland, 2023d) to the primary energy consumption (Itä-Suomen Energiatilasto 2020, 2021), it can be stated forest chips used in heat and power plants accounted for 10% of South Savo's primary energy consumption in 2020.

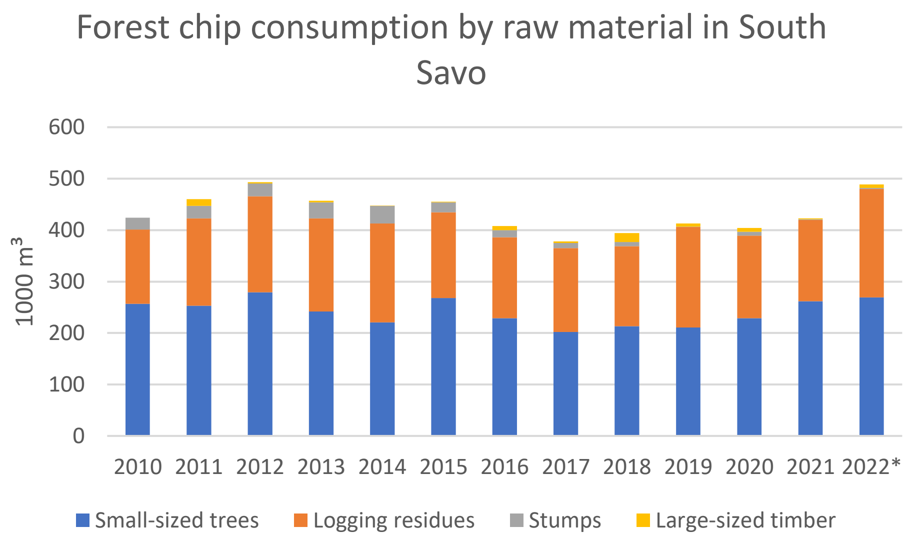


Figure 23. Forest chip consumption by raw material in South Savo 2010-2022. (Natural Resources Institute Finland, 2023d)

South Savo is an active region on wood production, where district heat production has switched to utilize forest energy wood in an early stage (Finnish Forest Centre, 2021). This is why the trend of forest chip consumption in South Savo differs from the one of Finland, and for example the peak year of forest chip consumption in South Savo so far has been in 2012, when the total consumption of forest chips used in heat and power plants was 492 000 m^3. The use of stumps has decreased since 2010, but otherwise there is not such an upward trend in the consumption of forest chips as there has been on the country level as presented in Figure 21.

6 Forest chip consumption in the ETS sector

This chapter discusses the present and future forest chip consumption for heat and power plants operating in the ETS sector in South Savo and in Finland. The calculated carbon dioxide emissions from forest chip combustion are also presented and the method how the carbon dioxide emissions are calculated is explained. The plants operating in the ETS sector that use forest chips as a fuel in South Savo are presented with some detailed information.

6.1 Forest chip consumption and CO_2 emissions in the ETS sector in Finland

According to Rautalin (2023), the total carbon dioxide emissions from the ETS sector in Finland was 19 Mt CO_2 in 2022. Significant amounts of sustainable biobased fuels were used in the ETS sector totalling for about 78 TWh. Energy wood had a share of 20% of the sustainable biobased fuels, being approximately 15,7 TWh. Energy wood refers to forest chips made from roundwood (small-sized trees and large-sized timber), forest residues or hog fuel from stumps as the amount of forest chips made from short rotation coppices are negligible in Finland (Natural Resources Institute Finland, 2023a).

As the consumption of forest chips in heat and power plants in total was 20,1 TWh in 2022, it means that approximately 78% of that amount was used in the ETS sector in 2022 when compared to the statistics of Luke (Natural Resources Institute Finland, 2023a). By using the carbon dioxide emission factor of energy wood, presented in Appendix 4, it can be found out that the stack emissions from forest chips combusted in the ETS sector was 6,3 Mt CO_2 in 2022.

Predicted consumption of forest chips in the ETS sector for 2025-2040 is presented in Table 2. The predicted consumption in the ETS sector is calculated by using the predicted use of forest chips of the WAM scenario presented in Table 1 and using the assumption that 78% of the total amount of forest chips are used in the ETS sector. The table also provides the predicted emissions from forest chip combustion. The predicted emissions are converted from TWh to Mt CO_2 by using the emission factor of energy wood presented in Appendix 4.

It is assumed in the emission calculations of this study that all forest chips used for heat and power production are combusted, although it is also possible that some of the forest chips could be converted to heat and electricity in some other ways, for example via gasification. It should be also noted that the predicted emissions have been converted directly from the amount of consumed forest chips and therefore the predicted emissions does not take into account possible emission reductions from carbon capture. These forementioned assumptions applies to the calculated emissions from combustion presented in Table 2 and Table 4.

Table 2. Predicted consumption of forest chips and carbon dioxide stack emissions from forest chip combustion in the ETS sector in Finland from 2025 to 2040.

	2025	2030	2035	2040
Consumption (TWh)	**18,7**	**21,1**	**22,2**	**21,5**
Emissions from combustion (Mt CO_2)	**7,5**	**8,5**	**8,9**	**8,7**

The estimated carbon dioxide emissions from forest chip combustion by raw material until 2040 among the plants included in the ETS sector is presented in Figure 24. The forest chips distribution by raw materials for the estimations of future consumption of each fraction, is following the average consumption of 2017-2022 which is presented in Figure 21. It is worthwhile to mention that the predicted emissions are based on the predicted future consumption which are presented in Table 2 and it does not take into account the possible decrease of consumption if forest chip combustion is included in the ETS any time in the near future.

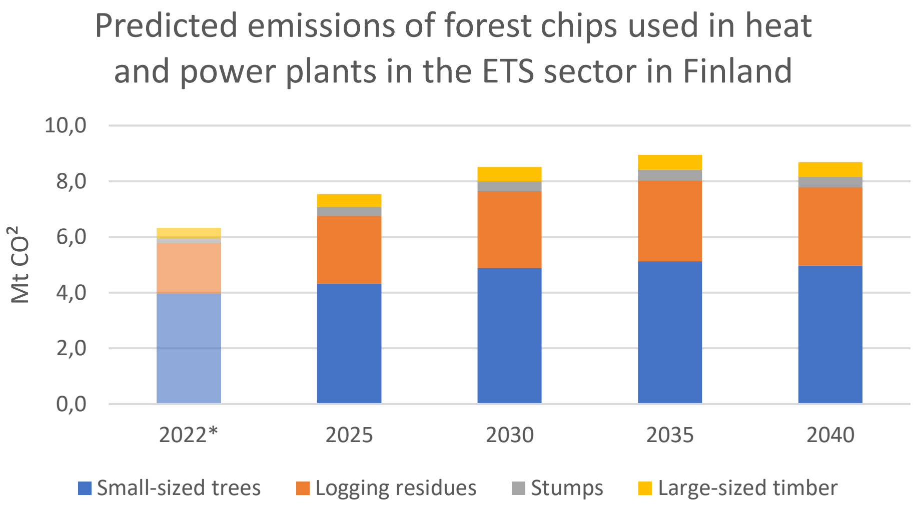


Figure 24. Predicted carbon dioxide stack emissions of forest chip combustion by raw material in the ETS sector in Finland until 2040.

The carbon dioxide emissions from forest chip combustion among the plants included in the ETS are expected to be the highest in 2035 totalling for 8,9 Mt CO_2, which is also the year when Finland is aiming to be carbon neutral. Year 2022 is also visible in Figure 24, representing the present emissions of forest chip combustion. It should be noted that due to the method used for dividing the consumption of forest chips by raw material for coming years, the share of the logging residues is expected to increase while the share of small-sized trees is expected to decrease by 2025. Due to the used method, the share of stumps is expected to grow from 3% to 4% from 2022 to 2025, but it should be noted that the use of stumps has been decreasing since 2010 (Natural Resources Institute Finland, 2023d).

6.2 Forest chip consumption and CO_2 emissions in the ETS sector in South Savo

The consumption of forest chips in the ETS sector in South Savo is estimated by using the forest chip consumption of each power plant included in the ETS as there are only five plants using forest chips which are included in the ETS as presented in Table 3. The consumption amounts were compiled by contacting the energy companies that operate the plants as the numbers for 2022 were not yet available elsewhere. It should be noted that the table includes the Tikkala heat plant, which is also included in the ETS as it is in the same district heat network with the Pursiala power plant (Lahtinen, 2023). In Tikkala there are also other boilers at the same plant, but only the capacity of the boiler that uses forest chips as a fuel is shown in Table 3 (Koivuniemi, 2023). The consumption of forest chips in these plants was 810 GWh in 2022. As the total consumption of forest chips in the heat and power plants in South Savo based on Luke’s database (Natural Resources Institute Finland, 2023a) was 964 GWh, it can be assumed that approximately 84% of the total amount of forest chips consumed in heat and power plants was used in the ETS sector in 2022.

From the five plants operating in the ETS sector, two plants are producing solely heat (Tikkala and Laitaatsilta), and the other three plants are CHP plants as presented in Table 3. In the table, the capacity of the plants is expressed as a total fuel power. This is because that is very likely to be the new Finnish term to describe the total rated thermal input, according to the proposal of Finnish Government (2023, 2,70) on the new Finnish Emissions Trading Act. The new Emissions Trading Act is intended to enter into force in 1.1.2024.

Table 3. Heat and power plants included in the ETS in South Savo that use forest chips as a fuel. (Anttonen, 2023; Koivuniemi, 2023; Lahtinen, 2023; Laitinen, 2023)

Plants using forest chips included in the ETS in South Savo 2022					
Municipality	Plant	Type	Total fuel power (MW)	Forest chip consumption (GWh)	Share of forest chips from used fuels
Mikkeli	Pursiala power plant	CHP	234	477	62,8 %
	Tikkala heat plant	HOB	3	13	
Savonlinna	Savonlinna power plant	CHP	81	210	46,2 %
	Laitaatsilta heat plant	HOB	20	21	100,0 %
Pieksämäki	Pieksämäki power plant	CHP	42	89	48,0 %
Total				**810**	**56,2 %**

The stack emissions from forest chip combustion in the ETS sector in South Savo was 327 kt in 2022, which is calculated from the consumption presented in Table 3 by using the emission factor of energy wood presented in Appendix 4. The Laitaatsilta heat plant used only forest chips as a fuel in 2022. The smallest share of forest chips of used fuels was in the

Savonlinna power plant, which uses significant amounts of forest industry by-products as a fuel (Laitinen, 2023). The weighted average share of forest chips of used fuels among the heat and power plants that use forest chips as a fuel in South Savo was 56%.

The largest CHP plant in South Savo is the Pursiala power plant in Mikkeli owned by Etelä-Savon Energia Oy (ESE). The consumption of forest chips for heat and power production in Mikkeli was 490 GWh in 2022 (Lahtinen, 2023). Comparing this amount to the statistics of Natural Resources Institute Finland (2023d), it can be said that the consumption of forest chips in the district heat network of Mikkeli was approximately 51% of the total annual forest chip consumption of South Savo in 2022.

The Pursiala power plant and the Tikkala heat plant, owned by ESE, are the only plants in the ETS sector in South Savo that used imported forest chips in 2022. The share of imported forest chips used in these plants was 6,5% in 2022, which means that the share of imported forest chips among plants included in the ETS in South Savo was less than 4% (Lahtinen, 2023). ESE imported forest chips from Russia at the beginning of 2022, but the imports from Russia ended in March due to Russia's invasion of Ukraine (Etelä-Savon Energia Oy, 2023a, 17). Therefore, it could be assumed that the share of imported chips in South Savo will remain relatively small or shrink to nothing in the future.

The predicted future consumption of forest chips in the ETS sector in South Savo are based on the email conversations with the people working in the companies that operate the plants that are included in the ETS. It should be clarified that the predicted future consumptions, presented in Table 4, include small adjustments by the author, so the amounts are not directly based on the conversations. Estimating the future consumption is difficult due to the future technology improvements such as non-combustion-based energy production technologies and other new technologies that improve energy efficiency.

Because of the uncertainties, the predicted future consumption of forest chips is presented only at regional level, not specified for each plant, as it is shown in Table 4. The predicted emissions are also presented in the table. The CO_2 emissions are converted from gigawatt hours by using the emission factor of energy wood presented in Appendix 4 and using the same assumptions that were used in the calculations for Finland presented in Table 2. The consumption of forest chips in the ETS sector is expected to grow in South Savo until 2025 and after that it turns into decrease. The predicted consumption of forest chips for 2035 is about 70% compared to the 2022 level.

Table 4. Predicted consumption of forest chips and CO_2 emissions from combustion in the ETS sector in South Savo from 2025 to 2035.

	2025	2030	2035
Consumption (GWh)	**850**	**700**	**570**
Emissions from combustion (kt CO_2)	**343**	**282**	**230**

It should be noted that the approximations given by the persons working for the energy companies in South Savo are topical information where the amounts for country level are from the time before Russia's invasion of Ukraine. This could be one of the reasons why it is expected that the consumption of forest chips in the ETS sector in South Savo will turn into decrease earlier than it is assumed to happen at country level. Another reason for this might be that the consumption of forest chips has been relatively steady in South Savo, as presented in Figure 23, and there is not as much growth potential for forest chips usage in South Savo like there is on the country level.

The estimated carbon dioxide emissions from forest chip combustion by raw material until 2035 among the plants included in the ETS sector in South Savo is presented in Figure 25. The forest chips distribution by raw materials for future emissions is following the average consumption of 2017-2022 presented in Figure 23, while the distribution of 2022 is based on the realized distribution of that year. The total amount of predicted emissions for 2025-2035 are from Table 4, while the emissions of 2022 are calculated from the realized consumption presented in Table 3.

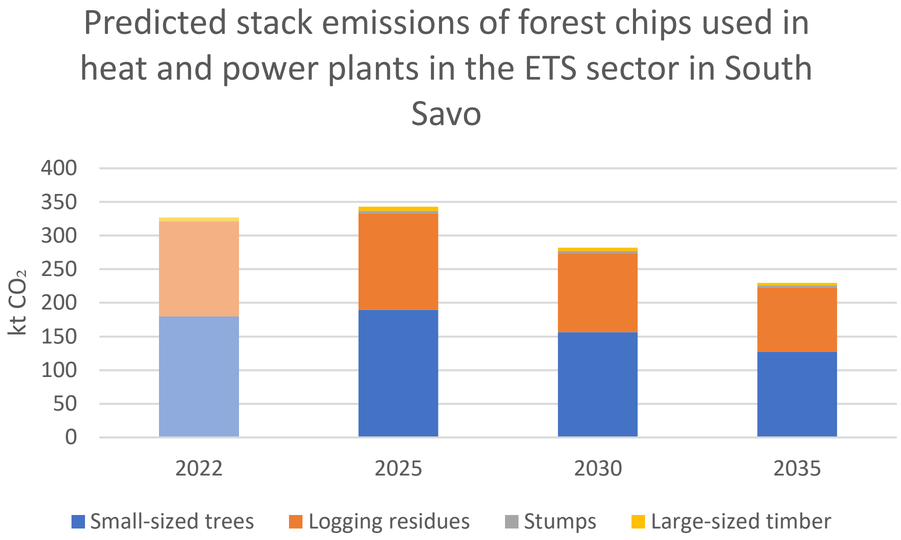


Figure 25. Predicted carbon dioxide stack emissions of forest chips by raw material in the ETS sector in South Savo until 2035.

In 2022, 55% of the carbon dioxide stack emissions from forest chip combustion in the ETS sector originated from small-sized trees, 43% from logging residues, and 2% from stumps and large-sized timber together as presented in Figure 25. For 2025-2035 the share of emissions from small-sized trees is 55% and the share of logging residues is 42%. The carbon dioxide emissions from large-sized timber and stumps together are about 3%. The CO_2 stack emissions are expected to be at their highest in 2025 with 343 kt CO_2.

7 Scenarios of incorporating forest chip combustion in the ETS

This chapter presents four different scenarios of incorporating forest chip combustion in the emissions trading system. Each scenario has a different specification of which fractions of the primary woody biomasses will be included in the ETS. The additional emissions towards the ETS are described for each scenario. The scenarios are described as follows:

- Scenario 1: All primary woody biomasses incorporated into the ETS
- Scenario 2: Cap for primary woody biomass from the average consumption of 2017-2022. The exceeding amount of PWB combustion will be included in the ETS
- Scenario 3: Large sized timber, small sized trees and stumps into the ETS
- Scenario 4: Large sized timber and stumps into the ETS.

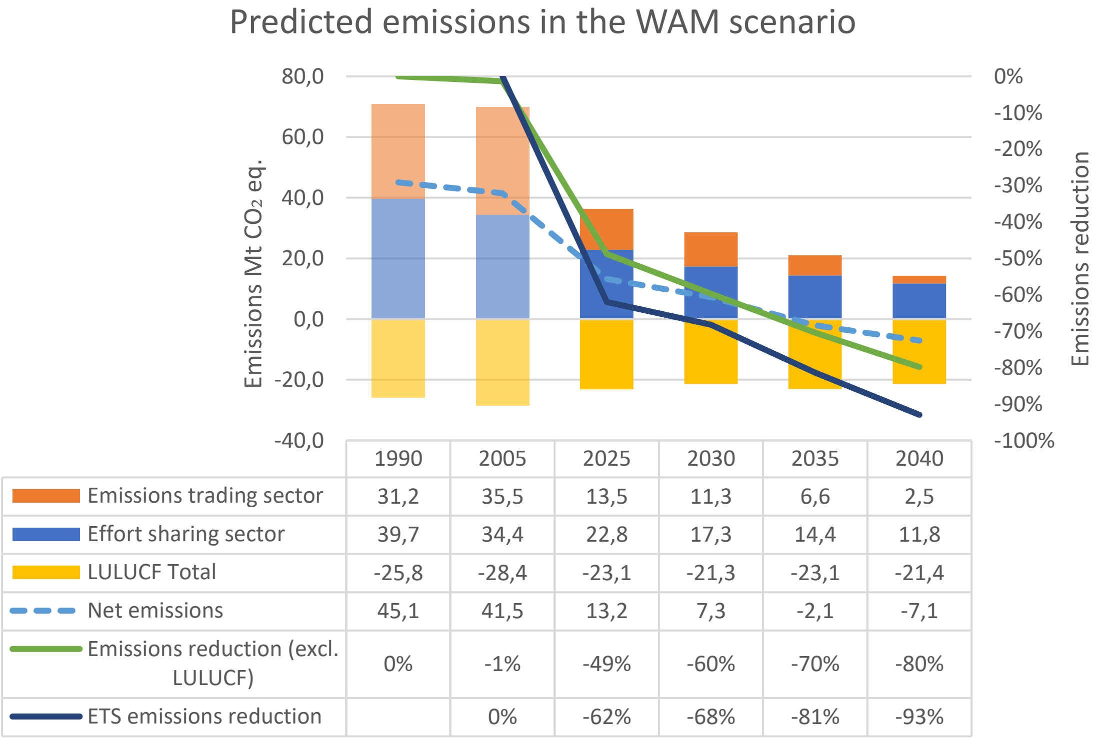
The first two scenarios are based on what has been on discussions during the RED revision. Another two scenarios were also created for this study. Scenarios 3 and 4 assume that forest residues would be the most likely fraction to be counted as a renewable, while stumps and large-sized timber are the first ones to be accounted as non-renewable. It could be also possible that there could be some kind of other cap for the emissions from PWB like a variation of scenario 2 with a decreasing cap. For further use of the results of this study, different scenario variations could be calculated from the emissions of scenario 1.

The emissions of the scenarios are examined on the country level for Finland and on the regional level for South Savo. It should be noted that the additional emissions for Finland and South Savo are calculated based on the predicted forest chip consumptions, which means that it is assumed that incorporating forest chips in the ETS does not affect the predicted future consumption of forest chips.

7.1 Emissions in the base scenarios

The WAM scenario, which is briefly described in section 5.3.1, is used for predicting the future CO_2 emissions in Finland. Figure 26 presents the future CO_2 emissions based on the WAM scenario for years 2025,2030,2035 and 2040. The emissions are divided between emissions trading sector, effort sharing sector and LULUCF sector. Net emissions, emissions reduction without LULUCF sector and emissions reduction in the ETS sector are also presented in the figure. The ETS emissions reduction is compared to year 2005 and the total emissions reduction (without LULUCF) is compared to 1990, which is why these years are also present in the figure.

As already mentioned in section 5.3.1, the climate targets set in the Finnish Climate Change Act are achieved in the WAM scenario. For example, the carbon neutrality is achieved in 2035 as the net emissions in the WAM scenario are predicted to be -2,1 Mt CO_2 as presented in Figure 26. The ETS sector emission reduction target for 2030 is -62% compared to 2005, but this is already achieved in 2025 in the WAM scenario.



	1990	2005	2025	2030	2035	2040
🟧 Emissions trading sector	31,2	35,5	13,5	11,3	6,6	2,5
🟦 Effort sharing sector	39,7	34,4	22,8	17,3	14,4	11,8
🟨 LULUCF Total	-25,8	-28,4	-23,1	-21,3	-23,1	-21,4
- - - Net emissions	45,1	41,5	13,2	7,3	-2,1	-7,1
— Emissions reduction (excl. LULUCF)	0%	-1%	-49%	-60%	-70%	-80%
— ETS emissions reduction		0%	-62%	-68%	-81%	-93%

Figure 26. Predicted future emissions in the WAM scenario for years 2025-2040, including the years of comparison for emissions reduction (1990) and ETS sector emissions (2005). (Lehtilä et al., 2021, 70; Maanavilja et al., 2021, 70; Statistics Finland, 2023f)

The WAM scenario is used as the base scenario for the future carbon dioxide emissions of Finland in this study. The predicted net sink for LULUCF sector for 2025 is -23,1 Mt CO_2 as presented in Figure 26. LULUCF sector was an emission source in 2021, so therefore it should be noted that it might be difficult to reach the predicted net sink by 2025 on the country level.

The base scenario for emissions in South Savo is adapted from the way how the South Savo Centre for Economic Development, Transport and the Environment (ELY Centre) defines its future carbon dioxide emissions for reaching carbon neutrality by 2035. South Savo ELY Centre (2023b) defines carbon neutrality as decreasing CO_2 emissions 80% by 2035 compared to 2005. The remaining 20% of the CO_2 emissions must be bind in carbon sinks, stored, or compensated in a sustainable way.

South Savo ELY Centre (2023) assumes a linear degradation of CO_2 emissions to achieve carbon neutrality by 2035. Therefore, the South Savo base scenario was created in this study for predicting the future CO_2 emissions in South Savo. It is assumed in the base scenario, that the CO_2 emissions from ETS sector and non-ETS sector will decrease linearly from the CO_2 emissions levels of 2021. The usage-based GHG emissions in 2021 were 1008 kt CO_2-eq in South Savo as presented in Figure 14. An emission reduction of 80% compared to 2005 means that the emissions in 2035 should be 295 kt CO_2 equivalents or less.

The predicted total CO_2 emissions, divided to ETS sector and non-ETS sector, in South Savo for years 2025, 2030 and 2035 are presented in Figure 27. The emissions from 2005 and 2021 are also present in the figure as 2005 is the base year for emissions reduction target and 2021 is the year for the latest available emissions. The threshold for carbon neutrality for 2035 is also presented in the figure as a dashed line. The predicted emissions are 804 kt CO_2-eq for 2025, 550 kt CO_2-eq for 2030 and 295 kt CO_2-eq for 2035.

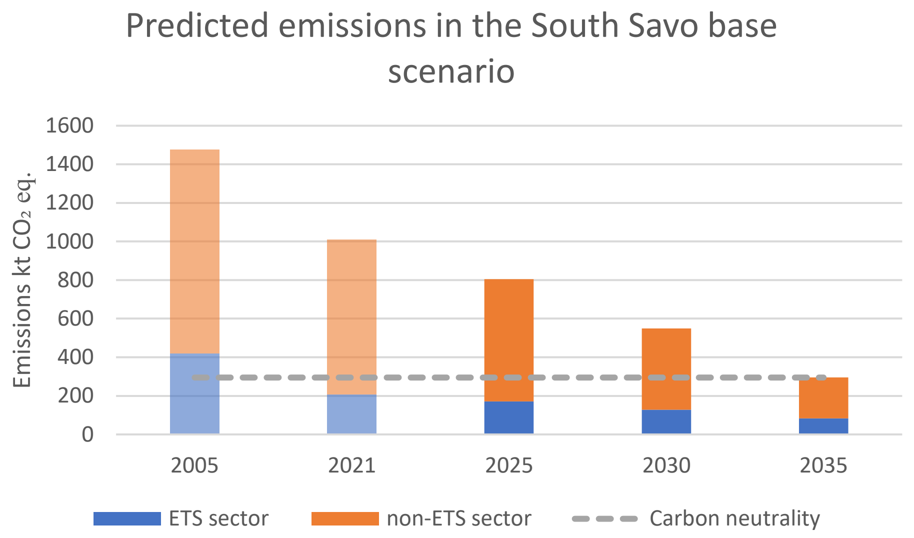


Figure 27. Predicted CO_2 emissions in the South Savo base scenario for years 2025-2035, including the latest emissions from 2021 and the year of comparison (2005).

It should be noted that the method how the future CO_2 emissions are calculated for South Savo is simpler compared on how the emissions are calculated for the country level. For regional level there is not as much data available as there is for country level, which is why the base scenario for South Savo includes more uncertainties.

7.2 Emissions in different scenarios in Finland

The main purpose of this section is to visualize that how much different scenarios would increase the CO_2 emissions if forest chip combustion were incorporated in the emissions trading system. The additional emissions from forest chip combustion from different scenarios in Finland are presented in Table 5. These emissions are calculated from the predicted emissions by raw material in the ETS sector, which are presented in Figure 24.

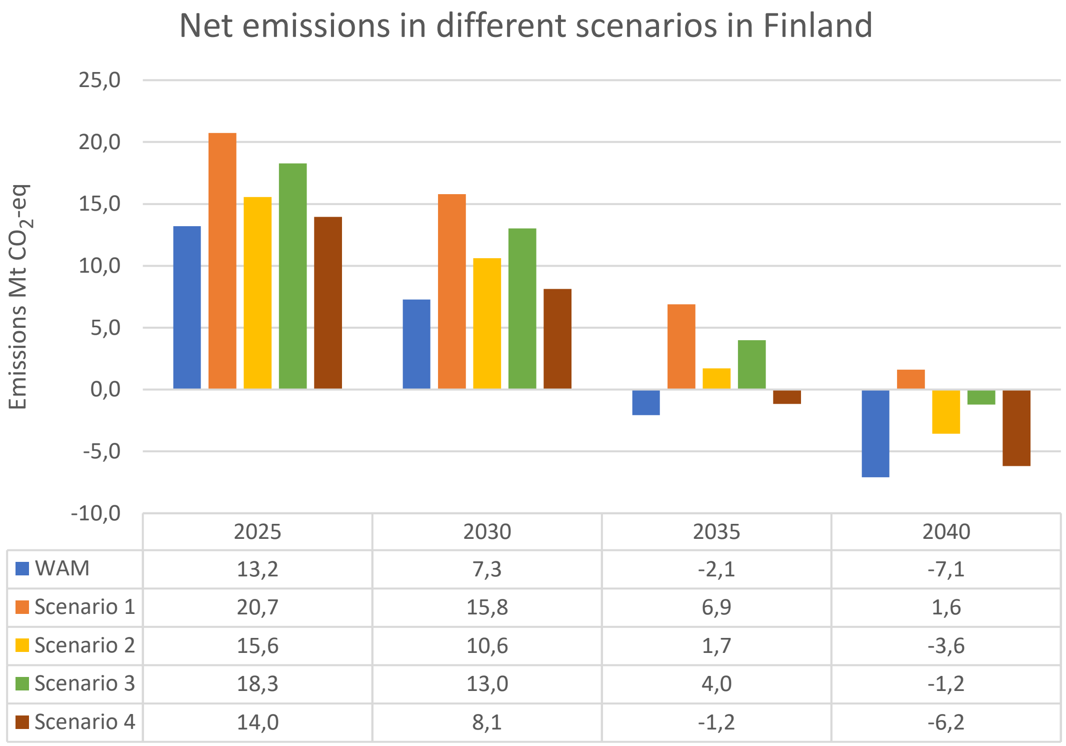
The emission cap for scenario 2 is calculated from the average consumption of forest chips in Finland between 2017-2022, which is presented in Figure 21, and assuming that 78% of all forest chips combusted in the heat and power plants in Finland during that period were used in the plants included in the ETS. By converting the average consumption of forest chips consumed in the ETS sector from cubic meters to CO_2, it is found out that the emission cap for scenario 2 is 5,2 Mt CO_2. The amount exceeding the cap is incorporated in the emissions trading system and presented as additional emissions from forest chip combustion in Table 5.

Table 5. Additional emissions from forest chip combustion in scenarios 1-4 on the country level.

Additional emissions from forest chip combustion (Mt CO_2)				
	2025	2030	2035	2040
Scenario 1	7,5	8,5	8,9	8,7
Scenario 2	2,4	3,3	3,8	3,5
Scenario 3	5,1	5,8	6,0	5,9
Scenario 4	0,8	0,9	0,9	0,9

It can be seen from Table 5 that the highest emissions from forest chip combustion would originate from scenario 1, which is logical since that is the maximum scenario where all forest chips would be included in the ETS. The lowest emissions would come from scenario 4, since that would include forest chips made from large-sized timber and stumps which both account for a small share of all forest chips combusted in heat and power plants in the ETS sector.

The WAM scenario functions as the base scenario for the other scenarios, which means that the net emissions of scenarios 1-4 are calculated by adding the additional emissions, presented in Table 5, to the net emissions of the WAM scenario. The net emissions of different scenarios are presented in Figure 28. It can be seen from the figure that in scenario 1, the net emissions are the highest for every year and it is the only scenario where carbon neutrality is not achieved even by 2040. The net emissions in scenario 1 are 6,9 Mt CO_2-eq in 2035, which is quite far from achieving carbon neutrality. Scenario 4 is the only scenario that would achieve carbon neutrality by 2035, which is also the national target for Finland.



	2025	2030	2035	2040
🟦 WAM	13,2	7,3	-2,1	-7,1
🟧 Scenario 1	20,7	15,8	6,9	1,6
🟨 Scenario 2	15,6	10,6	1,7	-3,6
🟩 Scenario 3	18,3	13,0	4,0	-1,2
🟫 Scenario 4	14,0	8,1	-1,2	-6,2

Figure 28. Net emissions in different scenarios in Finland from 2025 to 2040.

When considering the carbon dioxide emissions from forest chip combustion, it may be concluded that incorporating forest chip combustion in the ETS would make it more difficult for Finland to achieve its climate targets. It should be also noted that the global situation has changed since the WAM scenario was created, which increases its uncertainty.

7.3 Emissions in different scenarios in South Savo

The additional CO_2 emissions from forest chip combustion in different scenarios in South Savo are presented in Table 6. These emissions are calculated from the predicted carbon dioxide emissions from forest chip combustion in the ETS sector presented in Figure 25. The emission cap for scenario 2 is calculated from the average consumption of forest chips in South Savo between 2017-2022, which is presented in Figure 23. It is assumed that 75% of all forest chips combusted in the heat and power plants in South Savo during that period were used in the plants included in the ETS. By converting the consumption from cubic meters to CO_2 emissions from combustion, the average emissions for 2017-2022 is 251 kt

CO_2. This also works as the emission cap for scenario 2. The exceeding amount above the cap is accounted as additional emissions.

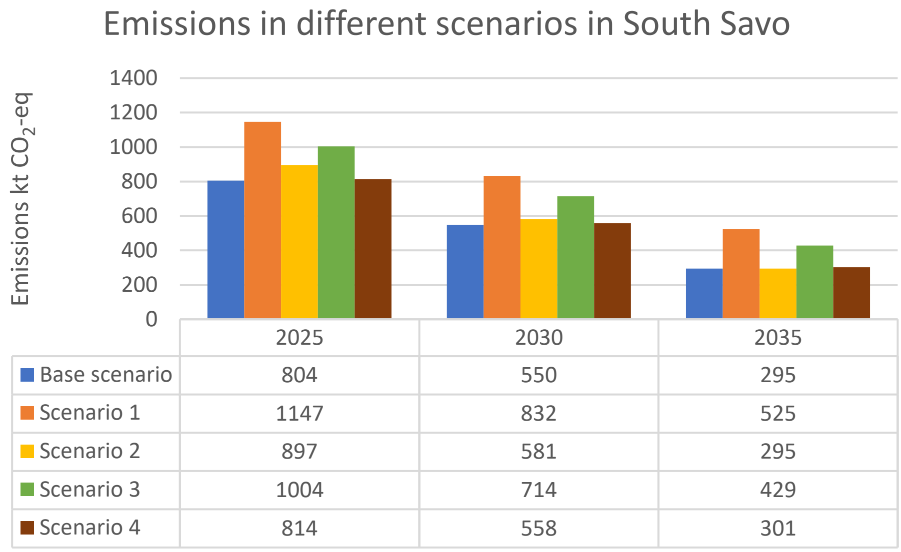
The assumption that 75% of all forest chips was combusted in the ETS sector in South Savo during 2017-2022 is based on the fact that the share was lower in previous years than it was in 2022 (84%). According to the environmental reports of Etelä-Savon Energia (2021, 21; 2022, 22) and the district heating statistics of Finnish Energy (2023b), consumption of forest chips among the plants included in the ETS in South Savo was 614 GWh in 2021 and 563 GWh in 2020. When comparing these numbers to Luke's statistics on forest chip consumption (Natural Resources Institute Finland, 2023a), the share of forest chips combusted in the ETS sector was 73% in 2021 and 70% in 2020. Precise information for 2017-2019 is not available, which is why the assumption is based only on the past three years. It is also possible that part of the forest chips was used for process steam production and that share is not visible in district heating statistics.

Table 6. Additional emissions from forest chip combustion in scenarios 1-4 in South Savo.

Additional emissions from forest chip combustion (kt CO2)			
	2025	2030	2035
Scenario 1	343	282	230
Scenario 2	92	32	0
Scenario 3	200	165	134
Scenario 4	10	8	7

The highest additional emissions in South Savo would originate naturally from scenario 1 where all the PWB is included in the ETS. The lowest average emissions would come from scenario 4 as the consumption of stumps and large-sized timber is very low in South Savo. There are no additional emissions from scenario 2 in 2035 as the consumption of forest chips does not exceed the emission cap after 2030.

The predicted future emissions of the South Savo base scenario shown in Figure 27 is used as the base scenario for scenarios 1 to 4 presented in Figure 29. The additional emissions from Table 6 are added to the emissions of the South Savo base scenario to find out the emissions of each scenario. The threshold for carbon neutrality is assumed to be 295 kt CO_2. It can be seen from the figure that scenario 2 is the only scenario which would reach carbon neutrality in 2035 though the scenario 4 would exceed the target only by 6 kt, which could be caught up with relatively small effort.



	2025	2030	2035
🟦 Base scenario	804	550	295
🟧 Scenario 1	1147	832	525
🟨 Scenario 2	897	581	295
🟩 Scenario 3	1004	714	429
🟫 Scenario 4	814	558	301

Figure 29. Emissions in different scenarios in South Savo 2025-2035.

The base scenario for South Savo is based only on the carbon neutrality target for 2035 and on a linear degradation of carbon dioxide emissions, not on actual measures. Therefore, the South Savo base scenario is very rigid and carbon neutrality could only be reached with scenarios that do not cause additional emissions in 2035. In scenario 2 the carbon neutrality is achieved in 2035 on the regional level, but when considering it on the plant level, it could be more difficult for some plants to stay under the cap if the cap would be set on the plant level. If scenario 1 or scenario 3 is to realize, additional measures should be taken to reach the carbon neutrality by 2035.

7.4 Inclusion of smaller plants in the ETS

During the revision of the Renewable Energy Directive some proposals were presented to lower the threshold for applying sustainability criteria for heat and power plants. In other words, the threshold determines whether the installation is included in the ETS or not. In July 2021 the European Commission (2021) suggested that the threshold should be lowered from 20 MW to 5 MW. The European Parliament (2022a) proposed a bit higher threshold of 7,5 MW in September 2022. Even though the threshold is remaining at 20 MW, it could be possible that at some point in the future the threshold will be lowered. Therefore, this section discusses that how a lower threshold would affect the consumption of forest chips in the ETS sector in South Savo.

The plants that use forest chips for heat and power production in South Savo were initially sorted out from the district heating statistics of Finnish Energy (2023b). The plants that have a capacity between 5-20 MW are presented in Table 7. If the threshold would be lowered to 5 MW, four more plants would be incorporated in the ETS. As the smallest plants in this list have a capacity of 8 MW, it means that the same plants would be on the list in case if the threshold would be 7,5 MW.

All the boilers in Table 7 are heat only boilers (HOB) producing district heat. The capacity of the plants is presented as district heat capacity, which in the case of heat only boilers is a bit lower than the total rated thermal input, which is used to determine whether the plant is included in the ETS or not. The share of forest chips from used fuels refers to the share of forest chips of all fuels used in the same district heating network as some of these district heat networks also include smaller plants that may use forest chips as a fuel. It is assumed that smaller plants in the same district heat network would be incorporated in the ETS with the main plant, in the case of lowering the threshold. However, plants below 5 MW are excluded from Table 7.

Table 7. District heating plants in South Savo with a capacity between 5-20 MW that use forest chips as a fuel. (Finnish Energy, 2023b)

Plants using forest chips with a capacity of 5 MW to 20 MW in South Savo 2021					
Municipality	Plant	Type	District heat capacity (MW)	Forest chip consumption (GWh)	Share of forest chips from used fuels
Juva	Puutarhatie heat plant	HOB	16	0,2	0,6 %
Rantasalmi	Nikkarintie heat plant	HOB	9	11,1	56 %
Mäntyharju	Mäntyharju heat plant	HOB	8	27,9	83,0 %
Kangasniemi	Kangasniemi bioheat plant	HOB	8	14,6	65 %
Total				**54**	**48,2 %**

The forest chip consumption in the plants with a capacity of 5-20 MW in South Savo was 54 GWh in 2021 as presented in Table 7. The share of forest chips of used fuels among these plants, also including the smaller plants in the same district heat network, was 48%. It should be noted that the Juva heat plant uses peat as the main fuel, and its consumption of forest chips was very small in 2021 (Finnish Energy, 2023b). Peat combustion can be economically viable for plants that are not included in the ETS as they do not need emission allowances for peat combustion.

The consumption of forest chips among the plants with a capacity between 5-20 MW was 54 GWh in 2021, which caused about 22 kt of carbon dioxide stack emissions when combusted. A rough assumption is made that the consumption of forest chips in these plants was the same in 2022. This would mean that 864 GWh of forest chips were used in the plants with a capacity higher than 5 MW as the consumption was 810 GWh in 2022 in the plants that are already included in the ETS in South Savo. This would mean that about 90% of the total amount of forest chips consumed in South Savo was combusted in plants above 5 MW, and the consumption of forest chips in the ETS sector would increase by 6,7% if the plants between 5-20 MW are taken into account.

Alternative scenarios 1b-4b were made to represent a situation where also the plants above 5 MW would be included in the ETS in South Savo. Carbon dioxide emissions based on these scenarios from 2022 to 2035 are presented in Table 8. Emissions for coming years are calculated by adding 6,7% to the additional carbon dioxide emissions of scenarios 1-4 which are presented in Table 6. The emission cap for scenario 2b is calculated by increasing the emission cap of scenario 2 by 6,7%. This leads to an emission cap of 267 kt CO_2 for scenario 2b and the emissions above that cap are calculated as additional emissions.

Table 8. Additional emissions from forest chip combustion in alternative scenarios 1b-4b in South Savo

Additional emissions from forest chip combustion (kt CO_2)				
	2022	2025	2030	2035
Scenario 1b	348	366	301	245
Scenario 2b	81	98	34	0
Scenario 3b	198	213	176	143
Scenario 4b	6	11	9	7

Lowering the threshold to 5 MW for plants that are included in the ETS would lead to a 6,7% increase in carbon dioxide emissions in scenarios 1,3 and 4 when compared to the situation where the threshold is 20 MW. For example, in scenario 1 which is the maximum scenario, CO_2 emissions in would be 15 kt CO_2 higher in 2035 than in the case where the threshold is 20 MW. In scenario 2b, the increment would be smaller as the emission cap would increase also with 6,7%. Nevertheless, there would not be additional emissions from scenario 2b in 2035. This means that in the case of scenario 2 it would not matter in the case of South Savo whether the threshold is 20 MW or 5 MW, when considering the carbon neutrality target of 2035.

8 Consequences of incorporating forest chip combustion in the ETS

This chapter presents the possible consequences of incorporating forest chip combustion in the EU ETS. The influence of emissions trading on the fuel costs of forest chips in heat and power production is discussed, with a focus on district heat production. In this chapter it is evaluated that how many emission allowances would be required for forest chip combustion and what is the worth of those allowances. The impact of incorporating forest chips in the ETS is discussed from the point of the energy production, the climate targets, and the supply security of energy. The impact on energy self-sufficiency for South Savo is discussed as well. Options to decrease carbon dioxide emissions from forest chip combustion are briefly discussed, focusing on the alternative district heat production methods suitable for South Savo.

8.1 Influence on fuel prices in energy production

Emission allowance has an influence on the fuel costs of those fuels that are not accounted as a renewable fuel in the ETS. Therefore, it would affect also on the cost of those forest chips that would be included in the ETS. Figure 30 presents fuel cost structures of domestic fuels with emission allowance price of 85 €/CO_2 tonne, which has been a typical emission allowance price during the third quartile of 2023 (Sandbag, 2023). Fuel cost structure is divided between the fuel price, the energy tax, and the cost effect of ETS. The cost effect of ETS for peat and forest chips is calculated by using the emission factors of milled peat and energy wood presented in Appendix 4. Excise duty for peat in Finland is 5,70 €/MWh in 2023 (Tax Administration, 2022). It is assumed in this study that there will not be any taxes neither any subsidies for forest chips in Finland in case if it is going to be included in the ETS. The possible free allocation of emission allowances is neglected from the calculations.

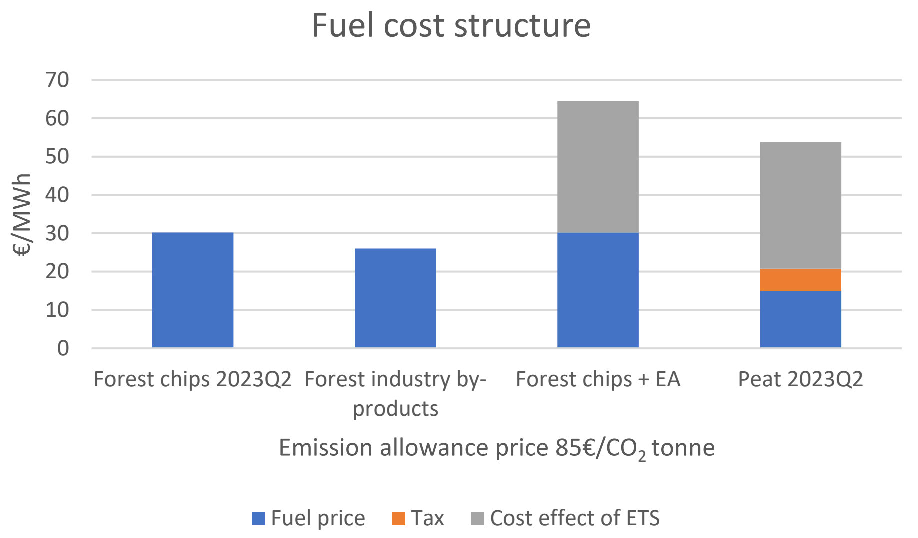


Figure 30. Fuel cost structures of domestic fuels used in district heat production in Finland.

The fuel prices used in Figure 30 are 30,2 €/MWh for forest chips and 15,1 €/MWh for peat (excluding excise duty), which are based on the fuel prices of the second quartile of 2023 (Statistics Finland, 2023h). The fuel price of forest industry by-products is assumed to be 26 €/MWh, which is an assumption of average price of different by-products. The cost of emission allowances would more than double the fuel price of forest chips from 30,2 €/MWh to 64,5 €/MWh with emission allowance price of 85 €/CO_2 tonne.

The fuel price of peat with the same emission allowance price is 53,7 €/MWh. The price of peat with emission allowance price of 85 €/CO_2 tonne is more than 10 €/MWh lower than the price of forest chips with emission allowance, which would make peat a viable alternative for those fractions of forest chips which are levied with the cost of emission allowance. However, if the demand of peat would increase it would probably increase the fuel price of peat as the availability of peat has decreased from the peak years due to the peat run down in Finland.

As the price of emission allowance is changing by demand and supply, Figure 31 presents the influence of emission allowance price on the fuel costs of typical domestic fuels used in heat and power plants in Finland. The fuel costs presented in the figure are for peat, forest industry by-products, and forest chips with and without the influence of the price of emission allowance.

The curve of peat looks a bit different than the others as there is a floor pricing mechanism for peat in Finland which takes place when the price of emission allowance decreases below 21,2 €/CO_2 tonne. If the price of emission allowance goes below the threshold, an additional tax is paid to ensure that the price does not undercut the floor price. There are also some alleviations on the energy tax for peat users that use less than 10 GWh of peat in a year, but these are not taken into account in the calculations as the alleviations are decreasing gradually until 2030. (Tax Administration, 2023)

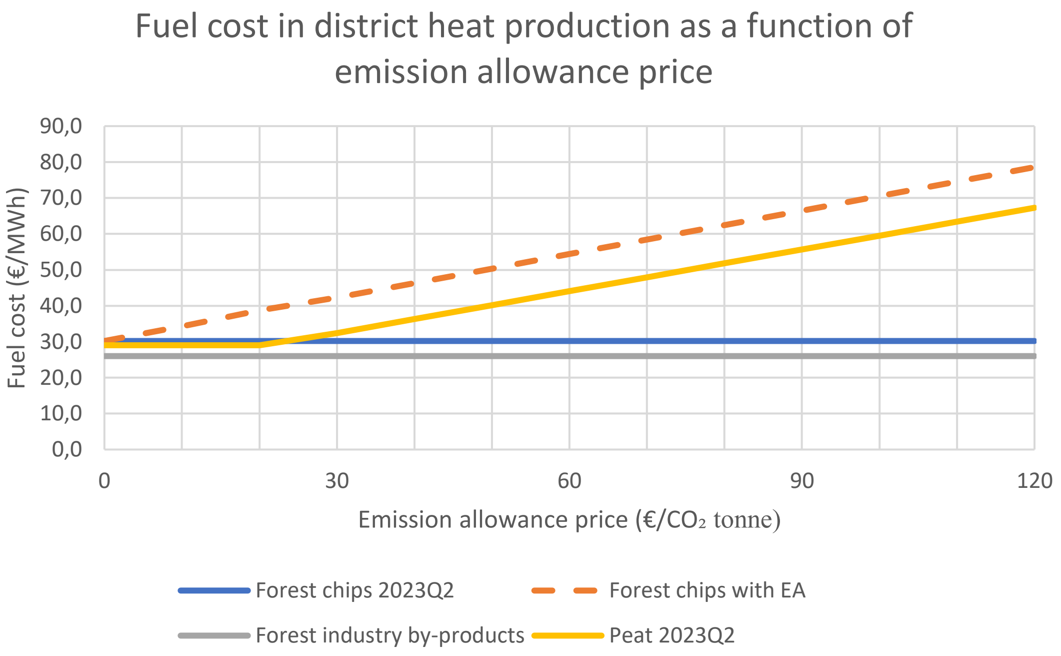


Figure 31. Emission allowance's influence on fuel cost on commonly used fuels in district heat production in Finland.

As there are no CO_2 emissions from forest industry by-products and from forest chips under the current ETS, the price of emission allowance does not affect the fuel price of these fuels as presented in Figure 31. When the cost effect of the ETS is considered on the price of forest chips, it would make it the most expensive domestic fuel. The fuel price of peat begins to increase when the price of emission allowance exceeds 21,2 €/CO_2 tonne, and above that the gap between fuel price of peat and forest chips (with EA) is increasing as the price of emission allowance increases. This is because the emission factor of forest chips (112 g CO_2/MJ) is higher than the emission factor of peat (107,6 CO_2/MJ).

8.1.1 Influence on fuel costs for example plants

Fuel costs for a typical heat production plant and a typical CHP plant can be calculated when the price of the fuel and the efficiency of the plant is known. The price of fuels for the example calculations are the same as in section 8.1 and the price of emission allowance is 85 €/CO_2 tonne. The fuel costs are calculated by applying the following equation.

$$K_{fu} = \frac{c_{fu}}{\eta} \tag{1}$$

where K_{fu} is fuel costs [€/MWh]

c_{fu} is fuel price [€/MWh_{fu}]

η is efficiency [-].

Fuel costs for heat production for both plants are compared with three different scenarios:

- Base scenario represents the current coverage of the ETS where forest chips is counted as renewable energy source
- Scenario 1 represents the situation where all forest chips are included in the ETS and the cost of emission allowances are included in the fuel price
- Scenario 2 represents the situation in South Savo in 2025, where 27% of combusted forest chips are included in the ETS as presented in Table 6.

Fuel costs for heat production plant

Fuel costs are calculated for a typical heat only boiler which produces district heat and uses 100% of forest chips as a fuel and has an annual efficiency of 89%. Table 9 presents the starting values and results of fuel cost calculations for the example heat only boiler in three different scenarios.

Table 9. Fuel costs in different scenarios for the example heat only boiler.

		Base scenario	Scenario 1	Scenario 2	
Annual efficiency	η	0,89	0,89	0,89	
Fuel price, forest chips	c_{fu}	30,2	30,2	30,2	€/MWh$_{fu}$
Forest chips share of fuel mix		100 %	0 %	73 %	
Fuel price, forest chips with EA (85 €/t CO_2)	c_{fu}	64,5	64,5	64,5	€/MWh$_{fu}$
Forest chips with EA share of fuel mix		0 %	100 %	27 %	
Fuel costs	$\mathbf{K_{fu}}$	**33,9**	**72,4**	**44,3**	**€/MWh**

It can be seen from the results of Table 9 that in the case of the example heat production plant fuel costs would more than double if all PWB would be included in the ETS as the situation is in scenario 1. Scenario 2 would increase the fuel costs with 10,4 €/MWh compared to the base scenario. Fuel costs affect the variable costs of heat plant as follows.

$$K_{var} = K_{fu} + K_{other} \tag{2}$$

where K_{var} is the variable costs [€/MWh]

K_{other} is other variable costs [€/MWh].

This means that variable costs increase the same amount as fuel costs increase, like for example in scenario 2 for the example heat plant, the variable costs would increase by 10,4 €/MWh compared to base scenario. Variable costs can be further used to determine the total heat production costs of a heat plant. However, it should be clarified that calculating the total heat production costs is out of the scope of this study. The total heat production costs can be calculated with the following equation.

$$K_{total} = K_{fix} + K_{var} \tag{3}$$

where K_{total} is the total heat production costs [€/MWh]

K_{fix} is fixed costs [€/MWh].

Fuel costs for CHP plant

The second example is a CHP plant which uses 50% forest chips and 50% forest industry by-products as a fuel and has an annual efficiency of 85%. The CHP plant produces district heat and electricity. Starting values and results for fuel cost calculations for the CHP plant are presented in Table 10.

Table 10. Fuel costs in different scenarios for the example CHP plant.

		Base scenario	Scenario 1	Scenario 2	
Annual efficiency	η	0,85	0,85	0,85	
Fuel price, forest chips	c_{fu}	30,2	30,2	30,2	€/MWh$_{fu}$
Forest chips share of fuel mix		50 %	0 %	36,5 %	
Fuel price, forest industry by-products	c_{fu}	26	26	26	€/MWh$_{fu}$
Forest industry by-products share of fuel mix		50 %	50 %	50 %	
Fuel price, forest chips with EA (85 €/t CO_2)	c_{fu}	64,5	64,5	64,5	€/MWh$_{fu}$
Forest chips with EA share from fuel mix		0 %	50 %	13,5 %	
Fuel costs	K_{fu}	**33,1**	**53,2**	**38,5**	**€/MWh**

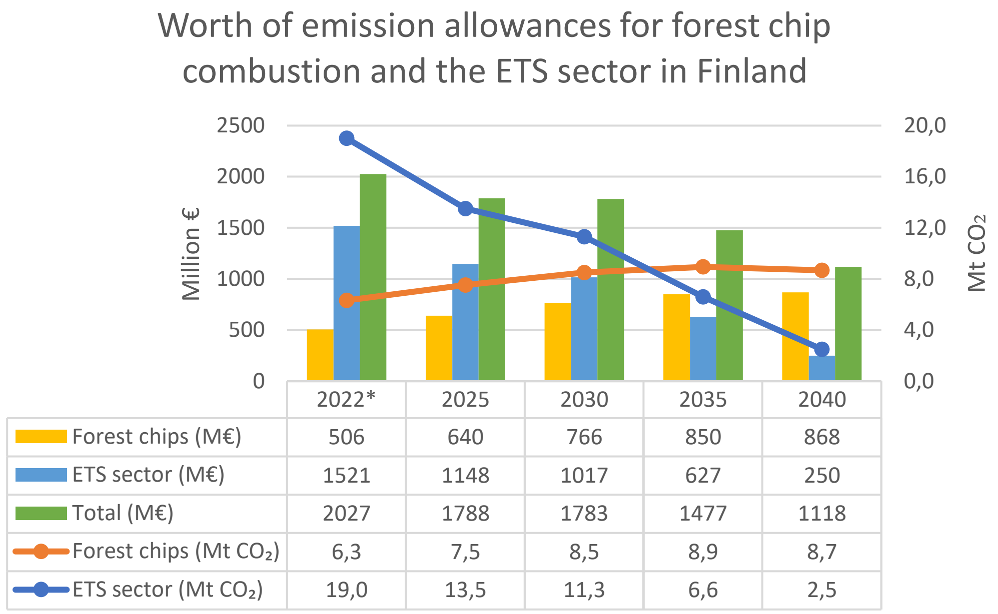
In scenario 1 the fuel costs would increase about 20 €/MWh and in scenario 2 about 5 €/MWh compared to the base scenario as presented in Table 10. The increase is not as intense in the scenarios for the example CHP plant as it is for the example heat plant due to a different fuel mix. It should be noted that the availability of forest industry by-products is linked to the production volumes of forest industry. In the report by AFRY (2023, 33) it is estimated that there will not be much of an increase in the availability of forest industry by-products in the near future. If forest chip combustion will be included in the ETS in some way, it would increase the demand of forest industry by-products which is therefore very likely to correlate in its price.

The CHP plant produces electricity and heat, which are sold separately. The production costs can be allocated between the end products with various cost allocation methods such as the exergy method, the energy method or the alternative heat generation method (Huhtinen et al., 2013, 322). The allocation of variable costs differs between allocation methods which reflects to the allocation of fuel costs as well. Without diving deeper to the cost allocation methods, it can be said that an increase in fuel costs will increase the production costs of the end products.

8.2 Worth of emission allowances required for forest chip combustion

The worth of emission allowances that would be needed for forest chip combustion and for the ETS sector emissions in Finland for 2022-2040 are presented in Figure 32. The worth of emission allowances requires for forest chip combustion are calculated from the emissions of scenario 1, which is the maximum scenario where all PWB combusted at plants operating in the ETS sector would be included in the ETS. As the numbers of this section are presented in means of worth, it means that also the emission allowances allocated for free are defined to have the same value as the price of emission allowance has.

The results for 2022 are calculated from realized stack emissions from forest chip combustion and realized emissions of the ETS sector. For the year 2022, the average price of emission allowance was assumed as 80 €/CO_2 tonne in the calculations. The predicted emissions from forest chip combustion and predicted ETS sector emissions for years 2025-2040, are also presented in Figure 32. The predicted ETS sector's emissions are based on the WAM scenario and the predicted emissions from forest chip combustion are calculated in Table 2. The average price of emission allowance for 2025 is estimated to be 85 €/CO_2 tonne. In the calculations of this section, the average price of emission allowance is estimated to rise by 5 €/CO_2 tonne every five-year period, reaching 100 €/CO_2 tonne in 2040. The worth of the required emission allowances are calculated by multiplying carbon dioxide emissions with the price of emission allowance.



	2022*	2025	2030	2035	2040
Forest chips (M€)	506	640	766	850	868
ETS sector (M€)	1521	1148	1017	627	250
Total (M€)	2027	1788	1783	1477	1118
Forest chips (Mt CO_2)	6,3	7,5	8,5	8,9	8,7
ETS sector (Mt CO_2)	19,0	13,5	11,3	6,6	2,5

Figure 32. Worth of emission allowances needed for forest chip combustion and ETS sector emissions in scenario 1 from 2022 to 2040.

If forest chip combustion would have been already incorporated in the ETS, the worth of emission allowances needed for it would have been a bit over 500 million euros in 2022 as presented in Figure 32. Together with the realized ETS sector emissions, it would have made the total worth of required emission allowances to be more than two billion euros. The predicted stack emissions from forest chip combustion in the ETS sector and the ETS sector's emissions are expected to cross after 2030, and in 2035 the stack emissions from forest chip combustion would be higher than the emissions of the ETS sector. This would mean that with the predicted consumption, forest chip combustion would need more emission allowances than other ETS sector emissions together in 2035, and it would increase the total worth of necessary emission allowances by 850 million euros.

The worth of emission allowances that would be needed for forest chip combustion in South Savo from 2022 to 2035 is presented in Figure 33. The worth of the emission allowances required for forest chips consumed in the ETS sector in 2022 is calculated from the realized stack emissions presented in section 6.2. The figure also shows estimated emissions from ETS sector in 2022 which is assumed to be 180 kt CO_2. The assumption is based on the fact that the ETS sector carbon dioxide emissions were a bit over 200 kt in 2021, as presented in Figure 27, and knowing that the usage of forest chips at plants operating in the ETS sector has increased from 2021 to 2022. The ETS sector emissions are not predicted for 2025-2035 as the South Savo base scenario does not define the sectors where the emissions originate from. The predicted worth of emission allowances for forest chip combustion is calculated from the predicted emissions of scenario 1, presented in Table 6.

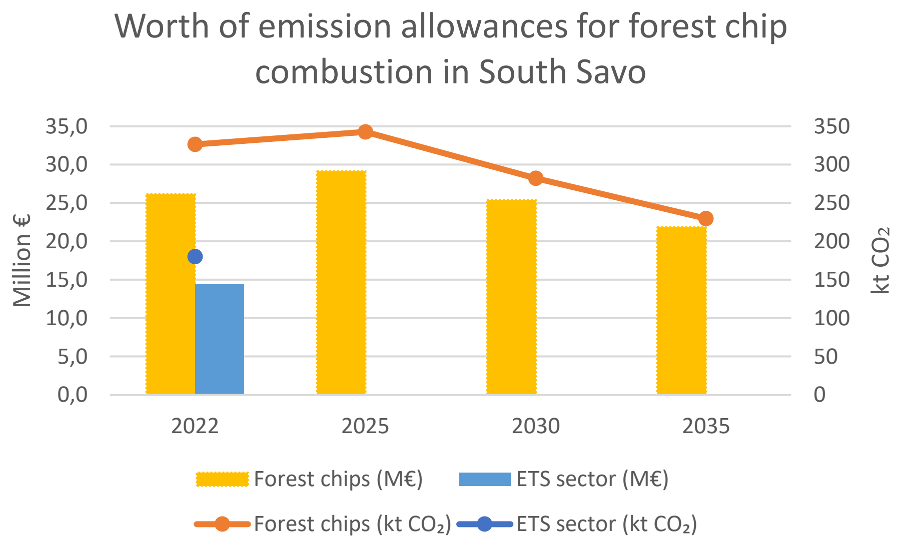


Figure 33. The worth of emission allowances required for forest chip combustion and CO_2 emissions from forest chip combustion in the ETS sector in scenario 1 in South Savo from 2022 to 2035.

It can be seen from Figure 33 that the stack emissions from forest chip combustion in the ETS sector were notably higher than the estimated ETS sector emissions in 2022. This would mean that if forest chips would have been included in the ETS in 2022, the worth of required emission allowances would have been 26 million euros, while the worth of the required emission allowances for the ETS sector emissions were a bit over 14 million euros. The situation in South Savo is different compared to the GHG emissions of the whole country since there is not much of emission causing industry in South Savo and the consumption of forest chips is already on a relatively high level.

In the present ETS, forest chips are an important fuel for carbon free energy production, and it has a considerable to role decrease carbon dioxide emissions from energy production in coming years. Increasing consumption of forest chips for energy production reflects to decreasing emissions in the ETS sector. It is assumed in the calculations of this section that the future trend of forest chip consumption would not change even if combustion of forest chips would be incorporated in the emissions trading system. However, in reality the consumption of forest chips in the ETS sector would be very likely to decrease if forest chips were incorporated in the ETS.

8.3 Impact on energy production

The increase in fuel costs due to forest chip incorporation in the ETS would appear directly in production costs of those heat and power plants which use forest chips that are affected by the cost of the ETS. The cost of emissions trading would be passed indirectly to the customers. Especially district heat customers would be affected since there is only one district heat provider in each area. This would lead to a situation where only the customers of those district heat providers which use forest chips and are in the ETS, would be affected by increased district heat prices. Customers of smaller district heat networks, where district heat production is not included in the ETS, would not be affected.

According to Finnish Energy (2023f), district heat prices are regulated by the Finnish Competition and Consumer Authority as district heat providers have a dominant position in the market. District heat prices must correlate to the production costs, and district heat providers are allowed to have a reasonable profit. District heat competes with other heating systems of buildings, like building-specific heat pumps, which also limits the pricing of district heat. Therefore, increased district heat prices might lead building owners to invest in other heating solutions.

Unlike the district heat market, the electricity market in Finland is open for competition. Finland is part of the Nordic electricity market which consist of several interlinked markets. Electricity producers can offer electricity production to the market for each hour of the following day. The hourly price is formed by fulfilling the electricity demand with the cheapest offers of each hour. Electricity from the market is then sold to electricity users by retailers or electricity producers can sell their own produced electricity to the end users. Electricity producers can also sell their electricity to big electricity consumers such as industry or electricity sellers with bilateral contracts. (Ministry of Economic Affairs and Employment of Finland, 2021, 3-4)

If the production costs of electricity in CHP plants increase it would reflect in the price of electricity sold for the customers one way or another. Depending on the pricing mechanism of electricity produced in a CHP plant, increased production costs could lead to smaller amounts of accepted offers in the electricity market and therefore lead to decreased annual electricity production of a specific plant. The indirect costs of emission allowances could lead to a loss of customers for district heat producers that use forest chips as a fuel. This puts district heat producers in a position where they need to find a solution to decrease their production costs.

Fuel cost wise a short-term solution could be to replace those forest chips affected by the cost of emission allowance with peat if peat is available with cheaper cost. In a longer-term, replacement with peat is not a viable option as the price of peat is also high due to the high price of emission allowance. As mentioned in section 8.1.1, the availability of forest industry side-streams is limited, and therefore it is not possible to replace large amounts of forest chips with them. The options to decrease the stack emissions of forest chip combustion is to replace district heat production with other heat production technologies or to decrease the stack emissions with carbon capture utilization and storage (CCUS) solutions. Alternative options for district heat production are presented in section 8.6.

8.4 Impact on achieving the climate targets

As presented in section 7.3, scenario 2 would not affect on the target of reaching carbon neutrality in South Savo by 2035. However, when considering scenario 1, which would cause the highest additional CO_2 emissions in 2035, the target would be exceeded by 230 kt CO_2. This equals to 570 GWh of combusted forest chips, which means that the same amount would have to be replaced with a carbon neutral fuel or with other carbon emission free energy production technologies.

Assuming that the average annual efficiency of production is 85%, it can be estimated that approximately 485 GWh of heat and electricity is produced with the given amount of forest chips in South Savo in 2035. When dividing heat and electricity production with an assumption that 75% of those forest chips would be used for heat production and 25% for electricity production it means that 363 GWh of heat and 121 GWh of electricity would have to be produced with other carbon free technologies to avoid the emissions caused by forest chip combustion in scenario 1 in South Savo.

In general, incorporating forest chip combustion in the ETS would hamper Finland and South Savo to achieve their climate targets. If forest chip combustion, or some fractions of it, would be incorporated in the ETS, it would decrease the share of renewable energy in Finland's energy portfolio. Replacing forest chip combustion with other technologies that use electricity, such as heat pumps, would mean an increase in the electricity consumption. This would require more investments in other carbon free electricity production than already planned.

8.5 Impact on energy supply security and self-sufficiency

As there is no sight of notable increases in the availability of forest industry side streams in the near future and the use of peat is declining, forest chips have an important role in security of supply in heat and power plants. The implementation of electricity-based heating solutions such as heat pumps and electric boilers are likely to increase in the future to enable achieving the climate targets. Supply security and delivery reliability of heat are expected to remain good on the country level if the growth for electricity consumption is moderate. However, the situation would be more difficult in case that electricity demand will grow heavily, and base load production decreases and is replaced by variable renewable energy (VRE). This could lead to a situation where high market prices of electricity appear more often. In that case, heat producers would need to get prepared to the high electricity prices for example with long-term heat storages and adequate reserve capacity. (Ministry of Economic Affairs and Employment of Finland, 2022, 163)

At the power plant level this is somewhat comparable to a situation where a CHP plant is replaced with other energy production technologies. For example, heat production of a CHP plant could be replaced with heat pumps and waste heat utilizing solutions and the electricity production of a CHP plant could be replaced with wind power. On the regional level, replacing forest chip combustion with electricity-based heat production would be likely to decrease the energy self-sufficiency of South Savo. In that case the electricity produced in South Savo is likely to decrease, while the share of electricity transferred from other regions would increase. This is because South Savo is not the most optimal location for wind power production in Finland, while the increase in renewable electricity production in the future will be based on the increase of wind power production.

8.6 Options to decrease carbon dioxide emissions from forest chip combustion

Incorporating forest chip combustion in the ETS would increase the fuel costs for its users and increase the interest to replace it with other energy production methods or to find possibilities to capture carbon from combustion. Other heat production methods and potential waste heat sources are briefly evaluated in this section by means of possible non-combustion-based district heat production solutions for South Savo. A two-way district heating business model, lowering the temperature of the district heat network, thermal heat storages and other forms of district heat network optimization are also potential solutions to reduce the combustion of forest chips in district heat production, but these are not further evaluated in this section.

8.6.1 Non-combustion-based district heat production

Electric boilers generate heat from electricity. As the share of variable renewable energy is increasing in electricity production, situations where a lot of electricity is available and the market price of electricity is low are becoming more common. Electric boilers can provide demand side flexibility and from the standpoint of energy company, it is profitable to produce district heat with electric boiler when the market price of electricity is low. Some of the advantages of electric boilers is that their operation is flexible, and the investment costs are relatively low. (Nielsen et al., 2016, 190)

In South Savo, Etelä-Savon Energia (2023b) has decided to invest in an electric boiler which will be constructed in the Pursiala power plant area in Mikkeli. The start-up of the electric boiler is planned for summer 2024. The electric boiler will reduce the use of combusted fuels in Pursiala and therefore decrease the carbon dioxide stack emissions from combustion.

According to AFRY (2020, 47), the use of heat pumps for district heat production is expected to grow in the future. Heat pumps can extract heat from different sources like air, water, ground or waste heat. Heat pumps can offer similar kind of advantages in district heat production like electric boilers do such as demand side flexibility as mentioned in the report by Nielsen et al. (2016, 190). Heat pumps also use electricity to generate heat, but with better efficiency than electric boilers. On the other hand, the investment costs of heat pumps are higher than the investment costs of electric boilers. The district heat production costs with heat pumps depend on the used heat source and the price of electricity (AFRY, 2021, 24).

Renewable hydrogen production is going to increase in Finland in the future as there are several planned investments on it. Renewable hydrogen is usually produced with water electrolysis which requires a lot of electricity. All the electricity is not transformed into the product, which means that the rest of the electricity is transformed into heat. The waste heat potential of electrolysis is about one third of the energy put in as electricity. Power-to-gas solutions can offer synergies in means of utilising the carbon dioxide from flue gases of a power plant. (Böhm et al., 2021; Ikäheimo, 2017, 173)

A good example of this kind of a power-to-gas production is the power-to-gas plant planned to Mikkeli. The plant would produce renewable synthetic methane and green hydrogen. The plant would also produce district heat from the waste heat of the electrolyser. The intended site for the plant is next to the Pursiala power plant, which enables the capture of carbon dioxide from the flue gases of the power plant. (Nordic Ren-Gas Oy, 2023)

In the future, nuclear energy could be produced with small modular reactors (SMRs), which can be used to generate district heat with low production costs. However, the technology is still on development stage. SMRs could locate closer to population centres than large-scale nuclear plants, though the social acceptance of SMR plants near population centres is still uncertain. (AFRY, 2020, 49)

According to AFRY (2020, 49), solar thermal heat is one option to reduce the use of fuels in a district heating network. Solar thermal heat can be generated either in centralized facilities or through decentralized installations. However, a limiting factor for solar thermal heat is seasonality, which contradicts with the heat demand. For example, Etelä-Savon Energia (2023c) produces solar thermal heat to its district heat network in two different locations in South Savo.

8.6.2 Waste heat utilization

According to AFRY (2022, 10) waste heat can be obtained from various sources such as:

- Condensing power plants
- Waste incineration plants
- Industrial installations
- CHP and heat only plants
- Data centres.

From these options listed above, the first two are not relevant for South Savo as there are no condensing power plants or waste incineration plants (AFRY, 2022, 12; Bröckl et al., 2021, 20). Industrial heat is a cost-efficient form of waste heat, but there are no industrial areas with substantial waste heat potential in South Savo (AFRY, 2022, 20-21). Waste-water treatment plants can also offer a potential renewable waste heat source for district heat production (The Directorate-General for Environment, 2022).

The main source of waste heat from CHP and heat only plants is the heat that is lost with flue gases. Heat from the flue gases can be recovered with flue gas scrubbers with heat recovery. In addition to flue gas scrubber with heat recovery, a heat pump can be installed which increases the amount of recovered heat. Heat recovery from flue gases increases the efficiency of heat production. (AFRY, 2022, 22-26)

According to the district heating statistics of Finnish Energy (2023b), there was only one district heat production plant above the capacity of 5 MW in South Savo in 2021 that has some kind of heat recovery system, so there is still potential to decrease fuel consumption with heat recovery from flue gases in South Savo. However, it should be noted that investing in heat recovery might not be viable for plants that are near the end of their service life.

According to AFRY (2022, 27), data centres generally have a significant potential for waste heat. Waste heat is produced as a result of the operation of data centres electrically powered equipment. Comprehensive, publicly accessible information about data centres is not available due to data security and competitive reasons. Business Finland (2023) has examined currently operating data centres and investment ready sites for data centres in

Finland. According to this report, there are currently no operating data centres in South Savo, but there is one potential investment ready site located in Mikkeli. However, district heating production is not the main business of data centres and related investment decisions are based on something different than district heat production.

9 Discussion

A key finding of this study is the additional carbon dioxide emissions originating from forest chip combustion, which are evaluated through different scenarios. The emission levels in 2035 has more weight than the emission levels in other years, as 2035 is the year when Finland and the region of South Savo are aiming to achieve carbon neutrality. Scenario 1 is the scenario where all PWB is incorporated in the ETS, which could be also expressed as the worst-case scenario for Finland, as forest chips have such an important role in the energy production in Finland. On the country level the net emissions in scenario 1 would be 6,9 Mt CO_2-eq, and the net emissions in the same scenario in South Savo would be 230 kt CO_2-eq in 2035. Scenario 4 is the only scenario on the country level where carbon neutrality is reached by 2035 and scenario 2 is the only one where carbon neutrality is reached in South Savo by 2035.

Another key finding of this study is the cost effect of emissions trading on the fuel cost of forest chips. However, this is somewhat in contradiction with the additional carbon dioxide emissions originating from forest chip combustion. Increased fuel costs due to the costs of buying emission allowances would make it very likely that the consumption of forest chips will turn into a decrease, but this is not taken into account in this study. The fuel price of forest chips has been increasing since Russia's invasion of Ukraine and the fuel price increased over 20% during a year after the invasion (Statistics Finland, 2023h). The recent increment of the fuel price of forest chips could lead energy companies to invest on alternative energy production technologies earlier than they otherwise would.

The future of the ETS includes uncertainties related to this work, such as the free allocation of emission allowances for district heat production after 2030 and the development of the price of emission allowance. It is not known for sure if emission allowances will be allocated for free for district heat production after 2030. It is also difficult to estimate how the allocation of free emission allowances would be treated for plants that use forest chips if forest chip combustion would be included in the ETS. For these two reasons the effect of free allocation of emission allowances is excluded from the fuel cost calculations. Estimating the price development of emission allowance is difficult, and therefore the rise of the emission allowance price is expected to be moderate in this study, reaching an average price of 100 €/CO_2 tonne in 2040.

If forest chip combustion were to be included in the ETS, it is not estimated in this study what would be the transition period for the regulations to come into force. However, it should be mentioned that for example in scenario 1, where all PWB would be incorporated in the ETS, the transition period should be long enough for energy companies to take necessary actions to reduce their carbon dioxide stack emissions from forest chip combustion.

Four different scenarios were created to represent different alternatives of which fractions of PWB would be incorporated in the ETS. Several assumptions were made when the scenarios were created, which is why the scenarios include uncertainty. The future consumption of forest chips in Finland is based on the WAM scenario. It was assumed that 78% of the total consumption of forest chips was consumed in plants that are included in the ETS in 2022. It was also assumed that in the future the same share of the total consumption of forest chips would be combusted in the plants operating under the ETS. However, it is predicted that the consumption of forest chips will increase in coming years in Finland, and it might be that most of that increment would originate from plants that are included in the ETS. Because of this, the share of forest chips combusted in the ETS sector may be higher than 78% in the future.

For scenario 2 the emission cap was defined based on the assumed forest chip consumption in the ETS sector. For country level the share of forest chips consumed in the ETS sector was assumed to be 78% for 2017-2022, which was the share in 2022. However, it is possible that the share was lower in reality. A lower share would mean that the emission cap will be lower, and the CO_2 emissions would be higher in scenario 2. For South Savo the cap is somewhat based on the consumption of previous years. If forest chips would be incorporated in the ETS based on an emission cap from the consumption of previous years, the emission cap formation should be examined more accurately. If the emission cap would be plant-specific, the calculation of the emission cap for an individual plant will be quite straight forward.

The predicted carbon dioxide emissions from forest chip combustion are calculated directly from the predicted consumption of forest chips. This does not take into account the potential carbon capture solutions that would decrease the CO_2 emissions of forest chip combustion.

It is also worthwhile to mention that if forest chip consumption would decrease due to alternative energy production methods or for some other reason, it would be likely to have a positive impact on forest carbon stocks through reduced felling rates. However, that is out of the scope of this study, and it is not further discussed.

This study provides a good foundation for decision-makers or anyone else interested in the topic of assessing the impacts of incorporating forest chip combustion in the ETS now or in the future. The future consumption of forest chips in Finland might look different in five years from now, but the methods used in this study should be applicable for predicting the impacts in the future as well. The practical part of this paper can be used as an example to conduct calculations with different values. The scenarios created in this study can be further modified for different purposes or to create scenarios with different definitions.

Further research could be done on the alternative heat production methods for replacing forest chip combustion on the regional level and on the country level as well. The production costs could be further evaluated for South Savo region and for example, marginal abatement cost calculations could be done on the regional level for South Savo to find out what would be the costs to reach desired emission reductions. However, energy companies do their own research to assess alternative heat production methods, but this is not usually publicly available material. It makes sense to assess these issues already at this stage, since it is possible that the fuel price of forest chips could continue to increase due to growing demand.

10 Conclusions

The aim of this thesis was to assess the impacts of the possible incorporation of forest chip combustion in the EU ETS in Finland and in the region of South Savo. The impacts were mostly assessed through the four different scenarios, which were created in this work. The main impacts assessed in this study were the carbon dioxide emissions of the different scenarios that would be caused by the incorporation of forest chip combustion, or some fractions of it, in the ETS. Another important issue assessed in this study is how this incorporation would affect the fuel cost of forest chips.

The literature review of this study gives an insight on the matters that are dealt with in the practical part. It was found out in this study that the consumption of forest chips in the ETS sector in Finland was about 15,7 TWh accounting for 78% of the total consumption of forest chips in 2022. The future consumption of forest chips in the ETS sector in Finland was calculated assuming that the share will be the same in the future. Detailed data was compiled by contacting the energy companies that operate the plants included in the ETS sector in South Savo that use forest chips as a fuel. The data included the forest chip consumption in 2022, assumptions of the future consumption until 2035, and the share of forest chips from used fuels in 2022. The consumption of forest chips in the ETS sector in South Savo was 810 GWh having a share of 84% of the total consumption of forest chips in 2022. The share of forest chips from used fuels was 56% among these plants.

The predicted consumption of forest chips of coming years in Finland is based on the WAM scenario, while the predicted consumption in South Savo is based on the amounts reported by the energy companies. The predicted carbon dioxide emissions from forest chip combustion were calculated from the predicted consumptions, and these were further used for calculating the predicted carbon dioxide emissions in each scenario. In the maximum scenario, where all PWB would be incorporated in the ETS, carbon dioxide emissions would increase by 8,9 Mt CO_2-eq on the country level and by 230 kt CO_2-eq in South Savo in 2035. If the plants with a capacity of 5-20 MW would be added in the ETS as well, the share of forest chips consumed in the ETS sector of the total consumption of forest chips in South Savo would increase from 84% to 90%.

If forest chip combustion were to be included in the ETS, the cost of emission allowances will more than double the fuel cost of forest chips from 30,2 €/MWh to 64,5 €/MWh with emission allowance price of 85 €/CO_2 tonne. It would make forest chips a more expensive fuel than peat is. The worth of emission allowances required for forest chip combustion was also assessed. If forest chip combustion had been already incorporated in the ETS, the worth of emission allowances required for forest chip combustion would have been about 500 million euros in 2022 in Finland. It would be likely that energy companies will begin to invest on alternative heat production technologies in case the fuel costs of forest chips would increase. Replacing forest chip combustion with electricity-based heat production technologies could decrease the energy self-sufficiency of South Savo or at least make it way more difficult to achieve South Savo's target of 60% energy self-sufficiency by 2030.

Incorporating forest chip combustion in the ETS would hamper Finland and the South Savo region to achieve their climate targets. If forest chip combustion, or some fractions of it, would be incorporated in the ETS, it would decrease the share of renewable energy in Finland's energy portfolio. It would also increase the emissions originating from the ETS sector and therefore increase the net emissions of South Savo and Finland. The production costs of district heat would increase for those plants using forest chips that operate under the EU ETS. Incorporating forest chip combustion in the ETS would put district heat companies to an inequal situation, as some companies have better possibilities to deploy alternative heat production methods than others.

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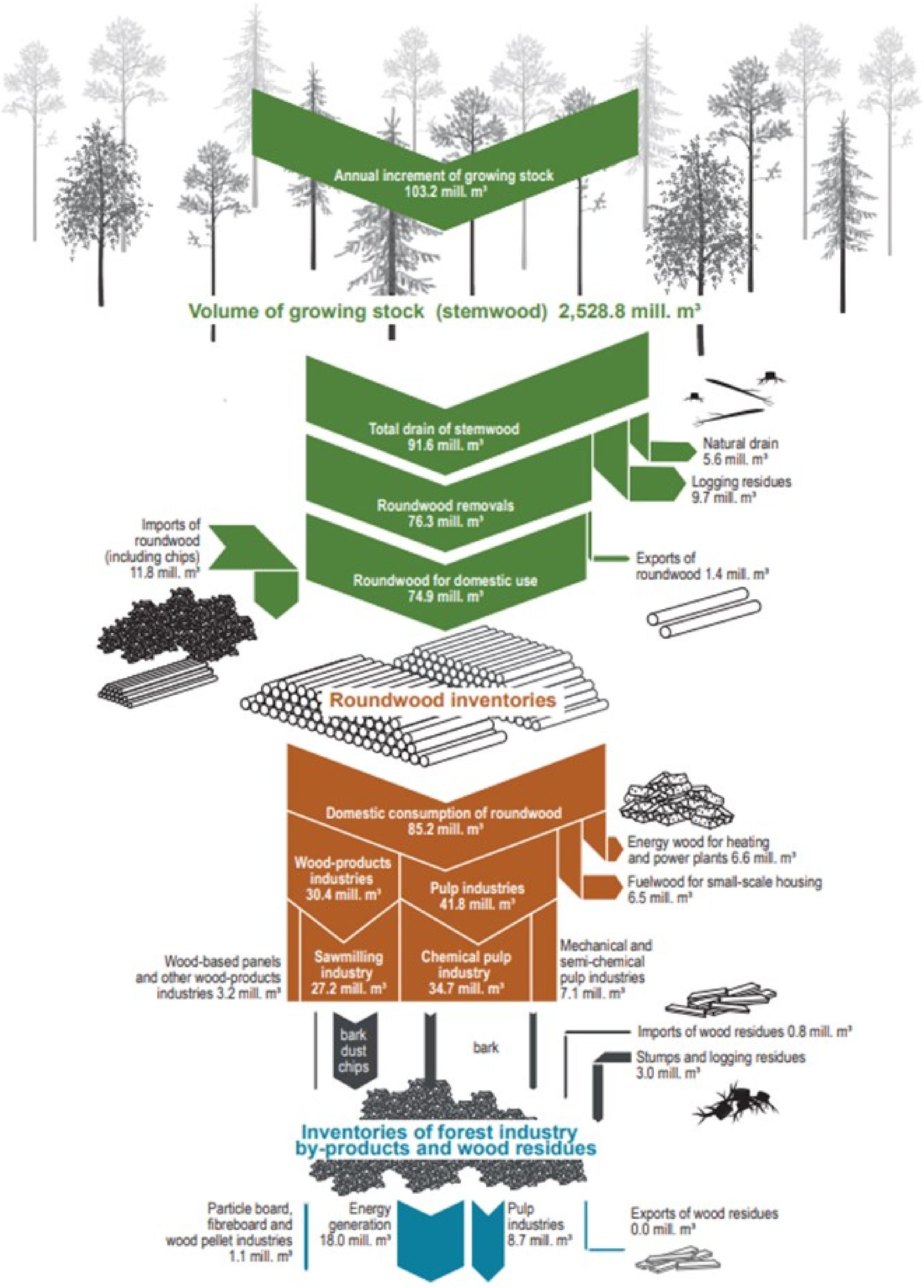
Appendix 1. Finland's roundwood flows in 2021. (Kulju et al., 2023, 15)



Appendix 2. Definitions for classification of energy wood. (Statistics Finland, 2023g)

21.10 Energy wood

Includes wood harvested for energy use collected from forests and wooded areas.

21.10.10 Firewood (stems and split firewood)

The raw material of chopped firewood is firewood (usually 1 m in length) or culled diameter stem. Chopped firewood is chopped and cut furnace-ready firewood used in households' wood-heated equipment, such as stoves, fireplaces and central heating systems. Typical properties as fired: moisture content 20–25%, net calorific value 13–15 GJ/t.

21.10.20 Chips from roundwood

Chips made from culled stem wood or from the entire superterranean biomass of the tree (stem wood, branches, needles). Typical properties as fired: moisture content 40–55%, net calorific value 7–11 GJ/t.

The sub-classification applied to limiting the subsidy for wood chips in the electricity production subsidy system of the Energy Authority starting from 2019. Based on the amendment of 20 March 2015 to the Act on production subsidy for electricity produced from renewable energy sources (1396/2010), by which the production subsidy for electricity produced with wood chips is limited to 60 per cent in case the chips originate from sawtimber and pulpwood suitable for processing in logging sites of large-sized timber. The sub-classification is not applied to the data collections of statistics.

21.10.21 Chips from roundwood, small-sized trees

Chips made from culled stem wood of small diameter or not suitable for processing or from the entire superterranean biomass of the tree of small diameter (stem wood, branches, needles).

21.10.22 Chips from roundwood, large-sized timber

Chips made from culled stem wood suitable for processing in logging sites of large-sized timber. Birch, pine or fir tree fulfilling the size and quality requirements of pulpwood or sawtimber.

21.10.30 Forest residue chips

After harvesting of commercial timber, chips or chippings made from branches and tree tops. Also includes chips or chippings produced from twig logs.
Typical properties as fired: moisture content 30–50%, net calorific value 8–13 GJ/t.

21.10.40 Hog fuel from stumps

Hog fuel and chippings produced from tree stumps and roots. Typical properties as fired: moisture content 30–40%, net calorific value 11–13 GJ/t.

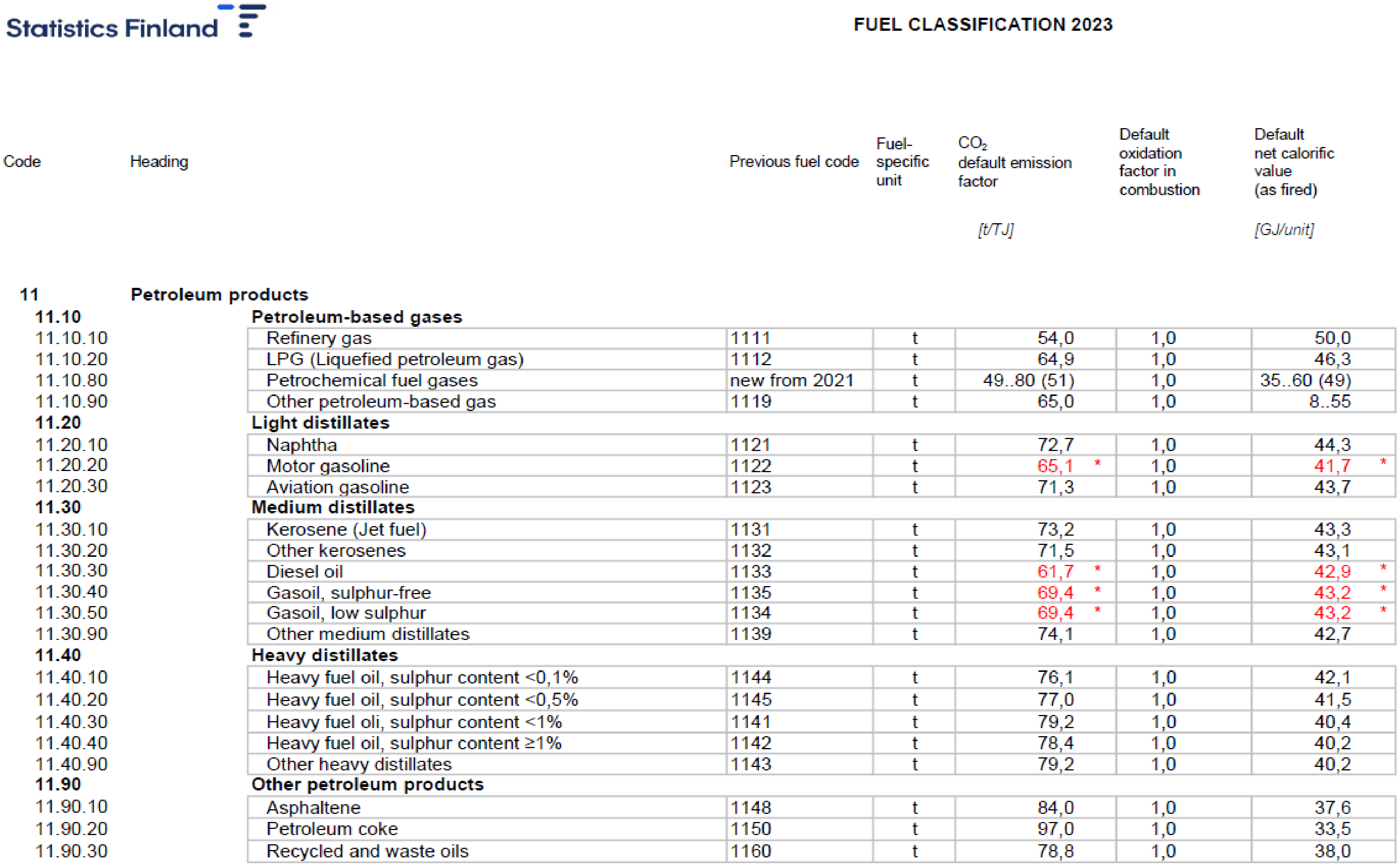
21.10.50 Energy willow (and other short rotation coppice)

Short rotation coppice willow is grown for energy use and is chipped prior to use. This category also includes also other short rotation forestry wood species that are grown for energy use.

Appendix 3. Consumption of solid wood fuels in heating and power plants in Finland and South Savo 2010-2022. (Natural Resources Institute Finland, 2023a)

			Forest chips, total	Forest industry by-products, total	Wood pellets and briquettes	Recycled wood	Wood fuels, total
2010	**Finland**	**GWh**	12489	17035	416	829	30770
	South Savo	**GWh**	849	1102	9	28	1989
2011	**Finland**	**GWh**	13709	17303	374	918	32304
	South Savo	**GWh**	910	1082	9	19	2020
2012	**Finland**	**GWh**	15189	17326	508	1354	34378
	South Savo	**GWh**	958	1055	12	13	2039
2013	**Finland**	**GWh**	15908	18374	696	1185	36163
	South Savo	**GWh**	893	1142	22	23	2080
2014	**Finland**	**GWh**	15099	18769	733	1334	35935
	South Savo	**GWh**	887	1166	18	16	2087
2015	**Finland**	**GWh**	14681	18447	1189	729	35045
	South Savo	**GWh**	889	1157	20	14	2081
2016	**Finland**	**GWh**	14805	19997	1040	1545	37387
	South Savo	**GWh**	802	1200	19	19	2040
2017	**Finland**	**GWh**	14427	21251	1355	1423	38457
	South Savo	**GWh**	756	1248	23	9	2036
2018	**Finland**	**GWh**	14844	20842	1287	1654	38626
	South Savo	**GWh**	782	1204	28	7	2021
2019	**Finland**	**GWh**	15111	21184	1363	1866	39524
	South Savo	**GWh**	823	1109	27	10	1969
2020	**Finland**	**GWh**	15176	19168	1252	1811	37407
	South Savo	**GWh**	802	973	21	11	1807
2021	**Finland**	**GWh**	19021	23304	2215	2232	46771
	South Savo	**GWh**	845	1187	24	7	2063
2022*	**Finland**	**GWh**	20170	20006	2140	2210	44526
	South Savo	**GWh**	964	1031	24	6	2025
* Preliminary data							

Appendix 4. Fuel classifications. (Statistics Finland, 2023g)



Statistics Finland

FUEL CLASSIFICATION 2023

Code	Heading	Previous fuel code	Fuel-specific unit	CO_2 default emission factor [t/TJ]	Default oxidation factor in combustion	Default net calorific value (as fired) [GJ/unit]
11	**Petroleum products**					
11.10	**Petroleum-based gases**					
11.10.10	Refinery gas	1111	t	54,0	1,0	50,0
11.10.20	LPG (Liquefied petroleum gas)	1112	t	64,9	1,0	46,3
11.10.80	Petrochemical fuel gases	new from 2021	t	49..80 (51)	1,0	35..60 (49)
11.10.90	Other petroleum-based gas	1119	t	65,0	1,0	8..55
11.20	**Light distillates**					
11.20.10	Naphtha	1121	t	72,7	1,0	44,3
11.20.20	Motor gasoline	1122	t	65,1 *	1,0	41,7 *
11.20.30	Aviation gasoline	1123	t	71,3	1,0	43,7
11.30	**Medium distillates**					
11.30.10	Kerosene (Jet fuel)	1131	t	73,2	1,0	43,3
11.30.20	Other kerosenes	1132	t	71,5	1,0	43,1
11.30.30	Diesel oil	1133	t	61,7 *	1,0	42,9 *
11.30.40	Gasoil, sulphur-free	1135	t	69,4 *	1,0	43,2 *
11.30.50	Gasoil, low sulphur	1134	t	69,4 *	1,0	43,2 *
11.30.90	Other medium distillates	1139	t	74,1	1,0	42,7
11.40	**Heavy distillates**					
11.40.10	Heavy fuel oil, sulphur content <0,1%	1144	t	76,1	1,0	42,1
11.40.20	Heavy fuel oil, sulphur content <0,5%	1145	t	77,0	1,0	41,5
11.40.30	Heavy fuel oli, sulphur content <1%	1141	t	79,2	1,0	40,4
11.40.40	Heavy fuel oil, sulphur content ≥1%	1142	t	78,4	1,0	40,2
11.40.90	Other heavy distillates	1143	t	79,2	1,0	40,2
11.90	**Other petroleum products**					
11.90.10	Asphaltene	1148	t	84,0	1,0	37,6
11.90.20	Petroleum coke	1150	t	97,0	1,0	33,5
11.90.30	Recycled and waste oils	1160	t	78,8	1,0	38,0

Code	Heading		Previous fuel code	Fuel-specific unit	CO$_2$ default emission factor	Default oxidation factor in combustion	Default net calorific value (as fired)
					[t/TJ]		*[GJ/unit]*
11.90.80		Petrochemical by-products	new from 2021	t	67..85 (78)	1,0	37..50 (41)
11.90.90		Other petroleum product (which?)	1190	t	80,0	1,0	30..50 (40)
12	**Coal**						
12.10		**Hard coal and anthracite**					
12.10.10		Anthracite	1211	t	98,3	0,99	33,5
12.10.20		Hard coal	1212	t	93,1	0,99	24,8
12.10.30		Coking coal	new from 2021	t	92,3	(0,99)	29,0
12.10.40		Pulverised injection coal for blast furnaces (PCI-coal)	new from 2021	t	95,9	(0,99)	30,8
12.20		**Coke**					
12.20.10		Coke	1230	t	107,0	0,99	29,3
12.20.20	*	Coke breeze *	new from 2023	t	115,0 *	0,99 *	26,8 *
12.20.30	*	Metallurgical coke *	new from 2023	t	112,0 *	0,99 *	28,6 *
12.30		**Coal based gases**					
12.30.10		Coke oven gas	1240	1000 m^3	41,5	0,99	16,7
12.30.20		Blast furnace gas	1250	1000 m^3	263,7	0,99	3,8
12.30.30		CO-gas	1260	1000 m^3	155,0	0,99	11,5
12.90		**Other coals**					
12.90.10		Semi-bituminous coal, brown coal, lignite	1221	t	108,0	0,99	20,0
12.90.20		Coal briquettes	1222	t	94,6	0,99	30,0
12.90.30		Coal tar	1228	t	91,3	0,99	36,3
12.90.40		Crude benzene (from coke oven plant)	new from 2021	t	84,2	(0,99)	39,5
12.90.90		Other non-specified coal	1229	t	108,0	0,99	10,0
13	**Natural gas**						
13.10		**Natural and liquefied natural gas**					
13.10.10		Natural gas	1311	1000 m^3	55,37 *	1,0	36,76 *
13.10.20		Liquefied natural gas (LNG)	1312	t	55,3	1,0	49,7
14	**Peat**						
14.10		**Peat**					
14.10.10		Milled peat	2110	t	107,6	0,99	10,1
14.10.20		Sod peat	2120	t	103,2	0,99	12,3
14.10.30		Peat pellets and briquettes	2130	t	97,0	0,99	18,0
14.10.40		Chips from swampwood	new from 2021	t	112,0	0,99	8,0

Code	Heading	Previous fuel code	Fuel-specific unit	CO_2 default emission factor	Default oxidation factor in combustion	Default net calorific value (as fired)
				[t/TJ]		[GJ/unit]
21	**Woody biomass fuels**					
21.10	**Energy wood**					
21.10.10	Firewood (stems and split firewood)	3111	t	112,0	0,99	14,0
21.10.20	Chips from roundwood	3112	t	112,0	0,99	9,5
	The sub-classification applied to the definition of the subsidy for wood chips in the electricity production subsidy system.					
21.10.21	Chips from roundwood, small-sized trees	3112a	t	112,0	0,99	9,5
21.10.22	Chips from roundwood, large-sized timber	3112b	t	112,0	0,99	9,5
21.10.30	Forest residue chips	3113	t	112,0	0,99	10,0
21.10.40	Hog fuel from stumps	3114	t	112,0	0,99	11,5
21.10.50	Energy willow (and other short rotation coppice)	3115	t	112,0	0,99	10,0
21.20	**Industrial wood residue**					
21.20.10	Bark	3121	t	112,0	0,99	7,5
21.20.20	Saw dust	3122	t	112,0	0,99	7,0
21.20.30	Wood residue chips	3123	t	112,0	0,99	10,5
21.20.40	Cutter shavings, grinding powder, etc.	3124	t	112,0	0,99	17,0
21.20.80	Unspecified industrial wood residue	3128	t	112,0	0,99	7,5
21.20.90	Other industrial wood residue	3129	t	112,0	0,99	8,8
21.30	**Black liquor**					
21.30.10	Black liquor	3130	t_{ka}	95,3	0,99	11,5
21.40	**By-products and residues from chemical wood processing**					
21.40.10	Pine oil and pitch	3141	t	77,0	0,99	37,0
21.40.20	Methanol and turpentine	3142	t	70,0	0,99	19..45
21.40.30	Fiber sludge	new from 2021	t	112,0	0,99	2,5
21.40.40	Paper	new from 2021	t	112,0	0,99	13,0
21.40.50	Odorous gases	new from 2021	1000 m^3	59,0	1,0	0..50
21.40.60	Lignin	new from 2021	t	112,0	0,99	17,4
21.40.90	Other residues from chemical wood processing	3149	TJ	112,0	0,99	
21.50	**Recovered wood**					
21.50.10	Recovered wood	3150	t	112,0	0,99	12,0
21.60	**Processed wood fuels**					
21.60.10	Wood pellets and briquettes	3160	t	112,0	0,99	17,0
22	**Non-woody biomass**					
22.10	**Vegetable-based fuels**					
22.10.10	Cereal crops and straw parts	3172	t	100,0	0,99	13,5

Code	Heading	Previous fuel code	Fuel-specific unit	CO_2 default emission factor [t/TJ]	Default oxidation factor in combustion	Default net calorific value (as fired) [GJ/unit]
22.10.20	Reed canary grass	3171	t	110,0	0,99	13,0
22.10.30	Vegetable oils and fats	3174	t	72,0	0,99	37,0
22.10.90	Other vegetable-based fuels	3179	t	100,0	0,99	15,0
22.20	**Animal-based fuels**					
22.20.10	Animal fats	3181	t	75,0	0,99	37,0
22.20.20	Manure	new from 2021	t	100,0	0,99	5,0
22.20.90	Other animal-based fuels	3189	t	100,0	0,99	15,0
22.30	**Biogas**					
22.30.10	Landfill gas	3211	1000 m^3	54,6	1,0	17,0
22.30.20	Biogas from wastewater treatment plants	3212	1000 m^3	54,6	1,0	23,0
22.30.30	Thermal biogas (gasified wood or other biomass)	3215	1000 m^3	108,0	1,0	5,0
22.30.40	Biomethane (grid)	3214	1000 m^3	54,6	1,0	35,10
22.30.50	Biomethane (off-grid)	new from 2021	1000 m^3	54,6	1,0	35,10
22.30.60	Liquefied biogas (LBG)	new from 2022	t	54,6	1,0	49,30
22.30.90	Other biogas	3219	1000 m^3	54,6	1,0	20,0
22.40	**Processed liquid biofuels**					
22.40.10	Bio-LPG /Biopropane	3223	t	65,0	1,0	46,2
22.40.20	Bioethanol (non-blended)	new from 2021	t	72,0	1,0	26,6
22.40.30	Bio jet fuel (non-blended)	new from 2021	t	72,0	1,0	43,9
22.40.40	Renewable diesel (non-blended)	new from 2021	t	71,6	1,0	43,6
22.40.50	Bio gasoil (FAME) *	3221	t	75,0	1,0	37,5
22.40.55 *	Bio gasoil (HVO) *	new from 2023	t	71,6 *	1,0 *	43,6 *
22.40.60	Biopyrolysis oil	3222	t	79,6	1,0	17,0
22.40.90	Other liquid biofuel (which?)	3229	t	79,6	1,0	15..40
22.90	**Other biomass fuels**					
22.90.10	Biosludge	3250	t	132	0,99	2,5
22.90.20	Biocoal	3260	t	112	0,99	18..33
22.90.30	Biopellets (non-woody)	new from 2021	t	112,0	0,99	17,0
22.90.40	Other odorous gas from industry	new from 2021	t	59,0	1,0	0..50

NB

BIO = biofuel, whose carbon dioxide emissions are not counted in the total emission amounts of Finland's greenhouse gas inventory.

1) CO_2 factor for mixed fuels, as well as for blended fuels, is an estimate taking into account only the share of fossil carbon.
The average bio-shares for these fuels is estimated yearly, which has an effect on the default coefficients.

2) Gasified waste (mixed product gas) is to be reported primarily in the fuel categories of the source materials of gasification.

3) The bio-share of the energy content is assumed to be 100%, CO_2 emission is caused by the decomposition of carbonates.

4) The default value used for density is at a temperature of 15°C. The uncertainty of density is assumed to be ±2 per cent.

5) The amount of natural gas according to gross calorific value is converted to net calorific value by dividing it by 1,1088.

Calorific values and emission coefficients describe the properties of fuel as fired,
inclusive of moisture content (except for 21.30.10, where the measurement unit is tonnes of dry matter).
Calorific value of natural gas has been specified in normal conditions (0 °C and 1.013 bar).

Emission factors are updated when necessary.
* Revised values or modified content
The latest classification can be found on Statistics Finland's web page: http://www.stat.fi/polttoaineluokitus

The CO_2 factors only describe CO_2 produced during combustion, i.e. they do not include CO_2 equivalent emissions from other greenhouse gases and life cycle emissions from the manufacture, transport, etc. of fuels.