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Estimating future consumption of forest chips based on insights from energy producers: a case study for Finland

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ABSTRACT
Forest chips have become a crucial energy source in Finland, largely driven by political decisions to promote renewable energy. This study examines trends in forest chip consumption in Finnish heat-only and combined heat and power plants, offering projections for 2026 and 2033 based on a survey for energy producers and the statistical data from 2023. The survey represented 79% of forest chip consumption in 2023, while the remaining consumption was estimated using linear regression analysis.

The findings suggest that forest chip consumption may increase from 11.0 to 11.4 million cubic metres (Mm^3, solid over bark) by 2026. The reduction in energy peat and fossil fuel use is likely to drive higher consumption of forest chips when electricity prices are high and electricity-based heat generation becomes unprofitable. The growing role of wood as a regulating power may also lead to increased roundwood burning as storage times lengthen.

By 2033, consumption is expected to decrease to 9.7 Mm^3, primarily due to the adoption of alternative energy production technologies, such as utilisation of waste heat. No investments in carbon capture and storage were identified. As the availability of biogenic carbon remains significant, climate policy should prioritise the promotion of these technologies.

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Renewable energy policy; climate policy; bioenergy; wood energy; energy transition; survey

Highlights

- Forest chip use may increase by 2026 as fossil fuels and energy peat are being replaced.
- Waste heat recovery and other investments will potentially reduce usage by 2033.
- In the future, electricity prices will also drive the use of forest chips.
- Longer energy wood storage times may promote the use of roundwood.
- The respondents had plans for carbon capture and utilisation, but not for storage.

Introduction

Wood fuels, including forest chips made from roundwood, logging residues, and stumps, are an important source of renewable energy in many countries (United Nations (2018)). However, in Finland the role of wood fuels in the energy system is particularly important (United Nations (2018); Eurostat (2024); Official Statistics of Finland (2023); Official Statistics of Finland (2024a); Díaz-Yáñez et al. (2013)). Use of forest chips has been central in the Finnish energy sector's transition towards renewable energy sources. According to statistics on Wood in energy generation Official Statistics of Finland (2024b), the consumption of forest chips in heat and power generation has increased significantly over the last 20 years, rising from two million to 11 million solid cubic metres over bark (Mm^3). In recent years, this development has been driven by the increased use of forest chips made from roundwood (Figure 1). Meanwhile, the consumption of fossil fuels and energy peat has decreased by 69% between 2004 and 2022 (Official Statistics of Finland (2023)).

The developments have been the result of political decisions and objectives. The EU's emission trade directive 2003/87/EC was set in 2003 to reduce fossil carbon emissions to achieve global goals to prevent climate change (European Parliament and Council (2003)). In addition, the EU (2009) set targets for a 20% share of renewable energy in Directive 2009/28/EC. The directive has been updated twice, and the latest update, Directive (EU) 2023/2413, also known as RED III, aiming to increase the share of renewable energy in the EU to 42.5% by 2030 (European Parliament and Council (2023)).

Finland's approach to meeting EU targets has involved increasing the share of bioenergy in energy generation, particularly through supporting the expanded use of forest chips in heat-only and combined heat and power (CHP) plants (Lehtilä et al. (2021)). In 2008, the Finnish government set a target to increase the annual consumption of forest

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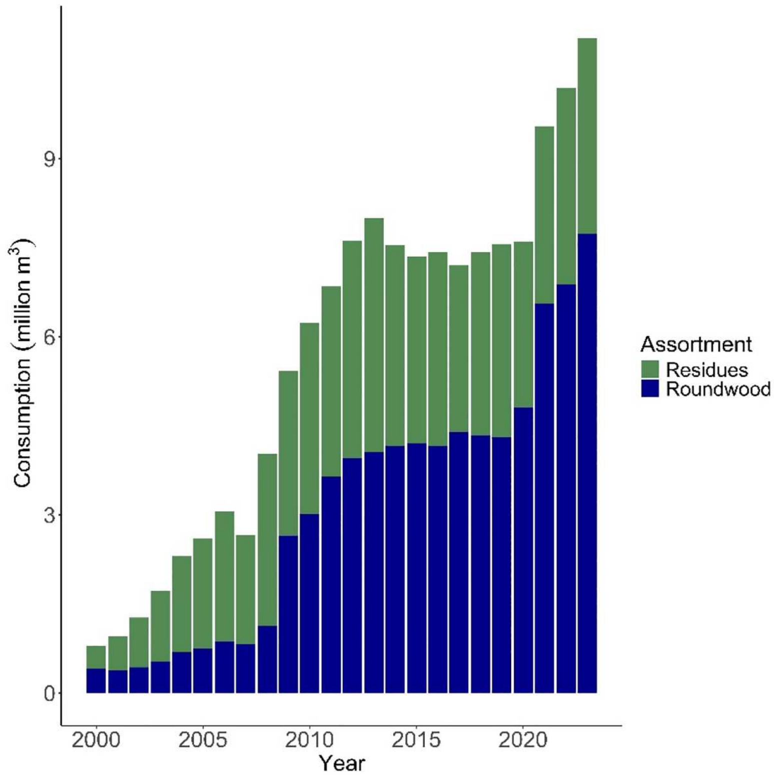

Figure 1. Statistics on the annual consumption of forest chips in heat-only and combined heat and power (CHP) plants in Finland indicate a significant increase in usage in recent years. This increase has been driven by forest chips produced from roundwood. "Residues" means logging residues and stumps (Official Statistics of Finland (2024b)).

chips to over 12 Mm^3 by 2020 (Finnish Council of State (2008)). Promoting the use of forest chips was also included as one of the objectives of the Finnish National Forestry Strategy 2025. The objective was justified not only based on climate benefits but also in terms of security of energy supply and economic impacts. Additionally, the harvesting of small-diameter roundwood for energy was seen as a potential solution for the improvement of silviculture and management in young commercial forests. (Ministry of Agriculture and Forestry in Finland (2015)).

As the amount of wood used has increased, the price of roundwood and forest chips has risen in recent years, making wood a less competitive source of energy (Official Statistics of Finland (2024c)). The rise in prices has also been driven by the Russian invasion of Ukraine, which ended wood imports from Russia to Finland (Viitanen et al. (2023)). In future, several studies such as those by Lehtilä et al. (2021) and AFRY Management Consulting Oy (AFRY) (2021) have estimated that wood fuel consumption in Finland will stay at a high level in energy generation. This is mainly due to the need to replace fossil fuels and peat in energy production.

Based on Law 416/2019 (2019), coal-fired power and heat generation will be banned in Finland after 1 May 2029. Correspondingly, in 2019, the programme of Prime Minister Sanna Marin's government (2019) aimed to halve energy peat consumption in energy generation by 2030, and later, in the programme of Prime Minister Petteri Orpo's government (2023), it has been decided to secure the availability of energy peat during the energy transition for the national emergency supply. However, the reduction in energy peat consumption has been faster than expected, and it had already fallen by 55% between 2019 and 2023 (Official Statistics of Finland (2024a)). Heat-only and CHP plants consuming solid fuels in Finland commonly use wood fuels or energy peat. The decline in energy peat consumption therefore partly explains the sharp increase in forest chip consumption since 2020 (Official Statistics of Finland (2024b); AFRY Management Consulting Oy (2020)).

In contrast with many previous studies, this study's motivation was to create an estimate of future forest chip consumption for Finland by examining energy companies' own investment plans, strategies, and estimates rather than relying only on modelling. This study solely focused on the forest chip consumption in heat-only and CHP plants and small-scale usage by farms etc. was excluded. We sought to investigate how companies themselves perceived the impact of political decisions, energy markets, the technological transformation in energy generation, and new energy generation options such as heat pumps, electric boilers, and waste heat recovery on their own forest chip consumption over the next ten years. From a global perspective, the development of Finnish energy generation provides an example of the progress of the green transition in the energy sector and the current and future role of bioenergy in meeting renewable energy targets. As the energy consumption of forest industry by-product wood depends on production volumes, this study focused solely on estimating the consumption of forest chips. Wood pellets and other post-consumer wood were excluded from the study due to their limited importance in Finnish heat and power generation.

Materials and methods

Statistical data on wood fuel consumption

In this study, the baseline of forest chip consumption in heat-only and CHP plants and the number of consumer plants were based on the statistical data from 2023. The data was decided to be utilised as it includes all significant heat-only and CHP plants that use solid wood fuels. These data were collected by the statistical services of Natural Resource Institute Finland (Luke) between January and May 2024 for the official statistics on Wood in energy generation (Official Statistics of Finland (2024b)).

The data include amounts of solid wood fuels consumed in 2023 by plant and wood fuel assortment. In addition to the quantities of forest chips and the various energy wood assortments they contain, the data also covered the consumption of solid by-product wood from the forest industry, recycled and post-consumer wood, and wood pellets. According to Documentation of wood consumption statistics (Official Statistics of Finland (2024d)), the data collected in several different units were converted to common units using general conversion factors. Of the data describing plants, the dataset includes information about the location at both the municipal and provincial levels, and whether the plant produced electricity in addition to heat.

The statistical data used in this research were preliminary, and plant-level consumption figures were revised in November 2024 with the publication of the final Wood in energy generation 2023 statistics. Provisional data were deemed capable of use in this research because the revisions to the data in previous years have been minor. In 2023, the final consumption of forest chips was 0.02% higher than in the preliminary statistics.

Research survey of future insights by energy producers

We estimated the consumption of forest chips for the next ten years mainly based on the estimates from energy companies that consumed solid wood fuels in heat-only and CHP plants. The basis of the conducted survey was the assumption that companies are best aware of their own future prospects such as upcoming investments and are therefore capable of providing the most accurate estimate regarding whether significant changes are expected in the usage of forest chips. The data were collected through a research questionnaire in which respondents were asked to estimate future consumption of forest chips at plant level in 2026 and 2033. In these estimates, respondents were asked to assume the same weather conditions as in 2023.

Based on the policy objectives of Prime Minister Petteri Orpo's government (2023), the EU's REPowerEU plan (2022) and the Renewable Energy Directive (EU) 2023/2413 (2023), the share of renewable energy sources is expected to increase significantly in the coming years, while the consumption of fossil fuels will gradually decline. In Finland, this trend has been reflected in practice through the investment plans and decisions made by many significant energy companies in recent years, particularly in electricity-based heat production, as the electricity generation increases in Finland (Official Statistics of Finland (2024a)). Several companies have also publicly announced their intentions to reduce or cease energy peat consumption for energy production in the coming years, in alignment with political targets (Finnish Government (2019)). The year 2026 was selected as a reference year because it was anticipated to be easier and more reliable for energy producers to assess the impact of policies and potential new investments on the development of forest chips consumption in the short term. However, the reference year was considered sufficiently distant for the impact of investments in alternative energy production from forest chips, which are currently under construction or have only recently been completed, to be reflected in the survey results.

In addition, year 2033 was chosen particularly to illustrate the impact of bioenergy with carbon capture and storage (BECCS) or utilisation (BECCU) on forest chip consumption. Several energy companies have publicly announced that they are exploring and planning investments in carbon capture and green hydrogen production, with many planning these investments for the early 2030s. Waste heat is also generated during hydrogen production and is intended to be utilised for district heating. Within ten years, other alternative forms of energy production, which are currently becoming more common, are also expected to become more widespread. The year 2033 was also deemed appropriate, as it is close to 2035, the target year for Finland's goal of achieving carbon neutrality. Specifically, the promotion of BECCS is a central climate action within the programme of Prime Minister Petteri Orpo's government (2023) and we wanted to see if this was reflected in the results of the survey.

In addition to forest chip consumption estimates, the survey included qualitative questions that aimed to identify potential new investments in energy production. These investments were expected to include technologies such as flue gas washers (scrubbers), electric boilers, heat pumps, and waste heat recovery systems, which could influence the consumption of forest chips and other solid wood fuels.

The design of the survey was undertaken in March 2024 and tested with several experts, including researchers and a representative of an energy company. The data collection was conducted in April and May 2024 by Luke's Statistical Services. The survey was sent to the same recipients who reported the 2023 data in the statistical survey on wood in energy generation. Luke conducts that survey annually to produce official energy and forestry statistics. The respondents were considered appropriate to answer the questions and were asked to forward the questionnaire to a more suitable recipient if necessary.

Respondents were selected based on their annual wood fuel consumption in 2023. A link to the voluntary questionnaire was emailed to the respondents of the statistical survey, who reported consumption of 7,000 megawatt-hours (MWh) or more at their heat-only and CHP plants.

The respondents to the research questionnaire accounted for 91% of the recorded forest chip consumption in 2023. Respondents were given two weeks to complete the survey. After the response period ended, data collection was supplemented by telephone interviews with the largest consumers of solid wood fuels, as well as companies that had announced new investments in energy generation in the public media. The collected data were utilised anonymously, combined with the statistical data for 2023.

Analysis

The development of forest chip consumption was analysed based on the research survey for those plants for which consumption estimates were available for both 2026 and 2033, as well as the actual consumption volume for 2023 based on statistical data. Consumption estimates were given either in loose cubic metres or in megawatt-hours. Based on conversion factors in the report by Alakangas et al. (2016), these volumes were converted to solid cubic metres and megawatt-hours, assuming that one solid cubic metre equalled two megawatt-hours. Heat-only and CHP plants for which only one year's consumption estimate was provided and verbal estimates that could not be converted into numerical values were excluded from the analysis of consumption changes. The same principles were applied to the analysis of energy peat consumption future development, which was sought in the research survey.

A total of 160 people, representing a total of 361 heat-only and CHP plants, responded to the survey. When 36 incomplete consumption estimates were removed, the analysed data of forest chip consumption estimates for 2026 and 2033 contained a total of 325 plants. For energy peat consumption, 54 incomplete plant-level data were removed, and the analysed data contained recorded energy peat consumption for 2023 and estimates for 2026 and 2033, for a total of 307 plants.

In addition to the plants that responded to the research survey, this study estimated the total amount of forest chips consumed by Finnish heat-only and CHP plants. To investigate this, future consumption of forest chips was predicted with simple linear regression models for those plants in the 2023 statistical data for which a survey-based estimate was unavailable (Eq. 1). A linear regression model was fitted for both dependent variables: (1) forest chip consumption in 2026; and (2) forest chip consumption in 2033.

$$Y = X\beta + \varepsilon, \quad (1)$$

where Y = the dependent variable, X = forest chip consumption in 2023, β = model parameters, and ε = the error term. The underlying assumption of the prediction model was that if forest chips were burned in 2023, their use would continue in the future and vice versa.

In this study, the data were processed, and the analysis was carried out at the plant level, and the results of forest chips and energy peat consumption predictions were reported at both the country and regional levels. To ensure data protection for the individual respondents, the regional analysis was conducted by dividing Finland into four major regions, as shown in the Figure 2, each comprising more than one province.

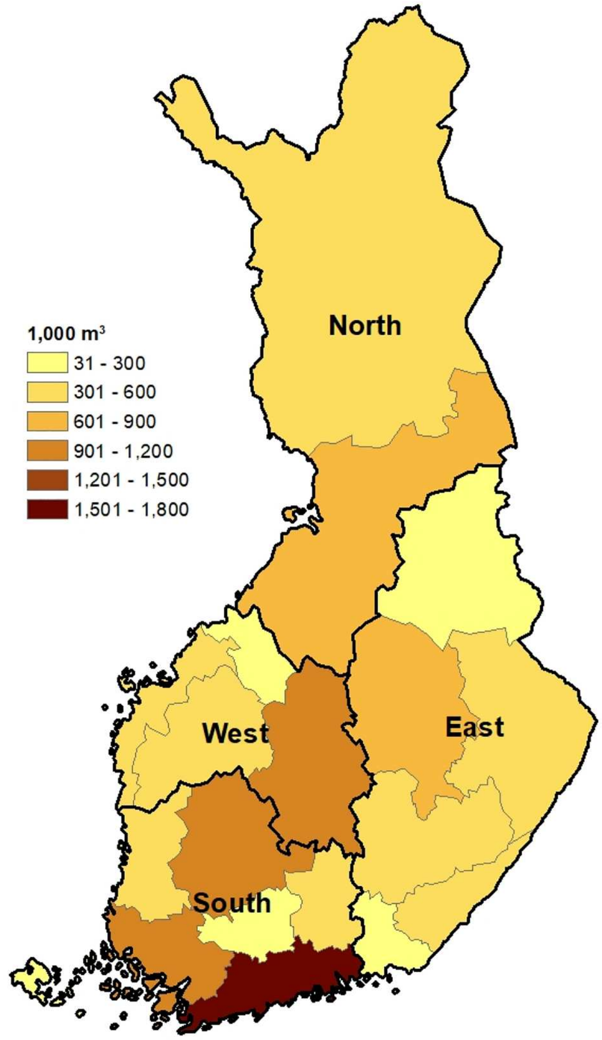

Figure 2. Annual forest chip consumption in 2023 by province and description of the regional classification used in this study. Statistical data indicate significant variations in the amount of forest chips consumed across different provinces andregions (Official Statistics of Finland (2024b)).

The analysis of future forest chips and energy peat consumption was supplemented by an examination of the qualitative responses in the survey questionnaire. These responses were analysed to identify perspectives on the future of forest chip consumption or factors influencing it and to determine whether there was any commonality between the different respondents. These factors were identified, and their prevalence in the responses was calculated.

Results

Forest chip consumption based on the survey

Based on the survey data analysed, of the 325 heat-only and CHP plants, a total of 244 plants had consumed forest chips in 2023. The total consumption volume of these plants amounted to 8.7 Mm^3 (17,409 GWh) in 2023, covering 79% of the total consumption recorded in Finland.

According to the survey respondents, forest chip consumption was expected to increase by 4% between 2023 and 2026. The average and median consumption of individual consumer

Table 1. The development of forest chip consumption in 325 heat-only and combined heat and power plants and average and median consumption of consumer plants based on the survey responses.

Year	Consumer plants pcs	Total consumption million m^3	Total consumption TWh	Average consumption for individual plant m^3	Median consumption for individual plant m^3
2023	244	8.7	17.4	35,675	6,957
2026	241	9.1	18.2	37,739	7,500
2033	236	7.8	15.5	32,840	7,079

plants was also expected to increase (Table 1). The consumption volume increased at a total of 131 plants, where the average consumption recorded in 2023 was 30,276 m^3. In contrast, 100 plants were expected to reduce their usage, with average consumption of forest chips in these plants amounting to 44,058 m^3 in 2023. This suggests that average consumption increased in smaller plants and decreased in larger ones. Additionally, in 2026, there were expected to be seven plants that did not consume forest chips in 2023. A total of 10 plants were expected to cease consumption by 2026.

In 2033, forest chip consumption is expected to begin decreasing. The total estimated consumption for 2033 was 15% lower than the estimated consumption in 2026 and 11% smaller than the recorded consumption of the same plants in 2023. The median consumption of individual plants consuming forest chips for 2033 was 6% lower than the estimated median consumption in 2026 but 2% higher than in 2023. Compared to 2023, consumption is expected to increase in 119 plants and decrease in 116 plants. The average annual consumption in 2023 for plants where consumption is projected to increase by 2033 was 26,676 m^3. The corresponding figure for plants where consumption is expected to decline was 46,568 m^3. Compared to the results for 2026, the plants where consumption is expected to increase between 2023 and 2033 are still smaller on average. In 2033, three forest chip consumer plants were not expecting to consume forest chips in 2026. Additionally, eight plants were expected to cease consumption between 2026 and 2033.

Regional differences in the estimated development of forest chip consumption were also recognised. The survey-based estimates for forest chip consumption by region are described in Figure 3. In contrast with the East and North regions, forest chip consumption in the South region was already expected to decrease by 2026. In the West region, consumption in 2026 was expected to be almost the same as in 2023.

Energy peat consumption based on the survey

Based on the survey estimates, energy peat consumption in Finnish heat-only and CHP plants is expected to decrease significantly over the next ten years (Table 2). When the survey-based energy peat consumption in 2023 with Official preliminary energy supply and consumption statistics (2024a) are compared, the estimated coverage of the survey for energy peat consumption was 58%. In 2026, the estimated consumption represented a 57% decrease from 2023. By 2033, the decline in consumption is expected to accelerate, when the

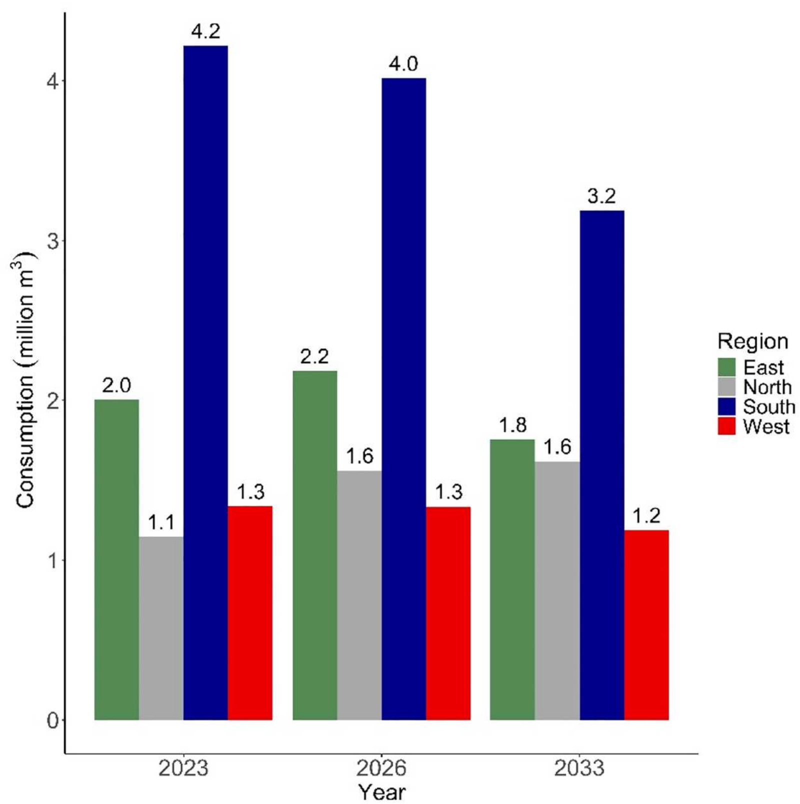

Figure 3. Forest chip consumption in 2023 in heat-only and combined heat and power plants and expected usage in 2026 and 2033 by region based on the responses to the research survey. The results indicate the regional differences in the development of usage.

Table 2. Development of energy peat consumption in 307 heat-only and combined heat and power plants and average and median consumption of consumer plants based on the survey responses.

Year	Consumer plants pcs	Total consumption GWh	Average consumption for individual plants GWh	Median consumption for individual plants GWh
2023	109	4,116	38	10
2026	89	1,780	20	10
2033	43	320	7	5

volume will be 82% lower than estimated consumption in 2026 and 92% lower than consumption in 2023.

Between 2023 and 2026, energy peat consumption is expected to increase at a total of 14 plants, where the average consumption recorded in 2023 was 4,838 MWh. In contrast, 73 plants were expected to reduce their usage, with average consumption of energy peat in these plants amounting to 51,225 MWh in 2023. Similarly, between 2023 and 2033, energy peat consumption was expected to increase in only six plants, with average energy peat consumption of 4,505 MWh in 2023. During this period, 93 plants were expected to decrease consumption, with their average consumption in 2023 being 42,899 MWh.

Moreover, based on the analysis of the questionnaire responses, the predicted increase in forest chip consumption was statistically most likely in those plants where energy peat consumption was expected to decrease. Energy peat usage was expected to decrease in 67% of cases where forest chip usage was projected to increase between 2023 and 2026. As between 2023 and 2033, the same kind of relationship was identified in 88% of cases where forest chip usage was expected to increase.

In 2026, it was expected that there would be six new plants consuming energy peat. The number of plants to be decommissioned by 2026 was 26. Respectively, by 2033, none of the plants plan to start burning energy peat after 2026, but 46 plants plan to cease burning by 2033.

Regional differences were also identified in energy peat consumption and its development (Figure 4). In 2023, consumption was highest in North and East regions, but in these regions the consumption is expected to decrease most. Among the responding heat-only and CHP plants, South region remains the smallest user of energy peat in all years.

Total forest chip consumption

The relationships between recorded usage in 2023 and estimated consumption in both 2026 and 2033 were found to be linear, based on the survey responses. Linear regression analysis was therefore performed for both years, using the 2023 consumption figures from the statistical data to predict the consumption in 2026 and 2033 for plants lacking the estimates of the research survey data (Table 3).

The importance of the modelled individual consumption projection is relatively low compared to those heat-only and CHP plants for which survey-based estimates were available (Table 4). The modelled projections for 2026 and 2033 include four larger plants, with consumption volumes in

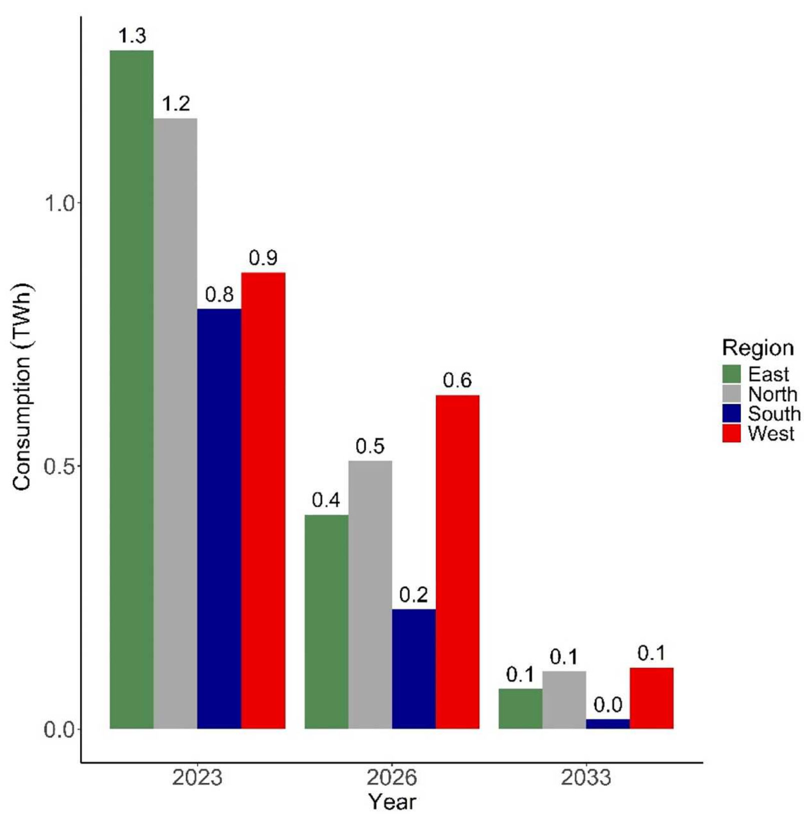

Figure 4. Energy peat consumption in 2023 in heat-only and combined heat and power (CHP) plants and expected usage in 2026 and 2033 by region based on the responses to the research survey. The results indicate a significant reduction in energy peat use by 2026. By 2033, the findings suggest that energy peat consumption will be nearly phased out.

Table 3. Statistics of the forest chip consumption models.

Model	n	β	R^2_{adj}	F-test
Consumption in 2026	239	0.96	0.88	F(1, 238) = 1,807, $p < 0.001$
Consumption in 2033	225	0.82	0.77	F(1, 224) = 771, $p < 0.001$

Table 4. Heat-only and combined heat and power plants for which consumption predictions were modelled using linear regression analysis.

Year	n	Average consumption of individual plant in 2023 m^3	Median consumption of individual plant in 2023 m^3
2026	289	7,879	2,440
2033	295	7,882	2,396

2023 ranging from 100,000 m^3 to 200,000 m^3. However, as the average and median consumption of the modelled plants presents, the majority of these were minor consumers. The difference between the amounts of modelled predictions between 2026 and 2033 is caused by six plants for which the consumption estimate based on the research survey was available only for 2026, and the 2033 consumption estimate was generated by modelling. Additionally, a total of 2.7% of forest chip usage in 2023, equivalent to 303,000m^3, was reported in the statistical data as province-specific totals. These data were treated in the modelling in the same manner as the plant-level data. In both 2026 and 2033, there were 75 instances of modelled province-level data.

In addition to consumption in 2023, we tested the explanatory power of the available background variables in accounting for the predicted changes in forest chip use. The variables studied included whether the plant produced heat only or combined heat and power, and the plant's location, either at the provincial level or divided into the four major regions used for reporting the study's results. Furthermore, the interactions of the former were tested. However, these background variables were not statistically significant at the 5% significance level and had no significant effect on the accuracy of the prediction models. It was therefore decided to exclude them from the models.

Based on these results, forest chip consumption in Finnish heat-only and CHP plants is predicted to increase by 3% between 2023 and 2026 (Table 5). By 2033, consumption is expected to decrease, and predicted consumption was 12% lower than recorded consumption in 2023 and 15% lower than predicted usage in 2026.

The results are presented by region in Figure 5. The development of total consumption was similar to the results of plants that only responded to the research survey.

Table 5. Development of annual forest chip consumption in Finnish heat-only and CHP plants and average and median consumption of individual plants. The predictions are based on the research survey responses and modelling results.

	Total consumption		Average consumption of individual plants	Median consumption of individual plants
	million m^3	TWh	m^3	m^3
2023	11.0	21.9	20,494	4,015
2026	11.4	22.7	21,241	4,017
2033	9.7	19.3	18,215	5,549

New investments and future views of energy generation

Several factors influencing the estimated consumption of forest chips were identified from the responses to the open-ended questions in the research survey. Phasing out of fossil fuels and energy peat will be partly replaced by burning forest chips in the coming years. This development is proven by the increasing forest chip usage volumes in the future consumption estimates for 2026 and noted by 11 respondents. By 2033, the consumption of forest chips was seen to decrease due to the technological development of energy generation. However, consumption of forest chips remains at a relatively high level.

Investment plans for new heat-only and CHP plants utilising forest chips were also under consideration. A total of 18 respondents mentioned potential or decided investment plans, three of which involved new plants, while the remaining plans focused on replacing end-of-life solid fuel boilers. Eleven respondents reported boilers that might be decommissioned. However, even in many of these cases, it was reported that the plants would remain in reserve for potential failures or periods of high demand.

According to the survey responses, there was interest in investing in energy efficiency improvements in heat-only and CHP plants. A total of 37 respondents mentioned scrubbers as a means to improve the energy efficiency of their plants, with investments either already made or planned. Based on the respondents' experience, scrubbers have reduced the consumption of forest chips by up to 20%. However, based on the survey, many larger plants already have scrubbers installed. In smaller plants, the profitability of such investments remains uncertain. One respondent noted that no suitable solution exists on the market for small plants with a thermal capacity of less than 3 MW. Another respondent also mentioned that the investment in a scrubber proved unprofitable when the plant burned only dry wood. Additionally, 24 respondents reported plans or interest in investing in heat pumps in connection with plants using wood fuels. Unlike scrubbers, these investments are mostly ongoing, and the first heat pumps were reported to become available only a few years ago.

Investments in electric heat boilers and other alternative energy generation technologies such as heat pumps, waste heat recovery, and heat batteries may have an impact on wood consumption in energy generation. This was also seen in the responses to the survey. A total of 26 respondents reported they had either completed or planned investments in electric heat boilers. Many of these investments were scheduled for implementation by 2026 and were primarily located at larger plants where wood was also burned. Several respondents also noted electric heat boilers as a potential substitute for wood fuels when the price of electricity is low. Based on the survey responses, these investment plans were more common among larger companies and forest chip consumers. However, in some of these cases, discussions of boiler investments had only taken place at a preliminary level, and no binding investment decisions had been taken.

Based on the survey, the outlook for energy generation indicates increasing within-year variation in forest chip

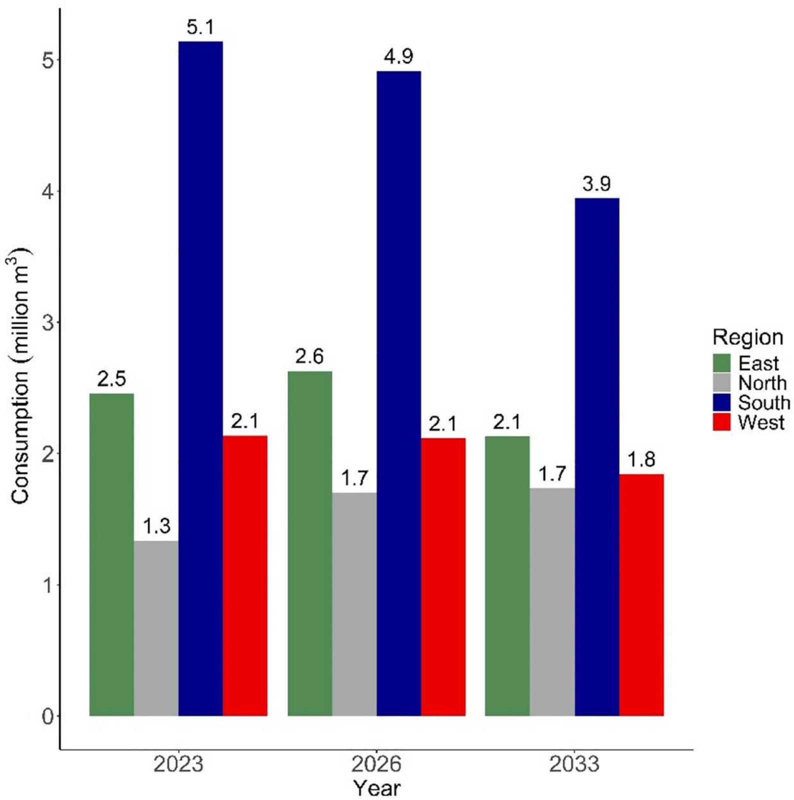

Figure 5. Recorded total consumption of forest chips in 2023 and predicted usage in 2026 and 2033 based on the survey responses and modelling. The regional trend in usage aligns closely with the pattern observed from the survey responses alone.

consumption due to increasing share of electricity-price-dependent heat production. Better preservation of roundwood in storage was one of the reasons 11 respondents expected the share of roundwood in consumed forest chips to increase in the coming years. A notable advantage of roundwood chips is the lower harvesting costs per cubic metre, and one respondent argued that it would be difficult to meet the required increased volumes of harvesting energy wood for forest chips only from logging residues or logging sites of small-diameter trees. Additionally, a total of nine respondents identified increased energy wood prices as one of the main factors limiting the competitiveness of forest chips. In some smaller plants, which are not part of the emissions trading system, it was reported that this situation had led to an increase in energy peat consumption.

Based on this study's results, wood combustion in energy generation will also be influenced in the future by the hydrogen economy and targets aimed at capturing the biogenic carbon dioxide released during combustion, which can be stored (BECCS) or utilised (BECCU). Some respondents mentioned the recovery of waste heat from hydrogen electrolysers to reduce the consumption of forest chips. However, green hydrogen electrolysers operating in conjunction with larger heat-only and CHP plants are expected to be deployed closer to 2033. It was also mentioned that if the economic viability of BECCU was high, it might increase the profitability of wood combustion and reduce the incentive to pursue alternative energy generation. In contrast with BECCU, investment plans in BECCS were not mentioned in the responses.

Discussion

The future of forest chip usage

The predicted consumption of forest chips in 2026 and 2033, as outlined in this study, is aligned with the findings of previous studies such as Ranta et al. (2020), Lehtilä et al. (2021), AFRY (2021), and Koljonen et al. (2024). These studies indicated that forest chip consumption in Finnish energy generation will remain at a high level in the near future. Additionally, these results are also reflected from a pan-European perspective by Zappa et al. (2019), whose findings concluded that a 100% renewable European power system cannot be achieved without biomass. Conversely, the results of their study suggest that the use of solid biomass and biogas should be increased. Although the importance of forest biomass in energy generation is substantial in Finland compared to many other countries, the results of this study may help other countries prepare for possible changes in the energy use of forest biomass.

However, according to the results of this study, forest chip consumption is projected to decline between 2026 and 2033. This development differs from the findings of Koljonen et al. (2024), who suggest that the consumption of domestic forest chips will continue to grow in the 2030s and will not decline in any of the three scenarios presented in their study. However, there were differences in usage levels between the various scenarios, which were found to result from the development of the energy system. This observation is also consistent with the results of this study, which indicated that the future consumption of forest chips depends on how investments in alternative energy production methods are realised. In addition, the use of forest chips was influenced by the extent to which by-products from the forest industry were assumed to be directed towards raw materials for industrial production rather than for energy generation. As Koljonen et al. (2024), similar trend was also anticipated in the earlier study by Lehtilä et al. (2021).

The development of alternative energy generation technologies

The results of this study conclude that the green transition in the energy sector is underway. The phasing out of peat consumption for energy was identified as one of the key factors contributing to the increase in forest chip consumption by 2026. Additionally, new investments aimed at improving energy efficiency or transitioning to electricity-based heat generation were found to be the most common drivers of changes in forest chip consumption, altering the role of wood energy as an energy source. As previous studies by Elberry et al. (2021) and Weiss et al. (2021) have shown, wind – and solar-based electricity generation is typically concentrated between spring and autumn. Greater balancing power capacity will be needed as the use of these weather-dependent production methods increases (Hirth and Ziegenhagen (2015)). In the past, energy peat and fossil fuels have been crucial sources of energy used to balance electricity and heat production during periods of high energy demand. However, alternative solutions are required to reduce their consumption.

The findings of this study support the view that forest chips are considered one of the key energy sources that will help balance the energy system in the near future. The benefits of biomass as an energy system stabiliser were also highlighted in a study by Jåstad et al. (2020). Furthermore, the development of energy storage solutions during periods of low demand should be prioritised. In addition to battery solutions and other technologies, green hydrogen production has been identified as a potential alternative (Elberry et al. (2021)). The results of this study indicate that forest chip consumption is expected to decrease, particularly in larger heat-only and CHP plants, while consumption is anticipated to increase in smaller installations. This may be due to investments in new energy generation technologies, which are primarily being made or planned by larger companies due to their greater resources for new investments.

Additionally, the increased fluctuations in the volume of forest chip usage, driven by electrification of heat production, are expected to extend the storage times for energy wood. As previous studies have demonstrated, dry matter losses during roundwood storage are generally lower than those of logging residues (Jåstad et al. (2020); Erber et al. (2012); Filbakk et al. (2011); Routa et al. (2015)). Moreover, the dynamics in the wood market, along with costs of energy wood procurement, further support the energy use of roundwood. Energy wood prices have risen significantly in recent years due to the replacement of Russian wood imports and the phasing out of fossils and peat for energy use (Official Statistics of Finland (2024c); Viitanen et al. (2023)). Along with rising prices, the harvesting cost and supply volumes of energy wood have increased, making harvesting sites for larger roundwood harvesting more competitive compared to those for small-sized trees, due to higher harvesting yields (Viitanen et al. (2023)). From this perspective, the principle of cascading wood use defined in RED III (2023) may not be fully implemented in the coming years, and wood that can be processed in the forest industry will also end up being burned in the coming years. However, the increased demand for roundwood could be mitigated by enhancing the supply chain and storage of other alternative energy wood assortments, such as logging residues. On the other hand, the supply potential of logging residues depends on the amount of regeneration fellings in even-aged forestry.

Biogenic carbon dioxide capture

Many investment plans for the hydrogen economy in Finland are related to the energy use of wood, as this study's results have identified. From an economic return-on-investment perspective, larger heat-only and CHP plants, as well as forest industry mills' boilers, have been identified as a potential target due to the substantial amounts of biogenic carbon dioxide that can be captured. Bioenergy with carbon capture and storage (BECCS) technologies has been acknowledged as a potential solution for mitigating climate change, especially on these sites (Kujanpää et al. (2023); Lipiäinen and Vakkilainen (2021)). In recent years, these targets have been integrated into policy programmes at both the national and EU levels (Finnish Government (2023); European Comission (2024)).

As an alternative to BECCS, biogenic carbon from wood combustion could be captured and utilised (BECCU) as a raw material – for example, in hydrogen-based industries – to prepare a product such as synthetic methane that can be used as a fuel in sectors where complete electrification is difficult to achieve (Saeidi et al. (2014)). These objectives were also reflected in the survey responses regarding forest chip usage until 2033. The consumption of forest chips was expected to decrease due to waste heat recovered from hydrogen-generating electrolysers.

Ultimately, the impact will depend on which of the current investment plans materialise, and whether further investment plans emerge in the future. The final effect on replacing forest chip use also depends on the price of the biogenic carbon captured. The results of this study indicated that potential income from captured carbon would increase the competitiveness of wood combustion compared to other alternative energy sources. However, this outcome is considered unlikely, as Kujanpää et al. (2023) report a significant amount of available biogenic carbon in Finland, and no competition between BECCS and BECCU is anticipated.

While the solid wood fuel consumption and availability of biogenic carbon remains high, a possible way to achieve climate benefits alongside emission reductions and biological carbon sinks could be to promote greater implementation of BECCS. Negative emissions have also been recognised as crucial for achieving the EU's climate targets, as highlighted by Zappa et al. (2019). Although BECCS has been identified as a potential means to achieve climate benefits, the generation of investment is largely dependent on economic incentives (Rodriguez et al. (2021)). This is also reflected in the results of this study, where none of the respondents reported investment plans for BECCS.

Energy and climate policy

The political climate surrounding wood energy has been changing for some time. Attitudes towards the utilisation of wood in energy generation are more critical than before. The EU has begun to question the role of bioenergy as a solution for mitigating carbon dioxide emissions and has imposed more climate and biodiversity-based restrictions on bioenergy use in the updated Renewable Energy Directive 2023/2413 (2023), for example. The current political trend is also reflected in energy policy, as the EU launched the REPowerEU plan (2022), which aims to promote energy independence and clean energy production. Instead of bioenergy, a key part of the plan is to increase the use of renewable electricity generation such as wind and solar power. Finland's targets are aligned, as Prime Minister Petteri Orpo's government programme (2023) includes the goal of replacing fossil fuels with electricity-based heat production by 2030.

The previous national political aims to increase forest chip consumption in energy generation are partly contradictory with Finland's current climate targets. Prime Minister Sanna Marin's government (2019) set an objective for Finland to achieve carbon neutrality by 2035, which was confirmed in the Climate Act 423/2022 (2022). The carbon sink of the land-use sector, primarily composed of forests, is considered crucial to achieving this objective, and target values have been established. Several studies indicate that the carbon sinks of Finland's land-use sector will not reach the level required to meet the carbon neutrality target under current harvesting volumes (Forsius et al. (2023); Hyyrynen et al. (2023)). Additionally, the calculations by Koljonen et al. (2024) estimated that Finland will not achieve carbon neutrality without additional measures, as emission reductions and carbon sinks have not progressed as anticipated.

The direct burning of roundwood also increases forest harvesting volumes and reduces the amount of carbon sequestered in forests. The climate benefits of using roundwood for energy are also lower than those of rapidly decomposing logging residues (Jåstad et al. (2020); Gustavsson et al. (2015)). Based on the findings of this study, the pressure to harvest roundwood directly for energy purposes may not decrease significantly in the next decade. According to several studies, this impact seems to outweigh the climate benefits of substituting fossil fuels (Kallio et al. (2013); Kunttu et al. (2021); Soimakallio et al. (2016)). On the other hand, increasing the share of renewable energy by promoting the use of forest chips was a policy objective in the past, and current levels of use are specifically a consequence of these objectives (Finnish Council of State (2008); Ministry of Agriculture and Forestry in Finland(2015)). The results of this study indicate that the direction of development does not change immediately.

The desire to decrease forest harvesting volumes has led to proposals for imposing taxes on wood combustion in larger heat-only and CHP plants, which, if implemented, could reduce the use of wood fuels and increase energy production from electric boilers and heat pumps (Muilu et al. (2024)). Additionally, previous studies have identified the impact of the price of emission allowances on the use of wood fuels for electricity and heat generation, as well as on the adoption of alternative energy sources to wood (Jåstad et al. (2020)). Although some respondents raised concerns about the uncertainties surrounding the future consumption of forest chips in the current political environment, this study does not directly account for potential future political decisions such as biomass taxes affecting wood combustion, as the estimates are based on survey responses.

However, the study by Jåstad et al. (2020) identified that reducing fossil fuel emissions from energy generation would be more expensive without wood energy in Northern Europe. They also argue that in countries such as Finland and Sweden, where the consumption of solid wood fuel for heat and power generation is high, reducing the use of wood chips in heat and power generation would potentially increase the price of heat and power significantly requiring investment, particularly in energy storage. However, in the longer term, as technologies develop, the use of biomass for energy may shift from electricity and heat production towards more advanced biofuels that can be used, for example, in road transport (Börjesson Hagberg et al. (2016)). This would be a positive development in terms of climate objectives, as biofuels for road transport are estimated to have the potential to achieve greater emission reductions than solid wood fuels (Jåstad et al. (2020); Börjesson Hagberg et al. (2016)).

Possible uncertainties in the results

There are still uncertainties about the results of this study. First, there is uncertainty in the consumption figures provided by the respondents, as the future consumption was estimated based on the current strategy or view of the companies. Future political or economic changes could not have been anticipated. Additionally, the consumption estimates of this study assumed that the weather conditions would remain the same as in 2023. Second, a potential source of uncertainty in this study's result is the inability to use energy peat consumption as an explanatory variable in the linear modelling of consumption projections. The statistical data used for modelling did not include information about energy peat consumption in 2023, and it could not be incorporated into the anonymised data. Additionally, variables such as region and plant size class were not statistically significant in modelling, probably due to the allocation of investments across different plants. Most of the volume in these total consumption estimates was still based on the survey responses, which reduces the importance of the modelled projections in the overall formation of the total consumption projections.

Conclusions

The results of this study suggest that forest chips will remain an important source of energy in Finland for at least the next decade. Globally, political objectives tend to aim at reduction of fossil fuels, and hence consumption trends may be similar in other countries that use forest chips.

However, as the use of fossil fuels and peat declines and electricity-based heat generation increases, this development will lead to greater variation in forest chip consumption. This variation will extend storage times and may result in higher consumption of roundwood for energy, thereby increasing roundwood harvesting volumes and possibly boosting the use of industrial roundwood in energy generation.

To mitigate the burning of industrial roundwood, the more efficient use of available logging residues and small-sized roundwood is crucial. In this context, improving the supply chain for logging residues and addressing the challenges associated to dry matter losses during storage may help to promote terminal storage. Additionally, alongside weather-dependent electricity, the development of energy generation technology should place greater emphasis on energy storage and, more broadly, on reducing overall energy consumption.

Although forest chips will continue to be burned in significant quantities, it is essential, for both climate and economic goals, that projects focusing on BECCU are implemented, while also exploring opportunities for BECCS. These two technologies are crucial for facilitating the transition to a renewable energy system and creating permanent carbon sinks. Ultimately, the operating environment – especially created by policies – plays a decisive role in the emergence and implementation of investment plans.

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CRediT authorship contribution statement

Tuomas Niinistö: Writing – original draft, Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization. **Perttu Anttila**: Writing – review and editing, Conceptualisation, Visualization, Methodology, Investigation. **Lauri Sikanen:** Conceptualisation, Methodology, Supervision, Resources, Writing – review and editing. **Kalle Kärhä:** Conceptualisation, Methodology, Supervision, Writing – review and editing. **Johanna Routa:** Conceptualisation, Methodology, Supervision, Resources, Writing – review and editing, Project administration.

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Data availability

The data on which this study and its results are based are confidential, and their publication is forbidden.

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