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Schedule for Reducing the Use of Peat and the Possibilities of Replacing It with Forest Chips in Energy Production in Finland

Tapio Ranta, Antti Karhunen, Mika Laihanen

School of Energy Systems, Lappeenranta-Lahti University of Technology (LUT), Lappeenranta, Finland
Email: tapio.ranta@lut.fi

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Abstract

Between 2018 and 2020, an average of 15 TWh of energy peat was consumed in Finland. Energy peat is used in 260 boilers in Finland, which produce district heat and heat and steam for industry, as well as electricity as cogeneration (CHP) in connection with district heating and industrial heat production. Peat accounts for 3% - 5% of the energy sources used in Finland, but its importance has been greater in terms of security of supply. With current use in accordance with the 2018-2020 average, the emissions from peat are almost 6 Mt CO_2 per year in Finland, which is 15% of emissions from the energy sector. In this study, the technical limitations related to peat burning, economic limitations related to the availability of biomass, and socio-economic limitations related to the regional economy are reviewed. By 2040, the technical minimum use of peat will fall to 2 TWh. The techno-economical potential may be even lower, but due to socio-economic objectives, peat production will not be completely ceased. The reduction in the minimum share assumes that old peat boilers are replaced with new biomass boilers or are alternatively replaced by other forms of heat production. Based on the biomass reserves, the current use of peat can be completely replaced by forest chips, but regional challenges may occur along the coast and in southern Finland. It is unlikely that the current demand for all peat will be fully replaced by biomass when part of CHP production is replaced by heat production alone and combustion with waste heat sources.

Keywords

Biomass, Supply, Market, Economics, Heat, Combined Heat and Power Generation (CHP)

1. Introduction

The continuing significant role of bioenergy in the increase in renewable energy has been identified in several studies. Bioenergy can provide flexibility services [1], be part of a polygeneration system [2], and allow for negative emissions [3]. In northern Europe in particular, the use of wood-based biomass in the energy sector will reduce the overall cost of energy production in the shift towards a carbon-free energy system [4]. Availability and price competitivity have been identified as challenges for increasing forest-based bioenergy, especially in retrofits from larger coal-fired power plants, but reduced system costs for the electricity generation system favour biomass-based electricity generation [5]. As a result, it has continued to be necessary for various EU countries to support bio-electricity production separately through tariffs and feed-in premiums. In heat production, the taxation of fossil fuels supports the use of biomass as a heating fuel [6]. The targeting of biomass to pure heating fuel reduces the local self-sufficiency of electricity generation and does not offer flexibility to the electricity generation system like cogeneration [7].

Based on the findings of the previous paragraph, this article investigates the possibility of replacing peat fuel with wood biomass in an effort to maintain the capacity of combustion products in the transition to carbon-free energy production in Finland. The main motive is to reduce CO_2 emissions because emissions from combusting peat require emission allowances, while wood biomass is considered emission-free. Over a period of one hundred years, the most significant emissions in the life cycle of peat use are caused by the combustion or decomposition of peat in other uses. The choice of production area and its after-use also has an impact on emissions [8]. The benefits of biomass fuel described earlier are relevant in Finland and as a motive for increasing the use of biomass. Peat is now used as fuel for energy production in only a few EU countries, Finland being the most significant, with Ireland, Sweden and the Baltic countries also being producers and users of peat. Energy peat is being phased out in Finland and Ireland, and horticultural and livestock peat is being produced in the Baltic region. In Sweden, the role of peat in energy production is very marginal, at less than 1% [9].

The energy use of peat in Finland peaked in the 21st century, when peat was burnt for a maximum of almost 30 TWh per year, which corresponded to about 7% of Finland's total energy consumption. In the 2010s, the annual energy consumption of peat in Finland decreased to less than 20 TWh and less than 5% of total energy consumption. The government aims to halve the use of energy peat in Finland by 2030 compared to the current level of 15 TWh (average in 2018-2020). With the current use in accordance with the 2018-2020 average, emissions from peat are almost 6 Mt CO_2 per year in Finland, which is 15% of emissions in the energy sector and 11% for all sectors [10]. The amount of peat production area does not currently limit the use of peat, whereas producers are taking measures to adapt to the decline in demand. The majority of peat is used in Finland for energy production. In addition, peat is used as horticultural and livestock peat, for example as a growth substrate and as animal bedding. The production of energy peat supports the use of peat for these other uses since it is harvested from the same production areas. The production of horticultural and livestock peat in Finland is about 2 million m^3, which is just over 10% of the amount of energy peat used in the corresponding period [11]. Globally, about half of the use of peat is for energy use and half for other uses. Thus, the energy use of peat is declining, but global demand for horticultural and livestock peat is expected to grow, which could lead to an increase in the global peat market [12].

The use of peat and the associated emissions from its combustion have varied considerably between 2010 and 2020. In 2020, the use of energy peat decreased by 25% compared to the previous year, which was explained by a significant decrease in separate electricity production, excise tax increases on fuels at the beginning of the year, and higher prices for emission allowances. The decline in peat consumption has continued in 2021, by 14% compared to the previous year, accounting for 3% of total energy consumption. Peat production volumes have been lower than consumption in recent years, with the exception of the summer of 2018. Peat can be stored for two or three years, as opposed to biomass for a maximum of one year. For peat production, annual variation is even higher than consumption due to weather conditions in summer (**Figure 1**). Energy peat production has fallen even more than consumption in 2021, when only 2.8 TWh was collected. Security stock levels for peat have also fallen to exceptionally low levels: 0.7 TWh in 2021. The typical year-on-year inventory level has been 10% of annual consumption.

Peat is typically used in Combined Heat and Power (CHP) plants (**Table 1**). Smaller Heat-Only Boilers (HOBs) typically use forest chips and still some oil as a reserve fuel. A reduction in the use of peat has occurred especially in CHP plants for the reasons mentioned above. The share of peat in fuels for heat and

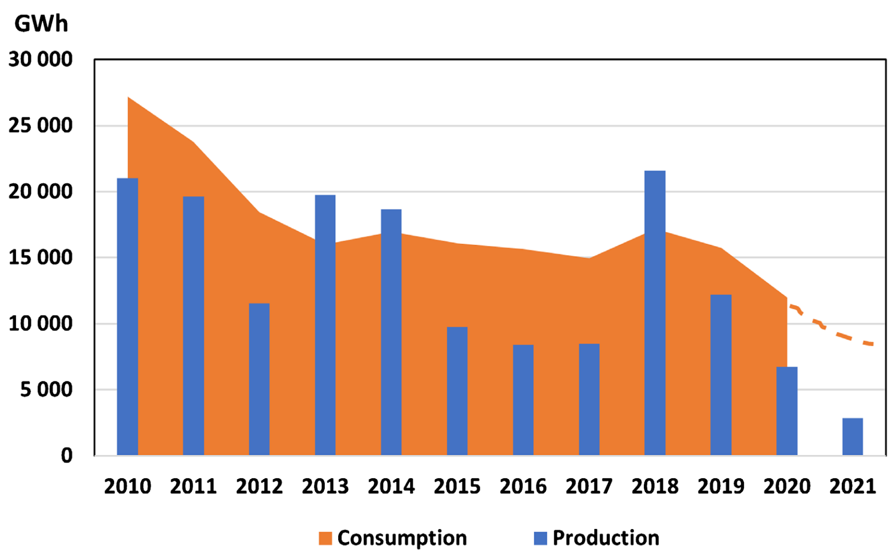

Figure 1. Energy peat annual consumption and production [13].

Table 1. Peat use (GWh) by plant type in 2018-2020[a] [14].

Type	2018	2019	2020	Total	%
CHP	14113	12568	9079	35,760	83
HOB	2348	2439	2391	7178	17
Total	16,461	15 007	11,470	42,938	

[a]Condensate parts produced in connection with combined heat and power production were included in CHP values.

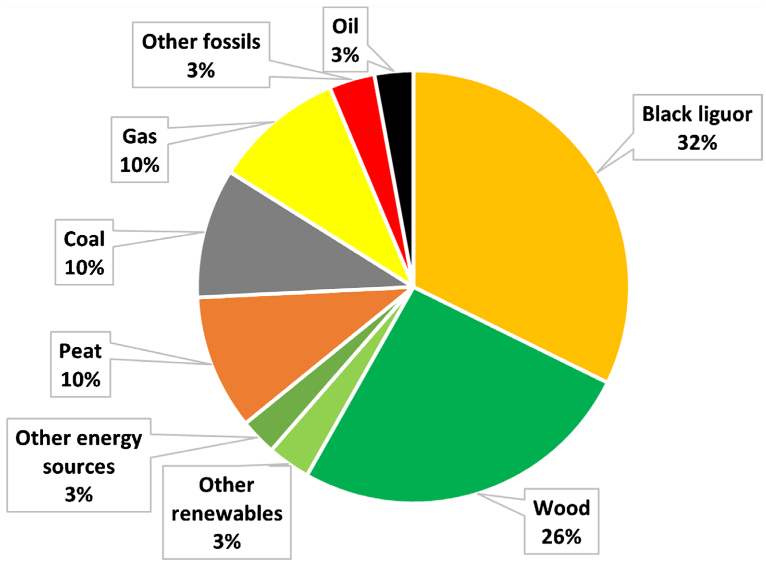

Figure 2. Electricity and heat production by fuel in 2018-2020[a] [14]. [b]Mixed fuels (such as recycled fuel) are divided into renewable and fossil fuels in relation to the fossil and bio-degradable coal contained in them. Other fossil fuels include blast furnace gas and coke oven gas and coke, and plastics fuels and other waste fuels and the fossil part of mixed fuels. Other renewable fuels comprise the bio part of mixed fuels and biogas. Other energy sources include hydrogen, electricity, and the reaction and secondary heat of industry.

electricity production has been 10% on average in 2018-2020, which is at the same level as coal and gas (**Figure 2**). Renewable fuels account for the largest share of 61%. Renewable fuels, mainly woody-based, are especially used in the production of industrial heat (77% in 2020), where black liquor from the forest industry alone produces 54%. Renewables accounted for 56% of district heating production and peat 13%. Renewables here include the utilisation of waste heat with flue gas scrubbers and heat pumps, which has clearly increased in recent years.

The competitiveness of forest chips in relation to peat is affected by the price of fuel, taxation and the price of emission allowances (EUA). Taxation of peat in heat production differs from other fuels in that its use is subject to an excise tax instead of energy content and carbon dioxide tax. As a result, the tax paid by peat, €5.7/MWh, is very low compared to other taxable heating fuels. The tax on peat is lower in CHP production because fuels are tax-free in electricity production. Here, a statistical power-to-heat ratio of 0.367 was used [15]. At present, the fuel cost of peat is double that of forest chips, mainly due to the increase in the price of emission allowances (**Table 2**). The price of the emission allowances in the calculation was €80/t CO_2. As a result, peat is no longer a competitive fuel and is being replaced by biomass or other forms of heat production. Peat remains competitive in small plants that do not have to pay fuel tax (peat fuel consumption < 10,000 MWh/a in 2022-2026 and <8000 MWh in 2027-2029) and are not covered by the emissions trading scheme (plant capacity < 20 MW).

2. Material and Methods

2.1. Factors Contributing to the Reduction of Peat Use

The replacement of peat with forest chips can be considered through the technical minimum requirement of peat use in power plant boilers, and through the regional techno-economic availability of forest chips, as well as the socio-economic impact, which aims to reduce the regional impact of the reduction of peat production (**Figure 3**). In practice, the rate of decline in peat use is the result of a combination of these factors. This study examined how and in what timeframe peat can be replaced by biomass, taking into account these three factors. The

Table 2. Current (2022) fuel cost by fuel and plant type (€/MWh).

Fuel	Price[a]	Tax[b]	EUA[c]	Total
Biomass (HOB/CHP)	24.3	0	0	24.3
Peat (HOB)	13.0	5.7	31.0	48.2
Peat (CHP)	13.0	4.2	31.0	49.7

[a]Energy prices. Official Statistics of Finland. Available from: https://www.stat.fi/til/ehi/2021/04/index_en.html; [b]Tax rates on electricity and certain fuels as of 1 January 2021. Available from: https://www.vero.fi/en/businesses-and-corporations/taxes-and-charges/excise-taxation/sahko-ja-eraat-polttoaineet/Tax-rates-on-electricity-and-certain-fuels/; [c]European Allowance (EUA) prices in the EU Emissions Trading Scheme. Available from: https://sandbag.be/index.php/carbon-price-viewer/.

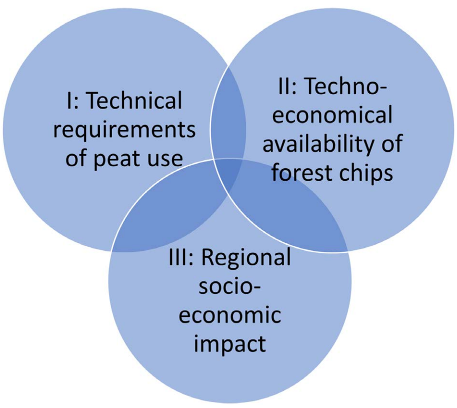

Figure 3. Factors contributing to the reduction of peat use.

technical operating minimum comes from the characteristics of the boiler type using the peat as well as the competitiveness of the peat fuel against forest chips. The location of the boiler in relation to forest chip reserves determines the techno-economical availability of forest chips. The reduction in the use of peat has regional socio-economic effects, such as increased unemployment for peat entrepreneurs and a weakened regional economy. The reduced security of supply should also be taken into account when assessing the rate of decline in the use of peat.

2.2. Technical Requirements of Peat Use

Peat is typically used in multi-fuel boilers, where various biomass fractions are most used in boilers in addition to peat. New boilers are usually designed to use 100% woody biomass fractions, but older boilers often have limits on fuel proportions. Peat contains sulphur, which is necessary to a small extent to prevent corrosion of the boiler caused by the chlorine contained in several biomasses. This sets a restriction on the share of wood fuels and the technical minimum use of peat for older multi-fuel boilers to prevent corrosion. In addition, when the calorific value of peat is higher than that of forest chips, in boilers dimensioned for peat, the peak output can decrease when using biomass alone. In addition to hot corrosion, increasing the proportion of wood can cause the fouling of heat transfer surfaces, an increased need for soot, an increased need for bed sand replacement, increased internal load and higher flue gas volumes, leading to lower steam production. Typically, it is necessary to combust some 20% - 30% of peat, or a similar proportion of other sulphur-containing fuels or sulphur inject systems in a power plant boiler to prevent corrosion.

Due to the large difference in fuel cost between biomass and peat, investments in sulphur supply equipment, for example, are expected to be profitable in several boilers; thus, the technical minimum of peat use for boilers can be further reduced. In addition, the fuel consumption of heat production is expected to decrease with the proliferation of flue gas heat recovery systems in plants.

The determination of the technical operating minimum was based on a study by AFRY, which utilised a boiler database with 260 units using energy peat [16]. Boilers over 100 MW covered 73% of peat consumption based on Bubbling Fluidised Bed (BFB) or Circulating Fluidised Bed (CFB) boiler technology, although these accounted for only about 17% of the number of boilers using peat [16]. The study was limited to boilers with a fuel output of more than 3 MW and whose use requires peat. In this case there were 48 boilers, based mainly on the size range of 20 - 100 and BFB technology (**Table 3**). In practice, there are more boilers that use peat, especially in the size range of 3 - 20 MW. Newer boilers do not require the use of peat, and smaller boilers (3 - 20 MW) can typically burn 100% of either wood or peat.

2.3. Techno-Economical Availability of Forest Chips

The availability of forest chips to replace peat was examined based on AFRY's

Table 3. Number of boilers by size class and type [16].

MW	n	BFB	CFB	Other[a]
3 - 20	3	1	-	2
20 - 100	20	17	2	1
100 - 250	13	9	3	1
>250	12	6	5	1
	48	33	10	5

[a]The other category consists mainly of grate boilers.

wood market model, being a linear optimisation model, which optimises biomass flows (forest industry by-products and forest chips) from each supply unit to each end-user within the limits set on an annual basis [17]. The optimal solution for the model is a state of equilibrium between supply and demand, where no buyer can buy wood at a lower price, or no seller can sell wood at a higher price. The transition from peat to wood biomass is assumed to take place when wood biomass is cheaper to use than peat. Operating costs take into account the price of fuel, taxes and the price of emission allowances. The basic assumption of the model is that the market is complete, resources are optimally allocated between users based on price, and the supply potential of forest resources can be mobilised efficiently, as end-users' ability to pay for wood fuels allows. In reality, there is at least a temporary imperfection and inefficiency in the wood market. An example of market imperfection is the diverse motives of strategic wood procurement and forest owners in wood sales decisions.

The wood biomass payment capacity of energy production plants was determined by the alternative fuel of the plants. For most energy plants using woody biomass, the alternative fuel is peat, where the ability to pay for woody biomass has traditionally been determined by the cost of peat. However, if the cost of peat increases significantly, imported wood chips or pellets will be the preferred option for domestic wood biomass.

Regarding the domestic supply of energy wood, LUKE's estimates of the forest wood supply potential and its regional development were utilised [18]. The potential supply was based on the largest round wood harvest that can be maintained. Between 2026 and 2035, it is estimated to be 79 million m^3. As an alternative scenario, an option based on an assumed harvest level of 65 million m^3 was assessed. In 2018-2020, the annual harvesting of round wood has varied between 58 and 69 million m^3 [19]. Energy wood potential estimates were made geographically for four regions (southern, western, eastern, northern) separately and two periods (2016-2025, 2026-2035) [17]. The energy wood potential consisted of logging residues, spruce stumps, harvesting wood and small-diameter energy wood. The difference between assumed and potential felling will increase in the latter period in Finland (**Table 4**). At the national level, the energy wood potential based on assumed felling in the period 2016-2025 is approximately

15% lower than the potential felling based on the maximum felling level that can be maintained, and the potential based on assumed felling in the period 2026-2035 is approximately 20% lower. Compared to the current use of energy wood (16.2 TWh in 2020), its potential is threefold with potential felling.

A baseline and maximum scenario were defined for energy wood demand [17]. The baseline scenario describes the assumed scenario to be the most likely at the moment, and the maximum scenario is the possible higher scenario of energy wood demand. In the baseline scenario, combustion-based district heating production will decline moderately as heat pump and waste heat solutions become more common as a replacement technology. District heating CHP plants that use fossil fuels or are nearing the end of their service life will be largely replaced by separate heat production using wood biomass. In industrial sites, CHP production is estimated to be profitable and CHP plants will be modernised mainly with CHP production using wood biomass. In the maximum scenario, heat pump and waste heat solutions are not as widespread in district heating production. District heating CHP plants that use fossil fuels or are nearing the end of their service life will be largely replaced by new CHP production using wood biomass. CHP production is also expected to be profitable at industrial sites, and CHP plants will be modernised with CHP production using mainly wood biomass.

The parameters used in the calculation are shown in **Table 5**. A higher emission allowance price was used in the maximum scenario. The values in **Table 5** describe the situation in 2035. Biomass and peat prices are slightly higher than at present. The price of electricity and the prices of emission allowances are lower than the current exceptionally high ones, which are expected to fall to lower levels. District heat production is expected to remain at its current level. There is an annual variation in the production of district heat, and in cold winters fuel consumption can increase by about 10% compared to the average year. For the coldest few months, the change in demand could be as much as 20% - 30%. The

Table 4. Energy wood potential (1 Mm^3 = 2 TWh).

TWh	2016-2025	2026-2036
Assumed felling	39.2	41.4
Potential felling	48.2	55.0

Table 5. Cost parameters used in the demand scenarios in 2035 [17].

Peat tax	5.7	€/MWh
Emission allowance	40/60	€/t CO_2
Electricity price	40	€/MWh
Biomass price	25	€/MWh
Peat price	14	€/MWh
District heat demand	37	TWh

wood fuel payment capacity of the HOB and CHP plants was calculated according to Table 2, using the values in Table 5 for the price of peat, tax and the price of emission allowances in both scenarios.

2.4. Regional Socio-Economic Impact

As a domestic and storable fuel, peat is important for energy security, whereas the properties of forest chips do not support its storability. If the biomass is stored for more than one year, the storage must take place as unchipped round wood. Logging residues or chipped biomass are not suitable for short-term storage. The challenge for storage is fluctuations in moisture content and dry matter losses resulting from microbiological activity and mould. When peat is replaced by biomass, the fuel may still be domestic, but biomass storage and logistics are more challenging than peat. However, as the use of biomass increases, the import of biomass to Finland is also increasing, thus some of the replacement can take place with imported fuel. According to LUKE's statistical service, the share of imported chips is about 1.8 million m^3 (24% of total use), of which Russia's share is about 1.5 million m^3. In 2022, the import of wood chips from Russia suddenly ceased, and the use of peat will have to be partially increased to replace it. There are also weather risks associated with the harvesting of domestic wood, which occasionally affect the supply of wood. The availability of biomass also depends strongly on the activities of the forest industry, for example, as the biomass utilised in Finland is mainly forest chips and industrial by-products generated in connection with the activities of the forest industry.

The increasing use of forest chips poses challenges to the functioning and adequacy of supply chains (harvesting chains, the willingness of forest owners to sell energy wood and the capacity of storage terminals) and to the condition of the forest road network. The reduction or ending of energy use for peat also poses challenges to the security of supply and the continued availability of energy peat, when there are fewer peat producers. Peat plays a more significant role in the security of energy supply than its annual primary energy use (approximately 3% - 5% of the energy sources used in Finland). The rapid decline in the use of energy peat is leading to a rapid decline in security stocks. In this case, fuel stocks that are important for security of supply and delivery will be lost. There is no substitute storage policy for biomass fuels, which reduces security storage of fuels.

The law on secure storage also relates to the storage of energy peat. However, the legal guidance for peat is different because peat is a domestic fuel. The law encourages and allows storage rather than directly forcing it. To ensure availability for weather risks, the goal is to have sufficient peat storage that is equivalent to about six months of use at the start of the peat production season. The peat storage agreement is made between the National Emergency Supply Agency and the peat producer for three years at a time. Peat fuel in security storage can only be used during the contract period with permission from the National Emergency Supply Agency, which pays the security storekeeper compensation from the resources of the Security of Supply Fund for the actual security storage. The compensation partially covers the capital costs of storage and material losses incurred by the security storer. A security storage facility may be established by a supplier of fuel peat with an average supply of at least 100 GWh per year for the production of energy. Security storage has so far been rather modest at 2 - 3 TWh, since the law does not demand the collection of energy peat in security stocks. There is no security of supply procedure for livestock and horticultural peat similar to security storage for energy peat.

The peat sector is an important employer in sparsely populated rural areas. There are a few large peat-selling companies and 517 small entrepreneur-type companies in Finland [20]. According to the statistics, 442 companies operate in peat production and 75 companies in peat transportation. The practical work of peat harvesting in the production areas has been outsourced to machine and transport entrepreneurs. The risk of annual and cyclical fluctuations in peat production and partly also the financial risk of the entire industry is thus borne by small entrepreneurs. In many other countries (e.g. Ireland, Lithuania and Latvia), the peat production companies handle and are responsible for tasks that are performed by small contractors in Finland. Independent entrepreneurs take care of and are responsible for everything in terms of practical work, the rehabilitation of a new area suitable for peat production, the implementation and maintenance of environmental protection structures for the actual extraction of peat and aftercare work in the peat area, and the transfer of the area of land to a new end use.

From the point of view of security of supply, there is therefore a need to maintain a certain stock of peat and also to maintain production chains, as they cannot be put back into production after being shut down. In order to reduce peat production in Finland, a scrapping premium will be used until 2024. Aid for the scrapping of peat machinery may be granted for equipment used for the harvesting of peat, with the exception of pulling tractors. The scrapping aid is intended to indirectly help the controlled decommissioning of the peat sector in a socially fair way. This situation can cause problems for production opportunities where the market-based use of energy peat is reduced and infrastructure is eliminated.

3. Results

3.1. Technical Requirements of Peat Use

When older boilers reach the end of their technical lifetime (40 years) and they are replaced by new boilers or other production, the technical minimum use of peat in Finland as a whole will decrease. An estimated 27 boilers burning peat will be removed or replaced in the review period 2020-2040, *i.e.* well over half of all current boilers in this study [16]. It was estimated that the technical minimum requirements of peat use was already clearly lower than actual peat use in recent years. By 2030, the technical minimum use of peat is estimated to fall to 6

TWh, and by 2040 to 2 TWh [16]. The reduction in the minimum share assumes that old peat boilers will be replaced with new biomass boilers or are alternatively replaced by other forms of heat production. In Heat-Only Boilers (HOBs), fuel change can be done without corrosion problems due to lower boiler temperature and pressure, where no corrosive conditions occur as in CHP boilers. Also, Circulating Fluidised Bed Boilers (CFBs) built after the 21st century are generally designed to be able to combust 100% biomass. The decline in peat use could be even faster if maintenance investments were made in boilers that currently use peat to enable it to be phased out. Fuel cost between biomass and peat are expected to grow, which will accelerate investments in sulphur supply equipment in old peat boilers.

If all peat were replaced by biomass with the current energy use of peat being about 15 TWh, the demand would be the same for biomass, corresponding to about 7.5 million cubic metres of forest chips. This would mean doubling the use of forest chips, as in 2020 7.5 million cubic metres of forest chips were used for heat and power plant use [21]. However, it is unlikely that the current demand for all peat would be fully replaced by biomass. This is due to, among other things, investments in non-combustion heat production, the proliferation of flue gas heat recovery systems in new and old plants, and possibly also the development of district heating demand.

On the other hand, forest biomass is also used to replace other fossil fuels such as coal, natural gas and oil. Some of the CHP plants are likely to be replaced by separate heat production plants using biomass, which means that the plant does not consume fuel for electricity production. If all peat CHPs removed by 2040 were replaced by separate heat production, the need for fuel to replace peat would be reduced by about 3 TWh [16]. In that case, the demand for biomass would be 12 TWh, corresponding to about 6 million cubic metres of forest chips. Instead of combustion of biomass, industrial-size heat pumps have been increasingly used in district heating networks that utilise waste heat, for example by recovering heat from wastewater, sea water, flue gases and district cooling return water.

In 2019, about 10% of district heating was produced with waste heat (*i.e.* roughly about 3.8 TWh), and Finnish energy estimates that the share will rise to the level of 30% by 2030 [22]. Therefore, part of the heat production of peat plants could be replaced by electric heat pump solutions, in which case the need for biomass would not increase as much. Other non-combustion technologies include geothermal energy, solar thermal and heat storage to balance consumption and production. However, there are constraints on geothermal energy, as a densely populated urban area in particular may have constraints that prevent the use of geothermal heat, such as underground structures and groundwater reserves.

3.2. Techno-Economic Possibilities to Supply Forest Chips for Peat Replacement

In the baseline scenario, the use of peat will decrease significantly by 2025, when it is predicted that the use of peat will decrease to about 3.2 TWh from the current 15 TWh. In the maximum scenario, the corresponding use of peat is 1.7 TWh by 2025. By 2035, the use of peat will decrease to 2.3 TWh per year in the baseline scenario and to 1.1 TWh in the maximum scenario [17]. The use is below the technical minimum, so that the greater reduction in the use of peat is based on investments in existing plants that enable the use of woody biomass. As a result of the replacement of peat, the use of energy wood will evolve according to **Table 6**, decreasing further in the future when CHP plants are replaced by thermal plants and non-combustion production methods as industrial heat pumps, especially in the baseline scenario. The fuel consumption for heat production is expected to decrease with the proliferation of heat recovery systems for plant flue gases. It is assumed that a flue gas heat recovery system will be installed in all new and existing baseload plants that do not already have a heat recovery system. In the maximum scenario, it is assumed that CHP plants using peat will be largely replaced by new CHP plants using wood biomass, which is why the demand for energy wood is higher. Non-combustion solutions are also being deployed less than in the baseline scenario.

Table 6. Use of energy wood in alternative scenarios to replace peat [17] (1 Mm^3 = 2 TWh).

TWh	2025	2030	2035
Baseline scenario	10.2	9.8	6.8
Maximum scenario	11.0	11.2	9.6

Based on the scenario calculations, domestic forest chips would be sufficient to completely replace peat, especially with the maximum maintained felling level. Across the country, the possibilities for acquiring energy wood are higher than demand with the actual felling being 15.8 - 18.6 TWh (maximum baseline scenario) and the largest maintainable felling being 30.2 - 33.0 TWh [17]. In the regional analysis, the most challenging replacement is on the coast and in southern Finland, where the demand for forest chips exceeds the supply potential, in which case the deficit must be met with domestic chips from eastern Finland or imported chips from the Baltic States. In the vicinity of the largest users of forest chips and peat, demand may exceed energy wood supply. There is also the use of coal in this area, which is also replaced partly by forest chips. Potential biofuel refineries may also be major users of forest chips on the coast in the future. However, their potential supply of forest chips will focus more on imports to coastal facilities.

3.3. Socio-Economic Impact of Peat Replacement

The decrease in the use of peat affects the amount of labour required for peat production. The direct employment effect of peat production is currently 1300 person-years and, taking into account the indirect effects, about 2500 people in

Finland [23]. The supply chain of the peat industry thus employs about 1.8 times as many people as the industry's own employment [24]. During the year, however, the number of people employed in the supply chain is clearly higher, as a large proportion of those employed, especially in peat extraction, are seasonal workers. It is estimated that the number of person-years will decrease linearly as peat production declines [22].

As coal leaves the fuel mix, peat will become the only alternative fuel for biomass in multi-fuel boilers, highlighting its importance for security of energy supply. Because peat and biomass are typically used in the same boilers, from an energy availability perspective, peat balances the challenges of biomass availability. Reducing the use of peat affects security of energy supply. The availability of the remaining biomass varies from year to year depending on natural phenomena, which makes security of supply difficult. The cessation of imports of wood chips from Russia will also affect the growing role of peat in maintaining security of supply.

If about 10% of the current use of peat and wood fuels in combined heat and power production (2018-2020) were covered by security of supply storage, it would require about 2.7 TWh of peat storage, especially now that wood chips import from Russia have stopped. In addition, peat is used in separate heat production, where its competitiveness is better if the plant is not covered by emissions trading and the use of peat is below the tax threshold. The use of peat in separate heat production was 2 TWh (2018-2020), which is expected to continue for the time being.

3.4. Development of Peat Use

The use of peat is expected to more than halve in the short term, as the government aims to achieve its targets by 2030 (Figure 4). On economical grounds, the use would be even lower than the technical constraints would require, which means that the necessary investments are being made to reduce the use of peat. The maximum scenario would accelerate investment with a higher price of

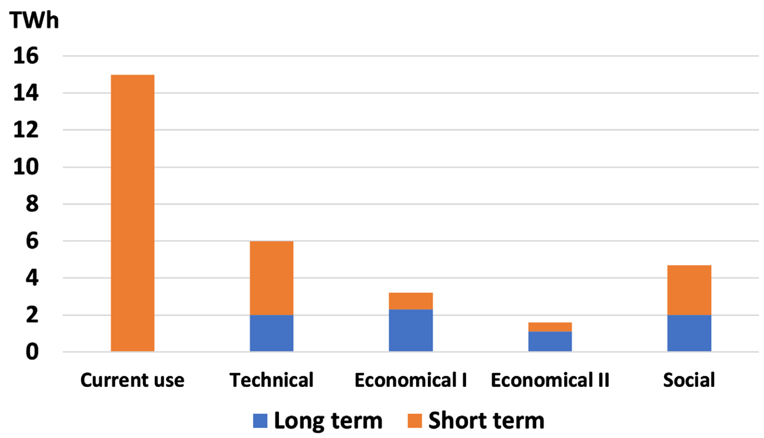

Figure 4. Future development of peat use according to different factors. Economical I = Baseline scenario; Economical II = Maximum scenario; Short term = 2020-2030; Long term = 2030-2040.

emission allowances. In the longer term, the difference between technical possibility and economical use of peat will level off as the power plant population is renewed. Socio-economic factors can also have a longer-term effect on maintaining the use of peat if the security of the supply of domestic fuels is to be ensured. Peat has a small role to play in this review, around 2 TWh, although the potential of wood fuels would allow all peat to be replaced.

4. Discussion

Based on the fuel cost level analysis, the use of peat would decrease to at least the same as or below the technical minimum level of the boiler stock (in which case investments will be made, for example, in the sulphur supply system). The use of peat could fall much faster, e.g. due to the climate targets of energy producers and the reduced competitiveness of peat due to the increase in the price of emission allowances. The remaining use of peat is largely based on maintaining the security of supply, with an emphasis on the socio-economic dimension. The use of peat is maintained for the longest time in heat plants outside the emission trading scheme.

The study produced by the Bioenergy Association estimated that the total use of energy peat in 2030 would be 7 TWh, which is due to the assumed increase in the price of emission allowances [25]. The price of emission allowances used in the calculations was €30/t CO_2, which is lower than in the calculation used here. In light of current price developments, the higher price of allowances in the calculations is justified, leading to lower peat use. In the low-carbon scenarios, where carbon neutrality should be achieved in 2035, the energy use of peat is about 0 - 1 TWh in 2035 and in 2040 it stops completely [26]. In the scenario analysis, the energy use of peat ceases when the marginal cost of emission reductions was approximately €100/t CO_2.

Domestic energy wood potential is high enough to replace the use of peat. However, the energy wood potential does not equal the availability of forest chips harvested for the market. Also, the regional balance (demand vs supply) affects availability. The regional availability of forest chips has previously been assessed with the help of forest chip balance maps (demand vs supply) when doing the impact assessment of the Energy and Climate Strategy [27] [28]. In practice, part of the growth in demand can be arranged through national long-distance transport by trains or the import of forest chips by vessels in areas suffering from a deficit of biomass. In addition to the replacement of peat, factors that may increase the use of forest chips include the replacement of coal and the production of bioliquids. However, the replacement of peat is through the primary use of forest chips, due to the suitability of the plant population for it. The price of forest chips used in the scenarios (**Table 5**) is expected to increase as a result of increasing demand, but the development of the price of wood biomass was not modelled separately to assess the replacement of peat. This could be an interesting future research topic. However, the optimisation model takes into account the increase in the logistics costs of wood biomass locally and its effect on the supply price.

Although the production of heat is increasingly moving away from combustion-based solutions, Finland will still need significant amounts of fuel in both district heating and industrial energy production. Peat has accounted for 3% - 5% of the energy sources used in Finland, but it has been more important for the security of supply. Peat has also made it possible to ensure the operation of heat and CHP plants that use wood chips in situations where forest chips are not available, for example, due to work stoppages in the forest industry or weather conditions. When biomass replaces peat, the security of supply inevitably deteriorates. Replacing the use of peat with more electricity than biomass would reduce the energy system's dependence on biomass. In terms of security of supply, the challenges could then focus more on the electricity system, both in terms of production and electricity transmission.

Various surprising changes affect the availability of forest chips and the rate of peat abandonment, such as the cessation of Russian imports for round wood and wood chips, changes in forest industry production, sustainability restrictions on the use of forest biomass, and policy changes such as taxation and subsidies. Other factors contributing to the growth in the use of forest chips are alternative uses such as coal being replaced in energy production and biorefineries, or on the other hand, factors related to curbing the growth include the use of non-combustion technologies in heat production, such as increasing the use of waste heat and deep geothermal heat. These have an impact on the development of the use of forest chips, but their impact does not necessarily have such a significant effect on the short-term development of the use of peat, which is ultimately driven by climate policy.

There are few international examples of the abandonment of peat and its fair implementation, but coal is being phased out in Germany and Denmark, for example. A shift away from fossil resources is a similar matter, whether it is peat or coal. Jobs are region-based, at least to some extent, and the transition can affect regions, workers and society unequally. The transition mechanism set up by the EU aims to ensure a fair transition to a climate-neutral economy [29]. Its main objective is to alleviate the impact of the transition by financing the diversification and modernisation of the local economy and mitigating the negative effects on employment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Schipfer, F., *et al.* (2022) Status of and Expectations for Flexible Bioenergy to Support Resource Efficiency and to Accelerate the Energy Transition. *Renewable and Sustainable Energy Reviews*, **158**, Article ID: 112094.

https://doi.org/10.1016/j.rser.2022.112094

[2] Joelsson, J.M. and Gustavsson, L. (2010) Reduction of CO_2 Emission and Oil Dependency with Biomass-Based Polygeneration. *Biomass and Bioenergy*, **34**, 967-984. https://doi.org/10.1016/j.biombioe.2010.02.005

[3] Johansson, V., Lehtveer, M. and Göransson, L. (2019) Biomass in the Electricity System: A Complement to Variable Renewables or a Source of Negative Emissions? *Energy*, **168**, 532-541. https://doi.org/10.1016/j.energy.2018.11.112

[4] Jåstad, E.O., Bolkesjø, T.F., Trømborg, E. and Rørstad, P.K. (2020) The Role of Woody Biomass for Reduction of Fossil GHG Emissions in the Future North European Energy Sector. *Applied Energy*, **274**, Article ID: 115360. https://doi.org/10.1016/j.apenergy.2020.115360

[5] Keller, V., *et al.* (2018) Coal-to-Biomass Retrofit in Alberta—Value of Forest Residue Bioenergy in the Electricity System. *Renewable Energy*, **125**, 373-383. https://doi.org/10.1016/j.renene.2018.02.128

[6] Banja, M., Sikkema, R, Jégard, M., Motola, V. and Dallemand, J.-F. (2019) Biomass for Energy in the EU—The Support Framework. *Energy Policy*, **131**, 215-228. https://doi.org/10.1016/j.enpol.2019.04.038

[7] Lindroos, T.J., Mäki, E., Koponen, K., Hannula, I., Kiviluoma, J. and Raitila, J. (2021) Replacing Fossil Fuels with Bioenergy in District Heating—Comparison of Technology Options. *Energy*, **231**, Article ID: 120799. https://doi.org/10.1016/j.energy.2021.120799

[8] Väisänen, S., Silvan, N., Ihalainen, A. and Soukka, R. (2013) Peat Production in High-Emission Level Peatlands—A Key to Reducing Climatic Impacts? *Energy & Environment*, **24,** 757-778. https://doi.org/10.1260/0958-305X.24.5.757

[9] Soimakallio, S., *et al.* (2020) Turpeen Rooli ja sen Käytöstä Luopumisen Vaikutukset Suomessa. Sitra. https://media.sitra.fi/2020/06/31150012/turpeen-rooli-ja-sen-kaytosta-luopumisen-vaikutukset-suomessa-tekninen-raportti.pdf

[10] Greenhouse Gases. Official Statistics of Finland. http://www.stat.fi/til/khki/2020/khki_2020_2021-05-21_tie_001_en.html

[11] Korhonen, T., Hirvonen, P., Rämet, J. and Karjalainen, S. (2021) Turvetyöryhmän Loppuraportti. http://urn.fi/URN:ISBN:978-952-327-856-1

[12] World Energy Council (2013) Strategic Insight. https://www.worldenergy.org/assets/images/imported/2013/10/WER_2013_6_Peat.pdf

[13] Energy Supply and Consumption. Official Statistics of Finland. https://www.stat.fi/til/ehk/2021/02/index_en.html

[14] Official Statistics of Finland (2021) Production of Electricity and Heat. https://www.stat.fi/til/salatuo/index_en.html

[15] Keto, M. (2010) Energiamuotojen Kerroin. Raportti Ympäristöministeriölle. Aalto-Yliopisto, Espoo. https://www.ymparisto.fi/download/noname/%7BA6ABCFF7-55FA-412C-A0C7-FEE5CC0A2F24%7D/30744

[16] Selvitys Turpeen Energiakäytön Kehityksestä Suomessa. Raportti työ-ja elinkeinoministeriölle (2020). https://afry.com/sites/default/files/2020-08/tem_turpeen_kayton_analyysi_loppuraportti_0.pdf

[17] Metsähakkeen Kysynnän ja Kehitys ja Riittävyys Suomessa. Raportti työ-ja elinkeino-

ministeriölle ja Huoltovarmuuskeskukselle (2021). https://afry.com/sites/default/files/2021-05/afry_metsahakkeen_kysynnan_kehitys_ja_riittavyys_suomessa_loppuraportti.pdf

[18] Anttila, P., Nivala, V., Hirvelä, H., Laitila, J. and Sikanen, L. (2021) Metsähakkeen Riittävyys Energiaturpeen Korvaajana. LUKE, Natural Resources Institute Finland. https://jukuri.luke.fi/handle/10024/547499

[19] (2021) Commercial Fellings 2020. Natural Resources Institute Finland (Luke), Natural Resources Institute Finland. https://www.luke.fi/en/statistics/commercial-fellings/commercial-fellings-2020

[20] Official Statistics of Finland (2021) Structural Business and Financial Statement Statistics. https://www.stat.fi/til/yrti/index_en.html

[21] (2022) Wood in Energy Generation 2021. Natural Resources Institute Finland (Luke), Natural Resources Institute Finland. https://stat.luke.fi/en/wood-energy-generation-2020-provisional_en

[22] (2020) Hukkalämpöjen Hyödyntäminen. Toiminta Kaukolämpöyrityksissä Katsaus. https://energia.fi/files/5369/Hukkalampokyselyn_Yht

[23] Holm, P. and Tyynilä, J. (2020) Energiaturpeen Käytön Lopettaminen: Alan Yritysten Menetykset. Taloustutkimus Oy. https://www.koneyrittajat.fi/media/Julkinen/Liitteet/tiedoteliitteet/LOP_Turve%20II.pdf

[24] Valonen, M., Huovari, J., Sajeva, M, and Alimov, N. (2021) Turvetoimialan Aluetalousvaikutukset. https://www.ptt.fi/media/julkaisut/tyopaperit/ptt_tp203.pdf

[25] Bioenergiary (2018) Kotimaisten polttoaineiden toimintaympäristö ja käyttöarviot 2030 Saakka "Omaa Energiaa".

[26] Koljonen, T., *et al.* (2020) Hiilineutraali Suomi 2035—Skenaariot ja Vaikutusarviot. VTT Technology 366. https://www.vtt.fi/inf/pdf/technology/2020/T366.pdf

[27] Koljonen, T., *et al.* (2017) Energia ja Ilmastostrategian Vaikutusarviot: Yhteenvetoraportti. http://tietokayttoon.fi/julkaisu?pubid=16902

[28] Anttila, P., *et al.* (2018) Regional Balance of Forest Chip Supply and Demand in Finland in 2030. *Silva Fennica*, **52**, Article ID: 9902. https://doi.org/10.14214/sf.9902

[29] Public Register of Documents, European Parliament (2020) Proposal for a Regulation of the European Parliament and of the Council Establishing the Just Transition Fund. COM_COM(2020)0022. https://www.europarl.europa.eu/RegistreWeb/search/simple.htm?relations=DOSSIER%23%23COM(2020)0022