



Sustainability of forest energy in Northern Europe

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Extended summary

This report summarises the research-based results on the use of forest biomass for energy in Northern European conditions. It discusses the trade-offs and win-win situations of growing forests, sequestering carbon and using wood for energy production in an economically viable and ecologically sustainable manner. Several recommendations are given:

The current Nordic forest industry activities and use of wood residues for energy production offer environmentally and economically sound solutions, where forests produce a continuous sustainable flow of biomass while maintaining, or even growing the carbon stock at the same time. These systems can be further developed, and research should concentrate on finding optimal situations, where forests can fulfil their several roles.

- The role of forests in climate change mitigation is twofold:
 - 1) Forests store carbon and act as carbon sinks.
 - 2) Sustainably managed forests serve as a continuous source of biomaterials and bioenergy to displace use of fossil resources.
- Continuous growth of forests needs to be ensured by sufficient investments in forests. To benefit both the bioeconomy and climate change mitigation, forest management needs to be optimised for both sustainable flow of biomass and carbon stock maintenance.
- Short-term optimisation of using forests only as carbon sinks can lead to unsustainable forest management in the long run.

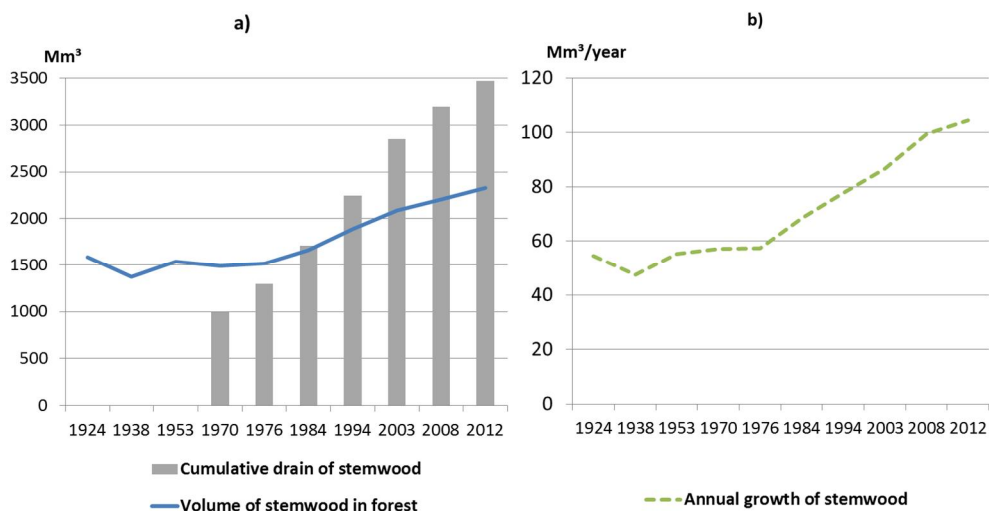


Figure ES1 Development of a) cumulative wood removal from forests (cumulative drain) and volume of stemwood in forests; b) annual growth of forests in Finland 1924–2012. Even if the cumulative amount of wood removed from forests (~3500 Mm³) is more than double the initial volume of wood (~1600 Mm³), the volume of stemwood in forests and the annual growth have been increasing.¹

The operational prerequisites of forestry must be maintained. Forestry should be considered from a long-term perspective, as the rotation period of a boreal forest can be even more than 80 years.

- In Finland, the development of forests has been inventoried since the 1920's, and the future projections show that the growth of forests as well as the total volume of trees growing in the forest will continue to increase.
- The increase in the growth rate of forests is a result of improving their age structure by harvesting and by effective sustainable forest regeneration and management efforts. If these activities would be halted the growth rate would eventually slow down.
- The EU-level policy frameworks and legislation should take into account the specific features of the forestry intensive Member States, and ensure the operational prerequisites for sustainable bioenergy production, which have been developed during decades of sustainable forest management.
- Wood-based bioenergy is the most competitive, when it is a by-product of the forest industry.

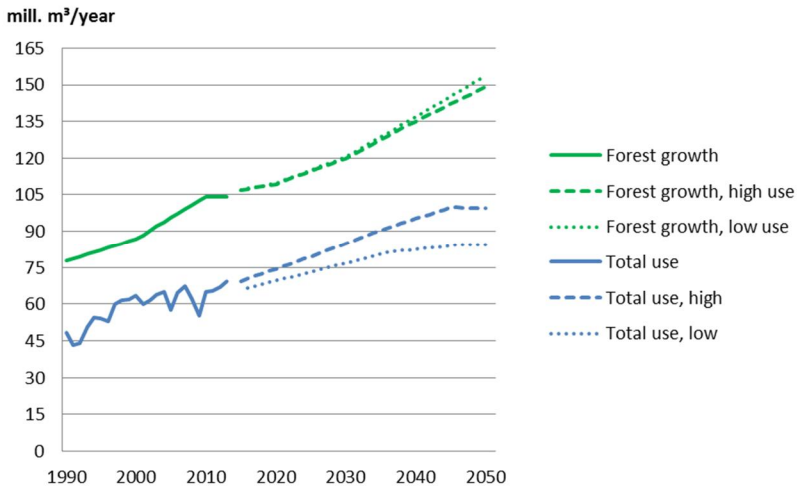


Figure ES2 Scenarios on the development of annual forest growth and use of wood in Finland. Solid lines show the realised growth and removals in 1990–2013 and dashed lines show the highest (high) and lowest (low) estimated growth and removals from the scenario results of the Low Carbon Finland 2050 project.² New pulp mill and biorefinery investments could significantly increase wood use. On the other hand, also the growth of forests could be boosted, e.g. by introducing species with high biomass production capacities or by fertilisation.

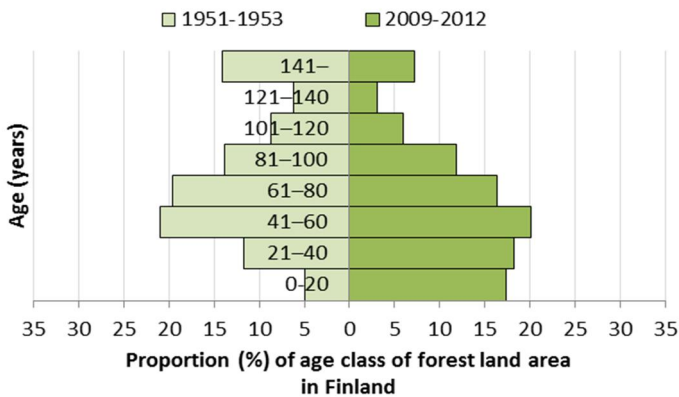


Figure ES3 The change in the age structure of Finnish forests. The current age structure supports the continuous growth of forests.³

To mitigate climate change, the use of residual forest biomass for energy production is the most beneficial forest energy option.

- In countries with significant forest industries, such as Finland and Sweden, a high share of forest energy comes from industrial and forestry residues. In 2014, around 25% of Finland's total energy consumption (372 TWh, 1 340 PJ) was produced with wood fuels (93 TWh, 333 PJ). 80% of Finnish wood-based energy was produced using by-products and residues from the forest industry and from silvicultural and harvest operations, of which 64% (61 TWh, 220 PJ) consisted of industrial residues such as black liquor, bark, sawdust and other wood residues, and 16% (15 TWh, 54 PJ) of logging residues, stumps and small-diameter trees combusted in combined heat and power (CHP) plants.
- Forest biomass is the most important renewable and domestically available fuel in many EU countries, which advocates its use for energy. However, there are trade-offs between harvesting and carbon sequestration: in the short-term, increasing harvest for bioenergy and other purposes reduces the net carbon sequestration into forests.
- On the other hand, management of forests increases their resistance against disturbances and stabilises the carbon stock.
- Using fast-decaying residual biomass either from harvests or from industrial processes is often a preferable option, as the residues would in any case release their carbon content quite rapidly if left to decay. Therefore, emission reductions can be reached already on shorter time-scales (e.g. 20 years). The use of growing forest biomass (e.g. roundwood) for energy usually creates emission savings only in the long run.

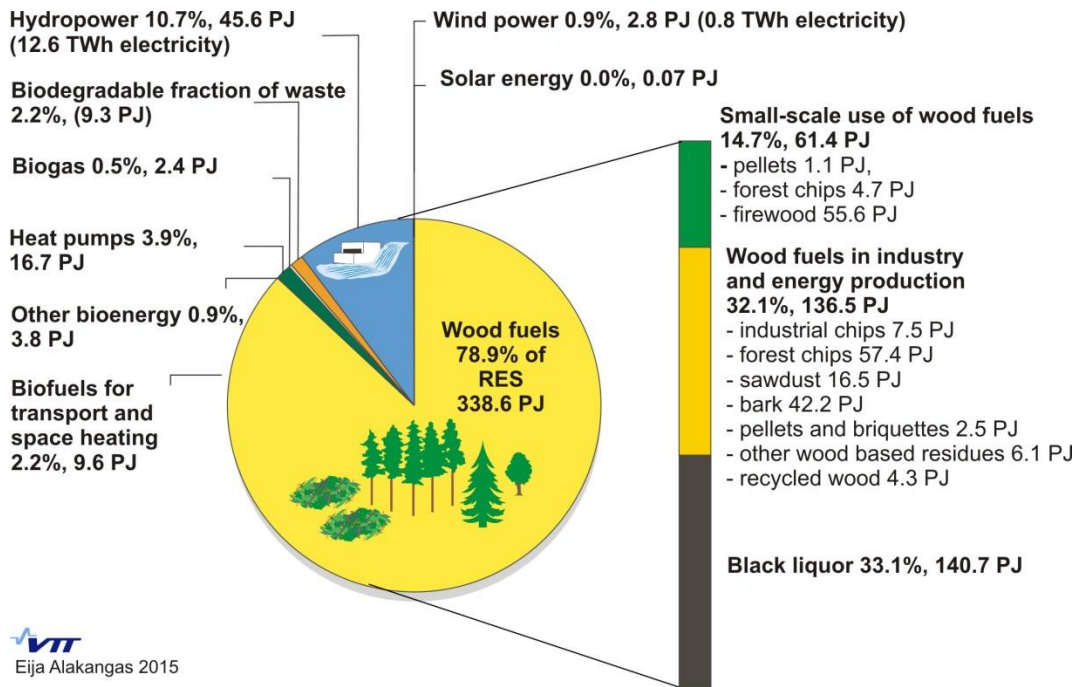


Figure ES4 Use of renewable energy in Finland at 2013.⁴

To mitigate climate change wood biomass should be used resource efficiently where high emission intensive, non-renewable products and energy sources are substituted or where carbon can be stored.

- The energy and material-efficient use of wood resources can be promoted in biorefineries producing high-value products, power, heat, and liquid and solid fuels with high overall efficiency. Long-lasting (e.g. decades) wood products act as carbon storages, and their demand should be boosted in order to increase production.
- In Finland, wood fuels are mostly converted to energy with high energy efficiency in CHP plants, where a total efficiency of 85% can be gained when heat is used. Wood can replace the use of peat and coal in multifuel boilers. Also, the integrated processes in pulp and paper mills gain an elevated self-sufficiency in energy use, or even an energy surplus.

International climate regulation should be based on verified emissions

- To quantify climate impacts of forest bioenergy, an accounting system based on the established IPCC framework would be preferable in future climate commitments instead of creating inconsistent frameworks within the EU climate policy.
- Analysis of carbon balances and warming impacts of alternative forest management scenarios are necessary for planning purposes, but international commitments and regulation should be based on verified emissions (ex-post).
- The accounting rules could also be a combination of verified emissions and projected politically negotiated baselines defining burden sharing between involved parties.
- For European and national 2030 and 2050 low-carbon policies, detailed climate, industrial, energy and economic analyses are needed. The policies, regulations and measures should take into account several elements and optimal road maps to ambitious targets supported by sustainable European forest management and investments.

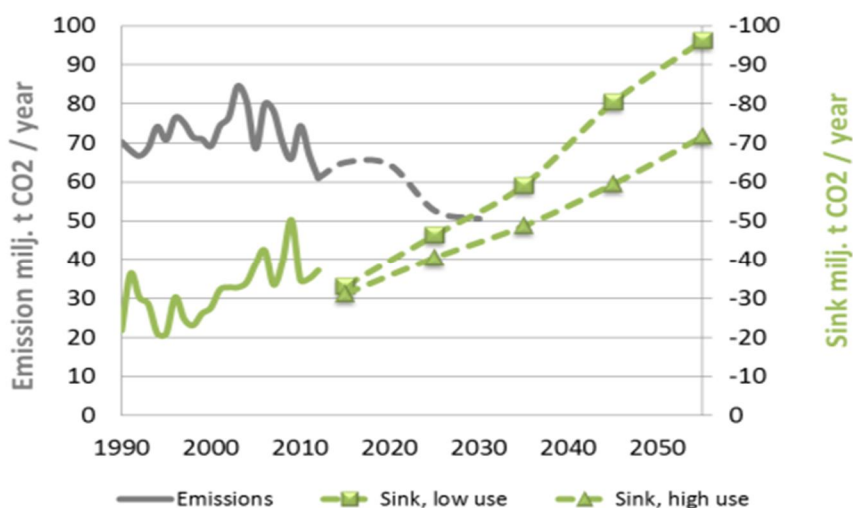


Figure ES5 The grey line shows the development of Finnish greenhouse gas (GHG) emissions excluding the land use sector (LULUCF) and the green lines present the forest carbon sink: past values (solid line) are from the Finnish GHG inventory⁶ and projections presented for low- and high-use scenarios (dashed lines) are from Low Carbon Finland scenarios². The forest sink may exceed the total GHG emissions after 2030–2040 when continuing sustainable forest management and forest and energy industry operations.

Careful management of forestry operations reduces ecological impacts

- Nutrient losses from leaching and harvest from forests can be reduced by good harvesting practises: a sufficient residue drying period on site for logging residues and delimiting of small-diameter trees for energy helps to return the nutrients to the soil before harvesting. For example, the Finnish silvicultural guidelines require leaving at least 30% of tops and branches on the harvest site.
- The reduced amount of dead wood in the forests can affect diversity of species dependent on it. Therefore it is important to recognise and protect the biodiversity hotspots and ensure that enough dead wood is left also in forests used for forestry.

Cascading use of wood should be considered from the perspective of the whole wood utilisation cycle.

- In the European bioeconomy, the role of the wood producing countries supplying virgin fibre differs essentially from the Central and Southern European consumer countries with more fibre recycling. As the fibre producing countries export a significant part of their wood biomass as pulp, paper and board, timber and plywood, a major part of the cascading cycles take place outside their borders.
- The optimisation of service life of wood fibres is important. However, cascading hierarchy should be applied prudently, considering national and regional circumstances. It may be very difficult to find a uniform principle for cascading use of wood that would lead to best possible solutions in countries with various circumstances.

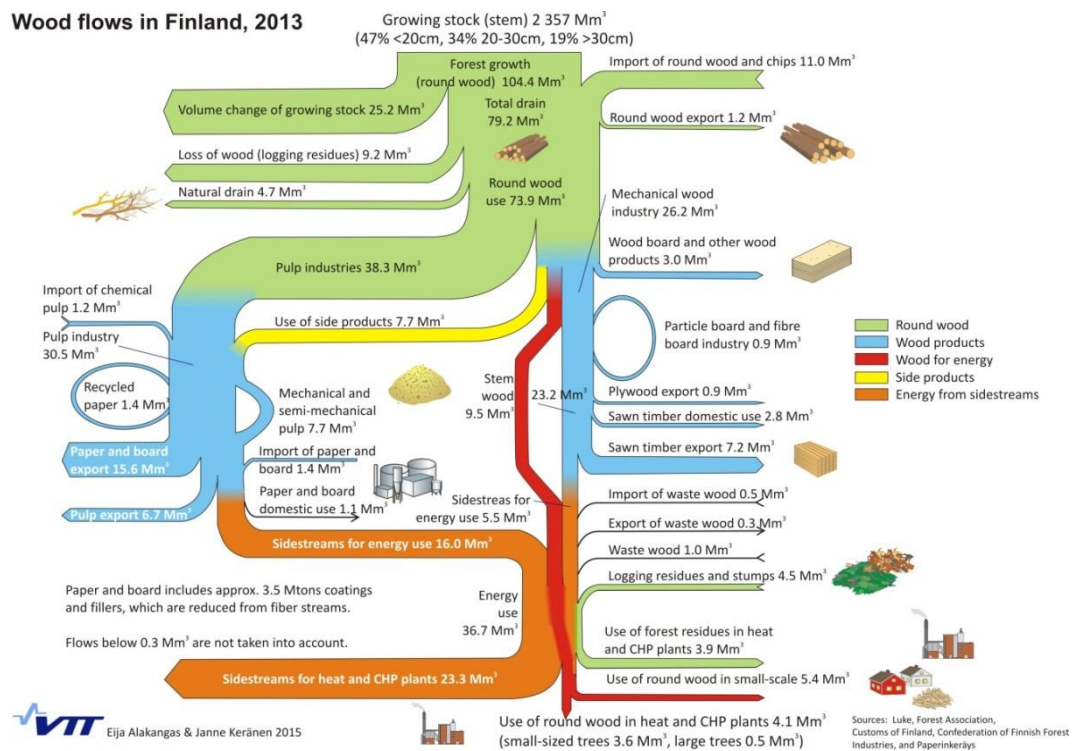


Figure ES6 Wood flows in Finland in 2013. Finland exports a large portion of produced wood products and thus the cascading cycles take place outside Finland.⁵

Preface

Increased demand for wood in the bioeconomy and bioenergy production means increased pressure on forest resources. Policies emphasising the targets for bioenergy, such as the European Union 2020 targets for renewable energy, have evoked concern on the sufficiency of biomass resources. As forests have multiple roles in supplying raw materials for industry and energy production, climate change mitigation, and in provision of ecosystem and recreational services, comprehensive assessments are needed to reach balanced and sustainable use of forests.

This report summarises the research-based results of the use of forest biomass for energy in Northern European conditions. It discusses the trade-offs and win-win situations of growing forests, sequestration of carbon and using the wood also for energy – in an economically viable and ecologically sustainable manner. The report is written by researchers of the ForestEnergy2020 research programme by VTT Technical Research Centre of Finland Ltd and Natural Resources Institute Finland (Luke). The project was funded by the Ministry of Employment and the Economy (steering group: Juhani Tirkkonen, Reetta Sorsa, and Hanne Siikavirta), VTT Technical Research Centre of Finland Ltd and Natural Resources Institute Finland (Luke).

The statements expressed in this report are from marked references or those of the authors, and do not necessarily represent the view of the Finnish Ministry of Employment and the Economy.

Espoo 6.11.2015

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Contents

Extended summary.....	3
Preface.....	11
1. Introduction.....	14
2. Forest energy as an integrated part of the forest industry.....	18
2.1 Forest resources and their use in the EU.....	18
2.2 Forest resources and their use in Finland	26
2.3 Future development of wood use and forest resources in Finland.....	31
3. Ecological impacts of forest energy production	37
3.1 Impacts due to wood harvesting.....	37
3.2 Controlling nutrient losses when harvesting logging residues	39
4. Forest biomass in climate change mitigation.....	43
4.1 Forests in the global carbon cycle	43
4.2 Climate impacts of using forest biomass.....	46
4.2.1 Climate impacts of wood use from growing stock	46
4.2.2 Climate impacts of logging residue harvest and use	49
4.3 Analysis of emissions from other life cycle phases	50
4.4 Other climate impacts.....	51
5. Perspectives on future regulation of forest energy.....	53
5.1 Climate policy regulation of forest bioenergy.....	53
5.2 EU Renewable Energy Directive	56
6. Cascading principle as a way to improve circular economy.....	60
7. Economics of forest energy.....	66
7.1 Forest biomass as part of the EU's and Finland's economies	66
7.2 Trade of wood for energy	68
7.3 Impact of EU 2030 climate and energy policies on the role of forest energy in the future.....	71

8. Conclusions and recommendations	76
Acknowledgements	80
References.....	81

Appendices

Appendix I: Finnish wood flows

Abstract

1. Introduction

Careful management and sustainable use of forest resources can lead to greater climate benefits in the long run by preserving forests as a continuous storage of carbon, and a source of renewable materials and energy.

Boreal forestsⁱ account for almost one-third of the world's forest cover⁷, and provide a variety of valuable, monetary and non-monetary, services. The Millennium Ecosystem Assessment⁸ has classified forest ecosystem services into four categories (Figure 1):

- 1) supporting services
- 2) provisioning services
- 3) regulating services
- 4) cultural services

Supporting and regulating services are crucial for life and they define the sound frontiers for human actions. Measured by monetary value the most important service has so far been the use of trees for provisioning services, i.e. wood products (sawn timber, pulp and paper), and for energy (in both liquid and solid forms). Though the importance of other provisioning services, e.g. picking berries and mushrooms can be remarkable for an individual actor or household, their market value altogether in the EU is only a fraction of the value of timber. However, the value of cultural services especially with respect to nature tourism can be substantial, e.g. in Finland the value added related to nature tourism was 42% of the value added of forestry and 17% of the value added of the whole forest sector in 2011⁹.

ⁱ The Boreal Region is found in the northern hemisphere, and in the European Union includes most of Sweden and Finland, Estonia, Latvia and Lithuania and much of the Baltic Sea. The dominant forest type contains a mixture of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) (EU Commission, Natura 2000 in the Boreal Region, ec.europa.eu/environment/nature/info/pubs/docs/biogeos/Boreal.pdf).

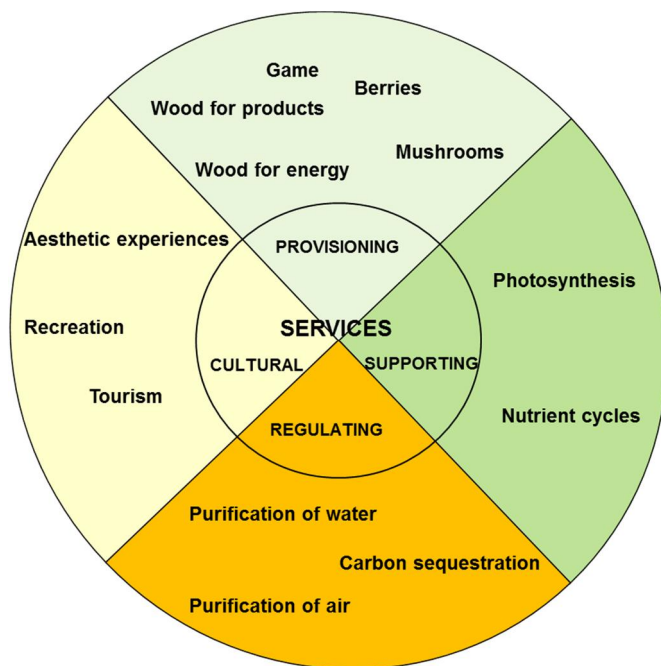


Figure 1 Forests provide several ecosystem services (Figure adapted from Millennium Ecosystem Assessment⁸).

Global warming scenarios suggest that boreal forests will enter a period of relatively rapid change. Climate scenarios predict that the temperature rise in Northern Europe could be even five to six degrees under continued high emissions (IPCC 2014)¹⁰, and that the boreal forest line will move north during the next century¹¹. The warming climate is predicted to increase growth of forests in northern regions, but also damage due to pests, fungal diseases and storms are foreseen to increase. By now, large natural disturbances such as wild fires are common, for example in Canada and Russia, but the damage caused by forest fires in Finland has been limited.ⁱⁱ

In order to efficiently mitigate climate change and to reduce its adverse impacts, drastic cuts in the anthropogenic greenhouse gas emissions are needed within the next decades. Increased use of forest and other biomass for energy has been identified as one of the central measures for climate change mitigation. However, during recent years, there has been a lot of discussion on the carbon neutrality of the use of forest biomass for energy by both policy-makers and scientists. Many

ⁱⁱ For example, in 2013 there were 1504 forest fires in Finland but the total burnt area was only 469 ha of the 23 million ha of forest land³. Storm damage occurred particularly during 2010, when in total 8 million m³ of wood was damaged, corresponding to 15% of annual harvest in Finland¹².

studies have pointed out that climate impacts of using boreal forest biomass for energy generation are not necessarily low^{13,14,15}. First, the use of biomass for energy causes an immediate release of carbon into the atmosphere, and this “carbon debt” is paid only when new trees grow sequestering the carbon back from the atmosphere. Second, leaving residual biomass in the forest instead of combusting it keeps carbon in the biomass longer and it is released only gradually when the biomass decays. Third, forests have an important role as carbon sinks in the mitigation of climate change. A concern has been presented, that the increased mobilisation of forest biomass for energy decreases the growth of forest carbon sinks and may in some cases even turn it into a carbon source.

However, short-term optimisation to use forests only as carbon sinks can lead to unsustainable forest management. In the long run, the use of forest bioenergy can provide a sustainable and secure source of renewable energy, despite possible short- to medium-term climate impacts. It has also been pointed out that forest management activities have largely been responsible for the present carbon stocks and high growth levels of Scandinavian forests. Studies have shown that the biomass production and output for energy production can be increased also in long-rotation forestry¹⁶. The volume of timber and thus carbon storage in the boreal (and also in the temperate) forests of the EU have been increasing rapidly despite growing use of wood for industry and energy. To plan for sustainable forest management, information from comprehensive analyses is needed. The energy and forest systems need to be assessed as a whole, in the context of evolving forest product markets, alternative policy options, and energy technology pathways¹⁷.

The European Union’s (EU) renewable energy policies aim to increase the use of renewable energy sources, reduce greenhouse gas emissions, diversify energy supply and reduce dependence on volatile fossil fuel markets. The emission trading system (ETS) is the main instrument in the EU aiming to reduce the GHG emissions. Its purpose is to decrease the competitiveness of fossil fuels and to increase the profitability of investments on renewable energy. However, lately the price of emission allowances has been so low that the system has not led to the desired outcome. The European Commission has established a market stability reserve in order to stabilise the development of the emission allowance prices and to improve the functioning of the market, starting from 2019. In addition, the EU Member States have set additional national bioenergy policies and sustainability criteria, which can differ significantly due to national conditions and priorities. Current policies support the EU climate and energy policy 2020 targets for renewable energy. The final aim of the EU climate policy is to cut greenhouse gas emissions by 80% by 2050 compared to the 1990 level¹⁸. According to the scenarios made, forest energy can have an important role in the path towards a low-carbon society, especially in countries rich in forestry, such as Finland and Sweden.

This report discusses forest bioenergy production from several viewpoints. First, development of forest resources in the EU and in Finland is presented, and a background for the discussion on how much and what kind of wood is used for

energy production is provided (Section 2). Second, ecological and climate impacts of the use of forest energy are discussed (Sections 3 and 4). Third, the role of forests in international climate policy and future EU regulations (Section 5), and the specific features of cascading use of wood in fibre producing countries (Section 6) are discussed. In addition, remarks on the economics and the future role of forest energy in low-carbon scenarios are presented (Section 7). Finally, the conclusions and recommendations concerning forest energy use are provided (Section 8).

2. Forest energy as an integrated part of the forest industry

2.1 Forest resources and their use in the EU

Forests cover 39 million km² (30%) of the Earth's terrestrial area. The share of the EU (EU-28) of this is 4.6%, i.e. 1.8 million km² (incl. other wooded land). This corresponds to 41% of the EU's total land area. Between the EU Member States the share of forest area ranges from 1% of Malta, 10% of Ireland and 11% of Netherlands, to up to 75% and 76% of Sweden and Finland (see Figure 2). Forest land area per capita is 0.36 ha in the EU. In the Netherlands, Belgium and the United Kingdom the average area is below 0.1 ha while in Finland it is 4.3 ha and in Sweden 3.3 ha. Lithuania and Estonia also have over 1 ha forest land per inhabitant.¹⁹

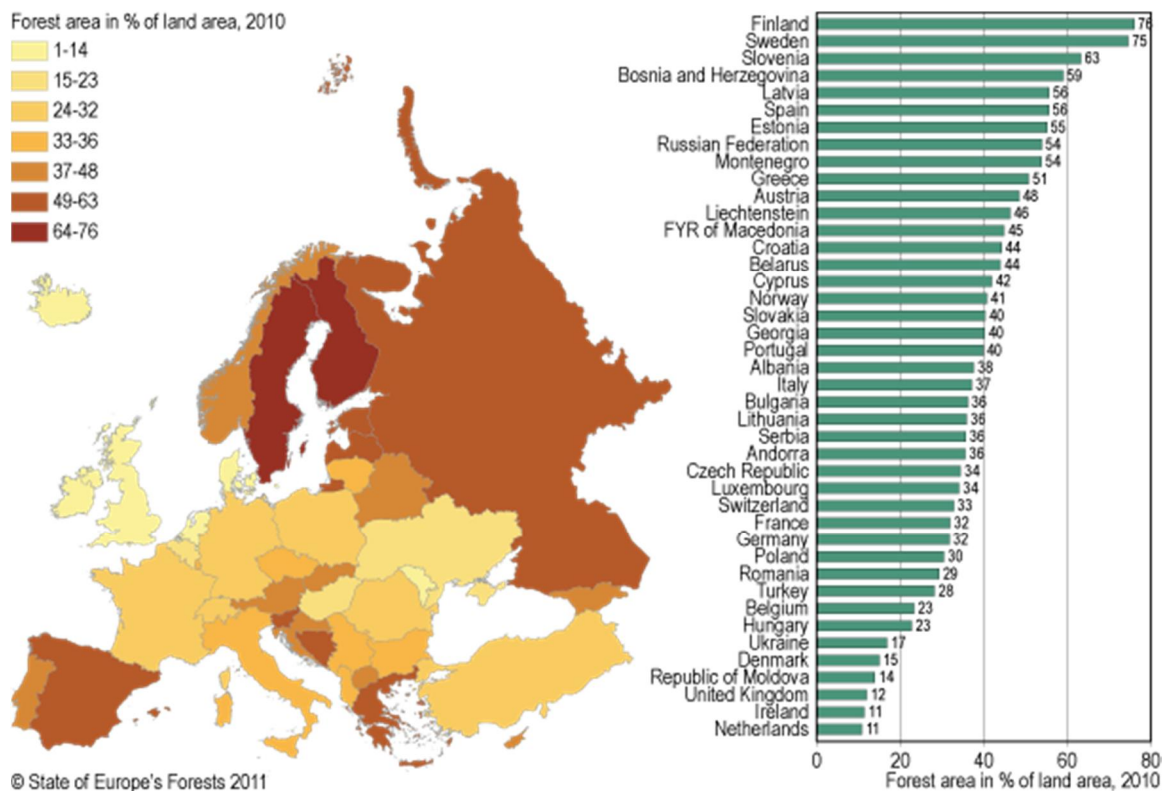


Figure 2 Percentage of forest area of land area in European countries (source: State of Europe's Forests¹⁹).

Half of the European forests are predominantly coniferous, a quarter predominantly broad-leaved and a quarter mixed forests. About 87% of the European forests are classified as semi-natural. Undisturbed forests and plantations cover only four and nine percent, respectively, of the forest area in Europe. Finland belongs to the boreal biome, and 90% of forest area is predominantly coniferous and 10% is broad-leaved. Similar forest types can be found in Sweden, Norway and Baltic countries. In addition, coniferous forests growing at high altitudes in Central and Southern EU have many similarities to the Finnish forests. Thus, the discussion presented in this report can apply to approximately over a half of the forested area in the EU, consisting mainly of coniferous forests.

Forest resources (both area and volume) have been increasing in Europe since the 1950s. Due to the afforestation and reforestation that has taken place after the Second World War, the age-structure of European forests has favoured growth: the mean age of forest decreased seven years from 67 to 60 years during 1950–

2010²⁰. This development results from forest management programmes run in many countries starting soon after the Second World War. The net annual increment (NAI, total increase of growing stock minus the losses due to the natural mortality) of stemwood in the EU is currently about 620 million m³/a. In recent years the stemwood removals have only been 60–70% of the net annual increment, resulting in increasing growth of forest reserves/stock. Besides the change of age structure, stand density and selective breeding, as well as increases in nitrogen deposition, carbon dioxide (CO₂) concentration and temperature, have beneficially affected the growth of European forests.

The forested area of Europe comprises 180 million ha, of which more than 70% is located in seven countries; Sweden, Spain, Finland, France, Germany, Italy and Poland. The largest forest resources among the EU Member States, as measured by area, are in Sweden (30.6 million hectares). In Spain there is 27.8 million ha of forest land, in Finland 23.1 million ha, in France 17.6 million ha and in Germany 11.1 million ha (**Table 1**). The average stem volume in the EU is about 155 m³/ha resulting in a total of 24 600 million m³ stemwood, of which 90.5% is growing on land available for wood supply. Measured as stem volume, Germany has the largest forest resource (3500 million m³) followed by Sweden (3 300), France (2 600), Poland (2 300) and Finland (2 200 million m³ in 2010 and 2 400 million m³ in the most recent inventory in 2015).

Finland and Sweden are the most forested countries in the EU. Three fourths of the land area of Finland, corresponding to 23.1 million hectares, is covered by forests (forest land and poorly productive forest). In addition, there are 3.2 million hectares of treeless or other sparsely stocked land areas (e.g. open mires, rocky grounds) as well as 0.2 million hectares of other forestry land (e.g. forest roads, storage sites).

Table 1 Forest resources in the EU Member States (source: State of Europe's Forests 2011¹⁹).

Country	Forest and other wooded land, 2010					Forest available for wood supply 2010		
	Million ha	% of land area	ha per capita	Growing stock, million m ³	Available for wood supply, million m ³	NAI*, 1000 m ³ /a	Fellings, 1000 m ³ /a	Fellings/NAI
Sweden	30.6	75	3.30	3 252	2 651	96 486	80 900	84
Spain	27.7	56	0.61	915	784	45 842	16 577	36
Finland	23.1	76	4.32	2 216	2 024	91 038	59 447	65
France	17.6	32	0.28	2 584	2 453	94 367	64 316	68
Germany	11.1	32	0.13	3 492	3 466	107 000	59 610	56
Italy	10.9	37	0.18	1 448	1 285	32 543	12 755	39
Poland	9.3	30	0.24	2 304	2 092	-	40 693	-
Romania	6.7	29	0.32	1 390	-	-	17 232	-
Greece	6.5	51	0.58	185	170	-	-	-
Austria	4.0	48	0.48	1 140	1 107	25 136	23 511	94
Bulgaria	3.9	36	0.52	656	435	14 677	7 781	53
Portugal	3.6	40	0.34	188	154	-	-	-
Latvia	3.5	56	1.55	635	584	-	12 421	-
United Kingdom	2.9	12	0.05	380	340	20 700	10 500	51
Czech Republic	2.7	34	0.26	769	738	23 086	17 940	78
Croatia	2.5	44	0.56	416	371	-	5 186	-
Estonia	2.3	55	1.74	447	398	11 201	5 714	51
Lithuania	2.2	36	0.69	482	408	10 750	8 600	80
Hungary	2.0	23	0.20	356	259	11 099	6 899	62
Slovakia	1.9	40	0.36	514	478	13 193	10 418	79
Slovenia	1.3	63	0.63	417	390	9 165	3 401	37
Ireland	0.8	11	0.17	74	74	-	2 826	-
Belgium	0.7	23	0.07	168	164	5 289	3 852	73
Denmark	0.6	15	0.12	114	112	5 796	2 371	41
Cyprus	0.4	42	0.44	9	3	38	10	25
Netherlands	0.4	11	0.02	70	56	2 250	1 552	69
Luxembourg	0.1	34	0.18	26	-	-	-	-
Malta	0.0	1	n.s.	0	-	-	-	-
EU-28	179.5	42	0.36	24 648	20 998	619 656	474 512	77

¹⁹ NAI refers to net-annual increment, which is the total increase of growing stock minus the losses due to natural mortality.

In recent years, growth in the use of wood-based products, especially the use of paper, has stagnated in Europe. This has mainly resulted from changes in consumption habits (e.g. electronic devices have replaced printed materials) but also from the economic recession. Presently saw milling, panel and plywood industries together account for 36% and pulp industry for 17% of the total wood

use in the EU. During the 2000s, mainly the use of wood for energy has increased, as significant targets have been set for increasing the use of renewable energy sources. Between 2000 and 2011, wood raw material use in the EU-27 bioenergy sector grew about 82 million m³, i.e. more than double the rate in comparison to the growth of both the pulp and paper and wood product sub-sectors. About 42% of the wood used in the EU is used for energy (Figure 3). Roundwood (split logs) is the dominant wood raw material type (about 73 and 97 million m³ in 2000 and 2011, respectively) used in the bioenergy sector consisting mainly of fuel wood used in fire places in private housing. Black liquor and industrial residues have traditionally been the other main wood raw material types for energetic uses of wood biomass in the EU. In addition the use of logging residues and recovered fuel wood as fuel has increased their significance in the overall wood fuel composition^{21,22}.

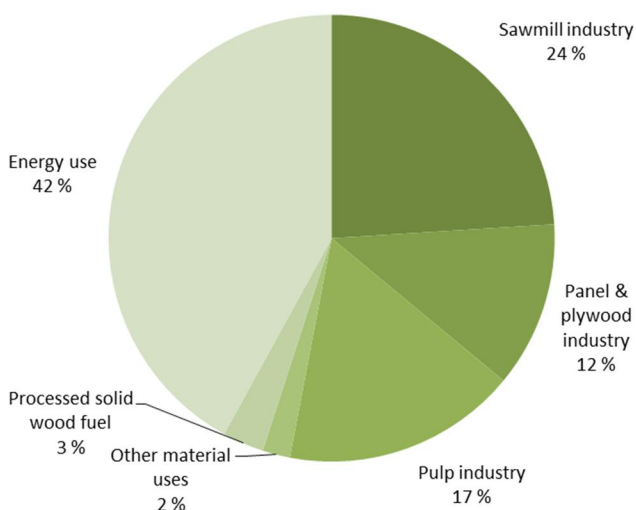
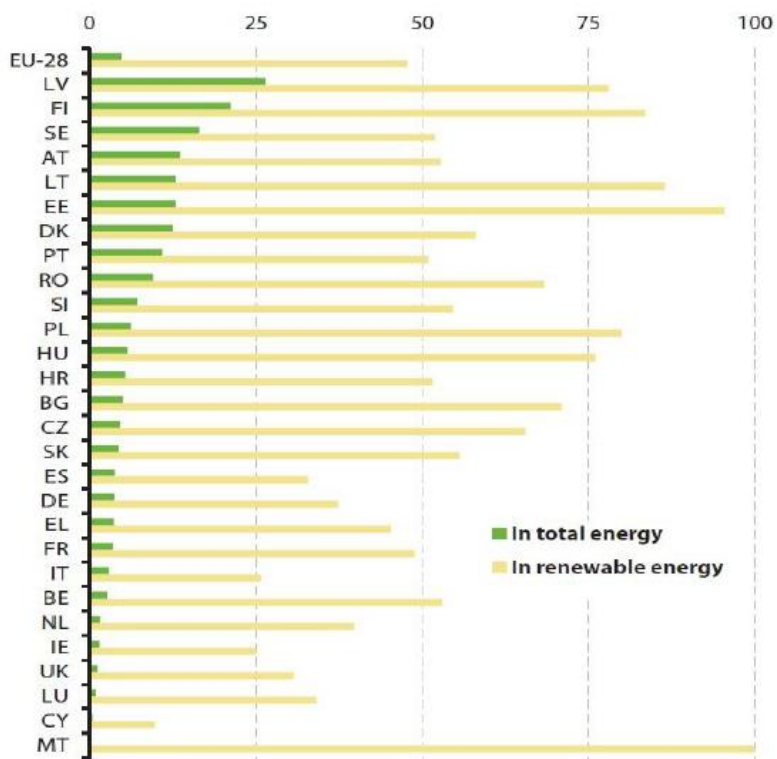


Figure 3 Use of wood resources in the EU, including secondary use (source: Eurostat 2011²³).

The total energy consumption of the EU increased until 2008 but since then the consumption has decreased mainly due to the recession. In 2013 final energy consumption was 1104 Mtoe of which 166 Mtoe was renewable energy (15%). The share of gross final energy consumption from renewable energy sources almost doubled between 2004 and 2013 in the EU, rising from 8% to 15% (**Table 2**). *Wood is the main source of renewable energy in the EU, and corresponds to about half of the total renewable energy production* (Figure 4).

Table 2 Overall share of energy from renewable sources, according to Renewable Energy Directive (2009/28/EC)²⁴ (source: Eurostat
<http://ec.europa.eu/eurostat/web/energy/data/shares>).

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2020 target
EU28	8%	9%	9%	10%	10%	12%	12%	13%	14%	15%	20%
Belgium	2%	2%	3%	3%	4%	5%	6%	6%	7%	8%	13%
Bulgaria	9%	9%	10%	9%	10%	12%	14%	14%	16%	19%	16%
Czech Republic	6%	6%	6%	7%	8%	9%	10%	10%	11%	12%	13%
Denmark	14%	16%	16%	18%	19%	20%	22%	23%	26%	27%	30%
Germany	6%	7%	8%	9%	9%	10%	10%	11%	12%	12%	18%
Estonia	18%	17%	16%	17%	19%	23%	25%	26%	26%	26%	25%
Ireland	2%	3%	3%	4%	4%	5%	6%	7%	7%	8%	16%
Greece	7%	7%	7%	8%	8%	8%	10%	11%	13%	15%	18%
Spain	8%	8%	9%	10%	11%	13%	14%	13%	14%	15%	20%
France	9%	10%	10%	10%	11%	12%	13%	11%	14%	14%	23%
Croatia	13%	13%	13%	12%	12%	13%	14%	15%	17%	18%	20%
Italy	6%	6%	6%	6%	7%	9%	11%	12%	15%	17%	17%
Cyprus	3%	3%	3%	4%	5%	6%	6%	6%	7%	8%	13%
Latvia	33%	32%	31%	30%	30%	34%	30%	34%	36%	37%	40%
Lithuania	17%	17%	17%	17%	18%	20%	20%	20%	22%	23%	23%
Luxembourg	1%	1%	1%	3%	3%	3%	3%	3%	3%	4%	11%
Hungary	4%	4%	5%	6%	7%	8%	9%	9%	10%	10%	13%
Malta	0%	0%	0%	0%	0%	0%	1%	1%	3%	4%	10%
Netherlands	2%	2%	3%	3%	3%	4%	4%	4%	4%	5%	14%
Austria	23%	24%	26%	27%	28%	30%	31%	31%	32%	33%	34%
Poland	7%	7%	7%	7%	8%	9%	9%	10%	11%	11%	15%
Portugal	19%	20%	21%	22%	23%	24%	24%	25%	25%	26%	31%
Romania	17%	18%	17%	18%	20%	23%	23%	21%	23%	24%	24%
Slovenia	16%	16%	16%	16%	15%	19%	19%	19%	20%	22%	25%
Slovak Republic	6%	6%	6%	8%	8%	9%	9%	10%	10%	10%	14%
Finland	29%	29%	30%	30%	31%	31%	33%	33%	34%	37%	38%
Sw eden	39%	41%	43%	44%	45%	48%	47%	49%	51%	52%	49%
United Kingdom	1%	1%	2%	2%	2%	3%	3%	4%	4%	5%	15%
Norway	58%	60%	60%	60%	62%	65%	61%	65%	66%	66%	68%



Source: Eurostat 2013

Figure 4 Share [%] of wood (and wood residues) as energy source in the EU in 2011 (source: AEBIOM 2013²⁶).

INFOBOX 1: Forest energy in National Renewable Energy Actions Plans of EU Member States by 2020

A study carried out for the EU Commission by Indufor (2013)²¹ indicated that the total use of wood biomass in the EU for bioenergy will rise from 292 million m³ in 2010 to 360 million m³ in 2016 (see Figure 5). However, according to the study, even with a 23% growth, there would still be a shortfall of 63 million m³ from domestic sources if we consider the bioenergy targets anticipated by the EU Member States in their National Renewable Energy Action Plans (NREAPs) for 2020²⁶. Thus by 2016, the amount of wood used for bioenergy (423 million m³) will be greater than that used for either the woodworking industries (332 million m³) or for pulp and paper manufacture (347 million m³). The huge increase foreseen will be drawn mainly from logging residues (+26 million m³) but also significantly from roundwood (+21 million m³) and industrial residues (+17 million m³) but very little from recovered wood (+4 million m³), thus confirming the missed opportunity of the unused potential of the last category. Only the use of black liquor can be expected to decrease, following the decreasing trend of pulp production in the EU-27.

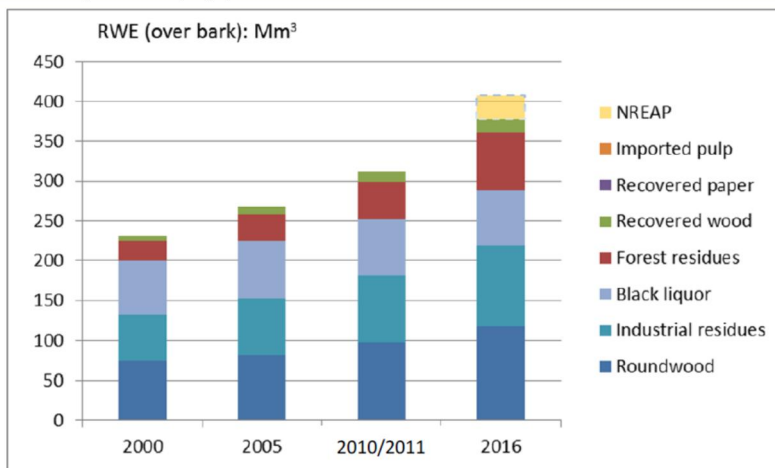


Figure 5 Wood raw-material used in the bioenergy sector in EU-27, expressed as roundwood equivalents (RWE). Figures for year 2016 are estimated (source: Indufor 2013²¹). RWE is the amount of wood biomass in any form, corresponding to the same amount of roundwood.

The NREAPs indicate that in 2020 about 11.8% of the gross final consumption in the EU is expected to be provided from biomass. According to the NREAPs, bioenergy will present about 17% of the EU projected heating and cooling and 7% of electricity consumption. In the transport sector, bioenergy is predicted to be the dominant renewable energy source (90% of renewable energy consumption in transport). The analysis of NREAPs show also that total biomass primary demand is expected to increase by 140% in 2020 and the major part is expected to come from solid biomass (i.e. 67% of total biomass)^{27, 28}. In 2015, only a few units producing advanced biofuels from wood-based raw materials were in operation, despite EU risk funding instruments, such as the NER 300 programme²⁹.

2.2 Forest resources and their use in Finland

In Finland forests have historically been a source of various products and game. Since the 16th century they have been a source of fur for trade, wood for building and fire, and land for grazing and cultivation (the main era of slash and burn agriculture was in the 19th century). Tar was the major export product of Finland during the 17th and 18th centuries. The value of lumber export outstripped the value of tar in 1830-1840 and since then industrial wood has been the most important forest product.

Nowadays, Finnish silviculture shares the same objectives with other EU countries aiming at the production of high-quality timber for wood processing industries and pulp and paper industries. Due to the importance of forests, Finland has established several norms and statutes for steering the usage of forests, and since the 1920's the National Forest Inventories have been used to estimate the amount and the quality of the forests¹. Thus, the Finnish statistics on forest resources are of high quality. The focus has been on securing the sustainable availability of forest biomass. Besides the sustainability target, Finnish forest management practices and guidelines have been founded on the understanding that laws of the natural boreal forest ecosystem, such as succession and climax phases, define also the development of production forests.

INFOBOX 2: Finnish Silvicultural Guidelines

The Finnish Silvicultural Guidelines³⁰ are recommendations prepared by different actors in the forest management field. To supplement the obligatory actions demanded by the forest law, they consist of voluntary guidelines on recommendable forest management practices of which forest owners can choose those that best suit their needs. The practises given include economical, ecological and cultural sustainability aspects. The Silvicultural Guidelines have been prepared over decades and they are renewed and improved at regular intervals. The most recent ones were published in 2014. A major change compared to the previous guidelines is the inclusion of the possibility to apply also the continuous cover forestry in which the forest contains trees in different age classes and a constant canopy cover is held. In addition, the guidelines aim to provide means to take into account the impacts of climate change on silviculture. The preparation of the guidelines is funded by the Ministry of Agriculture and Forestry, and they are written in cooperation with a wide range of partners consisting of government representatives, private industry, researchers and NGOs. The guidelines can be downloaded in Finnish, and bought as a book in both Finnish and Swedish on-line (<http://tapio.fi/>). Also, guidance on good practises for energy wood harvesting and growing has been published³¹.

Over 60% of the forest land in Finland is owned by private non-industrial forest owners consisting of 375 000 forest property entities. Altogether, there were 632 000 forest owners in Finland in 2013, corresponding to around 13% of the population³². To be able to sustain the production of wood and other ecosystem services, private and public forest owners invest annually over 300 million € in regeneration and other silvicultural practices. Thus, **over 10% of the gross value added to Finnish forestry (or 15% of the value of traded timber) is re-invested into the forest resource**³. This re-investment has enabled enhancing biomass production, improvement of plant material, maintenance of forest roads, efficient forest fire and forest damage control and maintenance of waters and watersheds located in forests.

Finnish forests have undergone development similar to forests in Europe, in general. The total drainⁱⁱⁱ exceeded growth in Finland during the 1950's and 1960's, but the concern related to the sufficiency of roundwood for the expanding forest industry resulted in active silvicultural measures from the late 1950's up to the early 1990's. Old and sparse forests were renewed using artificial regeneration resulting in the decrease of mean age from 102 to 63 years (Figure 6). Drainage (ditching) of forests growing on peatlands and fertilisation increased during the 1960's: the former peaked during the 1970's and the latter in the 1980's. Due to these measures, the age structure of the Finnish forest has allowed a continuous growth of forest resources.

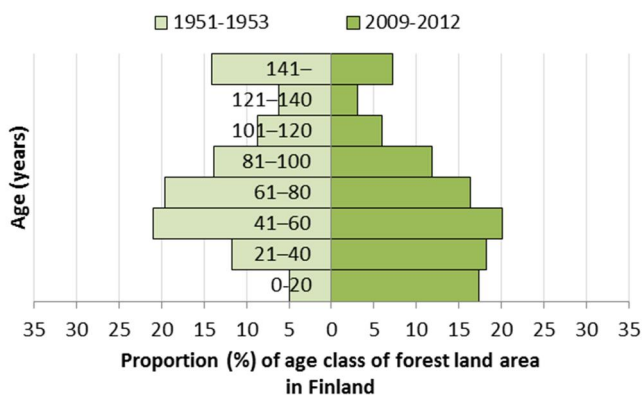


Figure 6 Changes in the age structure of Finnish forests (Statistical Yearbook of Forestry 2014³). The current age age structure benefits the continuous growth of forests.

ⁱⁱⁱ Includes the stem volume of all living trees either felled in commercial or non-commercial cuttings or died due to natural mortality.

Since the 1950s the annual growth of Finnish forests has doubled from 50 million to the current level of 104 million m³/year (green dashed line in **Figure 7b**) and the growth has exceeded the total drain lately by ca. 30 million m³ annually leading to an increase of growing stock from 1 500 million m³ to 2 200 million m³ (blue line in **Figure 7a**) despite the fact that simultaneously stemwood has been cut by nearly 3 500 million m³. It must also be noted that the total biomass accumulated in the forests is much bigger than that of stemwood. If the crown mass and stumpwood are taken into account, the biomass resource in Finnish forests is well over 3 000 million m³. An even more rapid relative increment of forest resources can be found in Spain and also in many countries outside Europe.

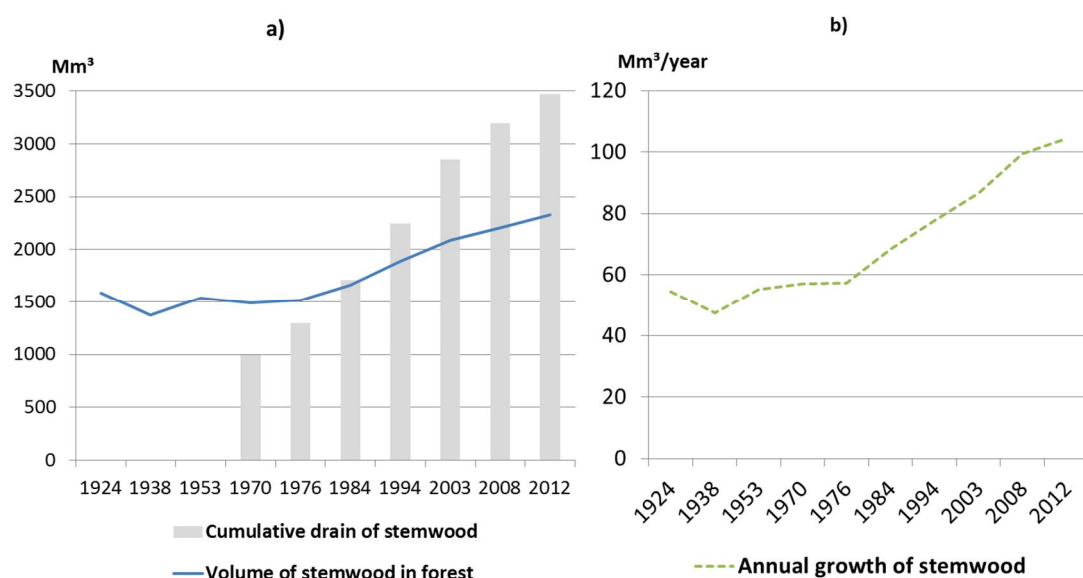


Figure 7 Development of cumulative drain and volume of stemwood (a) and annual growth of forests (b) in Finland 1924–2012. Even if double the amount of wood has been harvested compared to the initial volume of stemwood, the volume of stemwood in forests and the annual growth have been increasing (data from National Forest Inventories¹).

Annual harvest of the industrial roundwood in Finland has been c.a. 55 million m³ and traditional firewood for small-scale house heating 5–6 million m³. Energy biomass harvested from early thinnings has been around 4 million m³ consisting mainly of delimbed stemwood (87%) and the rest being whole trees. The volume of logging residues harvested for energy has been 2.5–2.8 million m³ and stumps 1 million m³. In addition, about 0.5 million m³ low quality stemwood (e.g. rotten or other unmarketable wood) is used in energy production³. The use of logging residues has increased significantly in recent years replacing particularly the use

of peat and coal (however, lately the decreased coal prices have also increased coal use in some heat plants in Finland).

The main users of primary wood in Finland are pulp and sawmill and wood product industries, which use altogether over 80% of primary wood. Only 13% of wood goes directly to energy generation (**Figure 8**). However, in 2014, around 25% of Finland's total energy consumption (372 TWh, 1 340 PJ) was produced with wood fuels (93 TWh, 333 PJ)⁴. **80% of Finnish wood-based energy is produced using by-products and residues from forest industry, silvicultural and harvest operations**, of which 64% (61 TWh, 220 PJ) by black liquor, bark, sawdust, and other industrial wood residues, and 16% (15 TWh, 54 PJ) by logging residues, stumps and small-diameter trees combusted in CHP plants. The small-scale use of wood for heating in residential houses, cottages and farms consisting mainly of pellets, residues and firewood corresponds to 18 TWh (65 PJ). The share of waste or demolition wood from the construction sector and wood from municipal solid waste is minimal in Finland. **Figure 9** shows the significant share of the use of forest industry residues, such as black liquor for renewable energy production in Finland.

There are no dedicated energy wood plantations or forests in Finland. Similar wood use systems can be found in Sweden, Germany, Poland and most EU countries. However, for example in France the use of traditional firewood represents c.a. half of wood-based energy production.

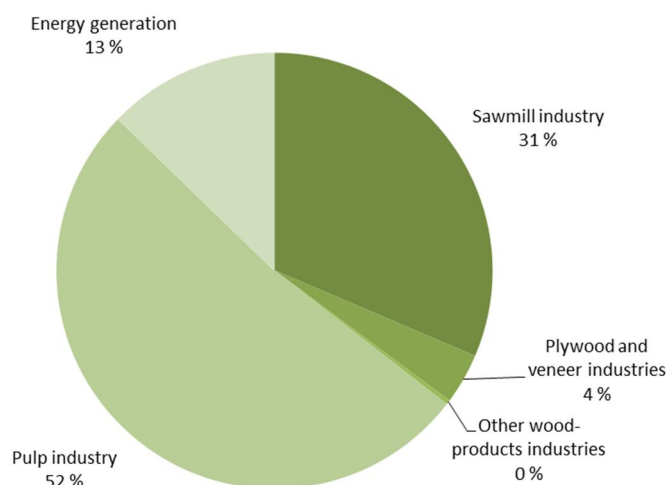


Figure 8 Use of primary wood in Finland in 2013 (Statistical yearbook of forestry 2014³).

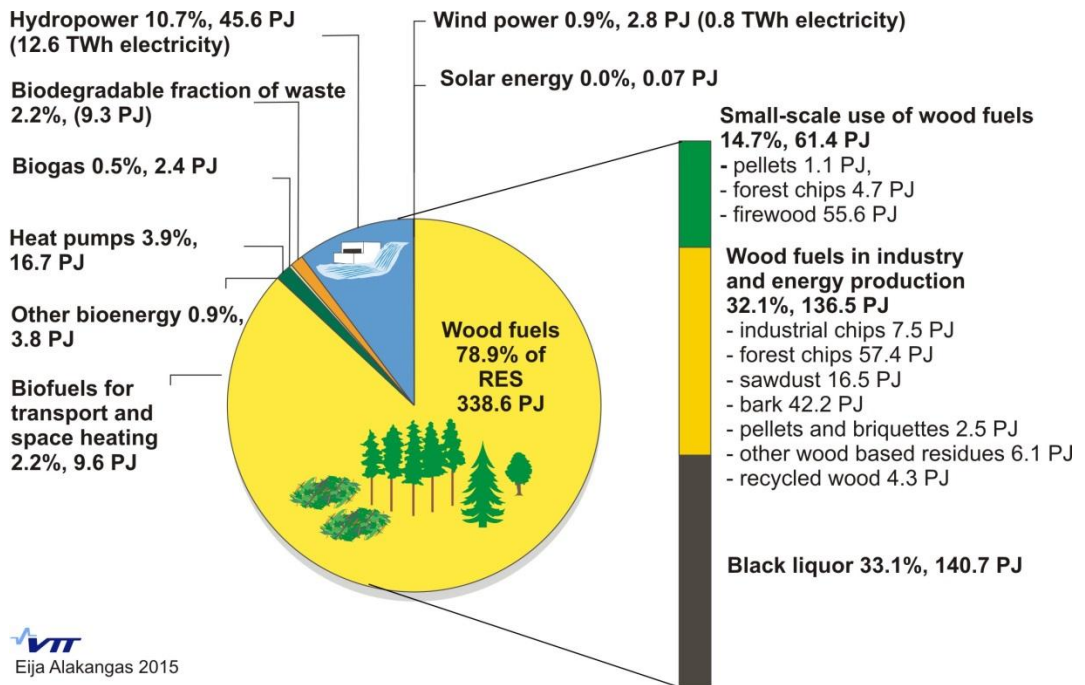


Figure 9 Use of renewable energy in Finland in 2013 (Statistics Finland 2014)⁴.

Finland is similar to other Nordic countries in that energy biomass is supplied from domestic forests located typically within a radius of 100 km from a heat and power plant. The role of imported energy biomass is marginal. The situation in many Central European countries and also in the United Kingdom is very different: the majority of energy biomass is imported from overseas, e.g. from North America. *Typical of Finland is that the wood biomass for energy production is used in industrial and municipal CHP plants and in district heating with high overall energy efficiency (e.g. 85%),* when heat is used. The CHP boilers are typically fluidised bed boilers designed for multi-fuel firing. Full efficiency can be gained with a flexible mix of solid biomass, coal and peat.

In Finland, both industry and energy wood is harvested from certified forests: approximately 95% of Finnish production forests are certified under the Finnish PEFC (Programme for the Endorsement of Forest Certification schemes) system. The Finnish system was endorsed for membership in the PEFC in the year 2000. In 2014, Finland had the third largest amount of area certified under the PEFC system, after Canada and the USA³³. Also the FSC (Forest Stewardship Council) certificate is in use in Finland, currently covering around 2% of Finnish forests³⁴. In addition, 13% of the total forest area in Finland is under restricted use, of which 9% is strictly protected and completely outside harvest operations³⁵.

2.3 Future development of wood use and forest resources in Finland

In Finland, the domestic raw wood demand has been practically stable since the middle of the first decade of the 2000s. However, the forest industry is expected to strengthen, renew and to use a growing volume of wood in the future. Simultaneously the demand for wood by the energy sector is increasing. For 2020, Finland's target set by the EU is to increase the share of renewable energy to 38% from final energy consumption.²⁴ According to a national renewable energy action plan, forest biomass plays a central role in achieving these targets and the most significant growth objective has been set for the use of logging residues to 25 TWh, 90 PJ (corresponding to 12.5 million m³) by 2020²⁶. According to the agreed EU targets, in 2030 the share of renewable energy from final energy consumption at EU level should be at least 27%.³⁶

In addition, Finland has committed to the EU's long-term target to reduce greenhouse gas (GHG) emissions 80–95% by the year 2050 compared to the 1990 emission level and to become finally a low-carbon or even carbon-neutral society. A parliamentary committee on energy and climate has recently prepared a low carbon 2050 roadmap for Finland, to serve as a strategy guide on the journey towards achieving this target¹⁸. According to the quantitative and multidiscipline scenario analysis^{iv}, the opportunity to use wood biomass for production of energy and processed products is one of Finland's major advantages in the transition towards a low-carbon society compared to many other EU Member States. **Table 3** presents the usage volumes of biomass by target and wood type for the years 2030 and 2050, as presented in the roadmap.

^{iv} The analyses were made in the Tekes funded research project "Low carbon Finland 2050 platform", which provided scientific background material for the parliamentary committee on energy and climate.

Table 3 The use of logging residues and stemwood in electricity, heat, and liquid biofuels production (the figures for 2030 and 2050 according to the Low Carbon Finland 2050 scenarios). As the distribution of the use of biomass between different targets and wood types varies by scenario, the figures presented in the table cannot be directly added together (adapted from: Ministry of Employment and the Economy, 2014¹⁸).

		2012	2030	2050
		TWh	TWh	TWh
Wood used in energy production	Electricity and heat production	15.3	29–34	29–32
	Production of liquid biofuels	0.	7–19	21–33
	Total	15.3	37–53	52–65
Use by wood type	Stumps	2.2	4–6	2–9
	Branches, tops etc.	5.2	11–12	11–14
	Small-dimensional wood, not including firewood	7.2	18–24	20–25
	Pulpwood (Stemwood)	0.7	0–10	12–27
	Total (TWh)	15.3	34–39	52–63

The Low Carbon Finland platform project² estimated that Finland's forests have the potential to fulfil the estimated future wood demand. Even though the use of logging residues and other wood raw material is increasing as the climate policy goals become tighter, the scenarios propose that the amount of wood used will stay below the forest growth level also in the future (**Figure 10**). Thus, *the volume of Finnish forests keeps on growing*. The cutting removals for energy wood will stay substantially lower than the removals for saw logs also in future (Figure 11). On the other hand, presently several new plans for construction of new pulp mills have occurred. These plans were not taken into account in the Low Carbon Finland scenarios, and would affect the figures presented below to some extent. If realised, these investments would increase the annual roundwood use by 10–14 million m³ by 2025 from the level presented in **Figure 11**. However, the investment decision has so far been made for only one unit (corresponding to ca. 6 million m³ roundwood consumption), and others are still in the planning phase.

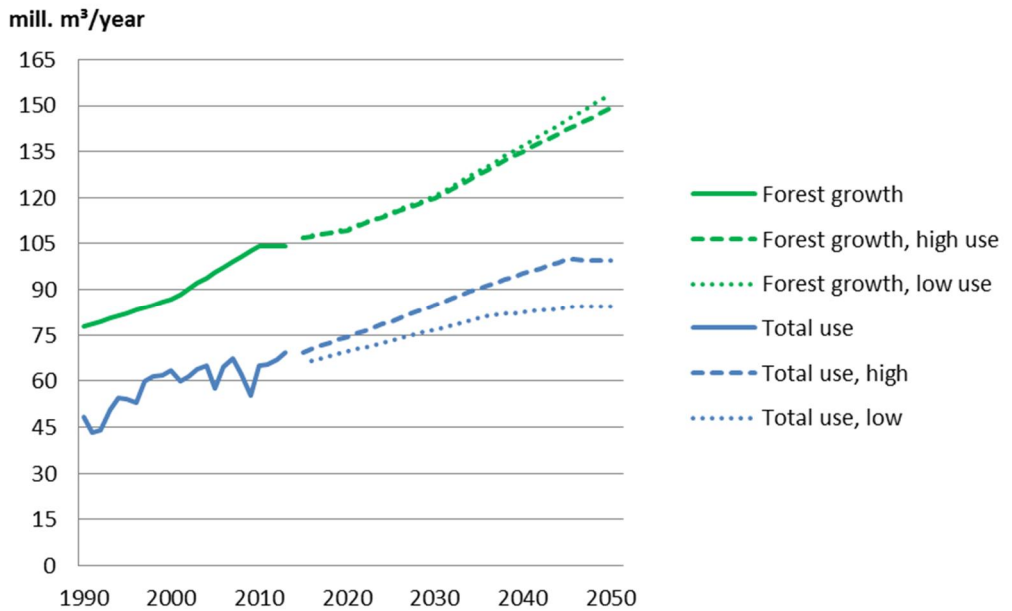


Figure 10 Scenarios on the development of annual forest growth. Solid lines show the realised growth and removals 1990–2013 and dashed lines show the highest (high) and lowest (low) estimated growth and removals from the scenario results^v of the Low Carbon Finland 2050 project².

^v High and low removals are based on maximum and minimum wood removals of Low Carbon Finland 2050 scenarios. “High” is a *Save* scenario describing a “modern oil crisis” with delayed global agreement on the two degree climate target but the EU still having a forward-leaning climate policy, conservative development of technology, emphasis on energy efficiency and material efficiency and use of domestic resources, current industrial structure, current urban and regional form.

“Low” is based on a *Stagnation* scenario which describes “Climate crisis” with a rise of global mean temperature of over four degrees resulting in economic crisis, closing society, slow development of technology, current industrial structure, current urban and regional form.

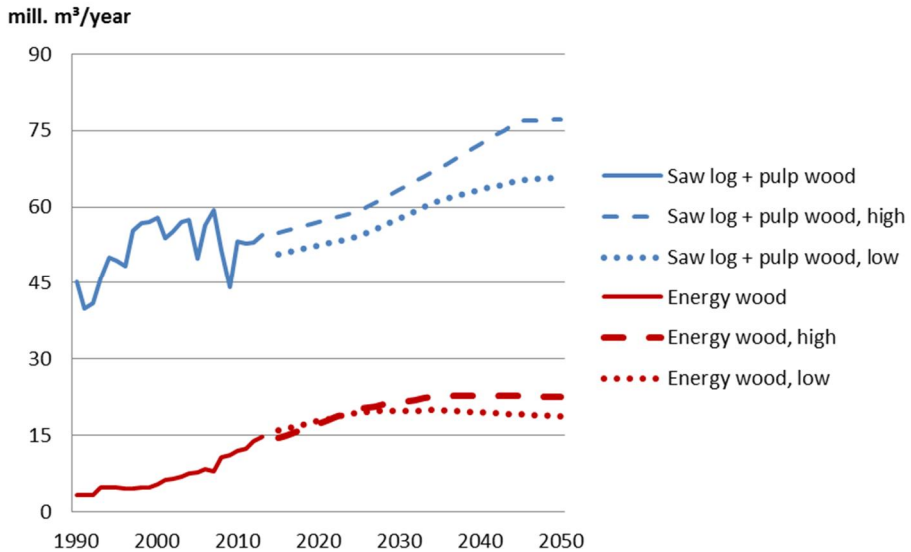


Figure 11 Cutting removals from Finnish forests. Solid lines are the realised removals 1990–2013 and dashed lines are the highest (high) and lowest (low) estimated removals from the scenario results of the Low Carbon Finland 2050 project².

Finnish forests form a carbon sink (Figure 12), which has been steadily growing³⁷. The magnitude of the forest sink is substantial: its size has been more than 40% of the national GHG emissions during 1990–2012. The scenarios propose that planned use of wood does not threaten the increasing trend of the forest sink. According to future projections, Finnish forests will continue to store more carbon from the atmosphere than is emitted back due to wood energy use or decaying.

The annual increment of forests has increased also elsewhere in Scandinavia in the past decades and consequently forests sequester more carbon than before. For example, intensive forest management activities (such as improved genetic material in seedling plantations, soil scarification, selection of tree species suitable for particular site conditions, shorter time between clear-cut and planting, increased pre-commercial thinning, and increased fertilization) in North-Central Sweden may increase biomass production by up to 26%, annual harvest by up to 19%, and carbon sink up to 34% over the next 100 years³⁸. On the other hand, a study concerning 24 EU countries projects that by 2030, the forest sink will decrease 25–40% from the 2010 level due to the aging of forests causing saturation of carbon sink, and due to increasing harvests³⁹. To enhance the forest growth, for example the growth potential of domestic and exotic tree species with high biomass production capacities should be examined in the EU. In addition,

their usability in the existing and foreseen forest and energy industries needs to be evaluated.

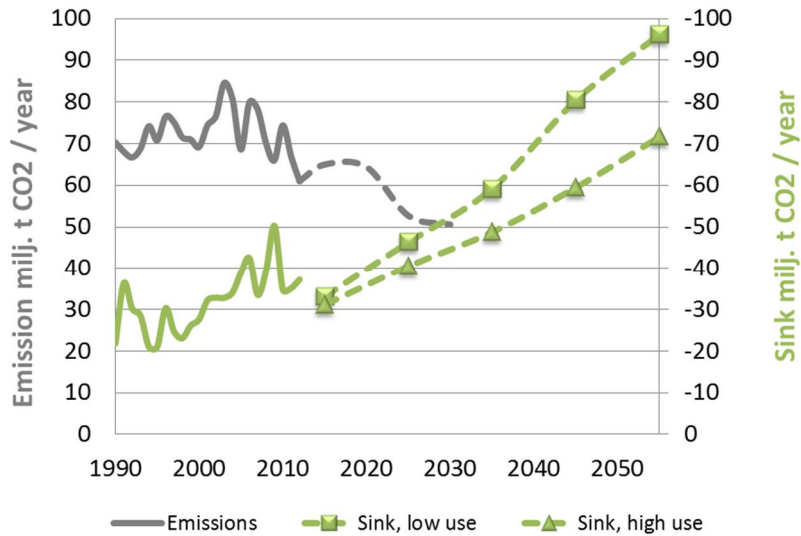


Figure 12 Development of Finnish GHG emissions excluding LULUCF (grey lines) and forest carbon sink (green lines): past values (solid line) are from the Finnish GHG inventory⁶ and projections presented for low- and high-use scenarios (dashed lines) are from Low Carbon Finland scenarios². The forest sink is expected to exceed the total GHG emissions after 2030–2040.

Main messages of Section 2:

FOREST ENERGY AS AN INTEGRATED PART OF THE FOREST INDUSTRY

- As a result of intensive forest management, growth rate and carbon sequestration are at a high level in European countries in spite of intensive use of wood.
- The increase in the growth rate of forests is a result of improving their age structure by harvesting and by sustained forest management efforts. If these activities would be halted, the growth rate would eventually slow down.
- The growth of Finnish forests has doubled since 1950 and the growing stock is increasing despite the increased harvesting of stemwood.
- The magnitude of the forest sink in Finland is substantial: its size has been more than 40% of the national GHG emissions during 1990–2012.
- The future scenarios predict that the planned increased use of wood will not threaten the increasing trend of a forest carbon sink.
- Currently 80% of Finnish wood-based energy is produced by using by-products and residues of the forest industry, such as black liquor, bark and sawdust (64%), and logging residues such as branches and tops, stumps and small-diameter trees (16%).

3. Ecological impacts of forest energy production

Most of the wood-based forest energy is obtained as by-products of stem-only harvesting for roundwood (e.g. sawdust, bark, lignin-rich black liquor, and logging residues). In this respect many of the ecological effects of bioenergy production can be considered similar to those of thinning and final felling. In the first decade of the 2000s, also the use of logging residues, small-diameter trees and stumpwood for energy increased rapidly and therefore more attention has been paid to the environmental impacts of intensified harvests. For example, concerns occurred due to additional logging residue harvesting and its impacts on nutrient cycles. These ecological impacts and the solutions to control them are discussed in this chapter.

3.1 Impacts due to wood harvesting

Undisturbed growth of trees requires that all necessary nutrients for growth (e.g. nitrogen, phosphorus and potassium) are available in sufficient amounts and ratios with each other in forest soil. Part of the nutrients absorbed by plants are bound in the standing biomass for a long period of time and part of them return annually to the soil in the form of litterfall. Nutrient uptake and litterfall are the largest nutrient fluxes and the decomposition of litter is the most important process releasing nutrients for biological nutrient cycling^{40,41,42,43}. Harvesting of forests causes a disturbance to nutrient cycling and removal of biomass decreases nutrient stocks in forests. The influence of harvesting differs between sites. At the most fertile sites, the absolute amount of nutrients removed from the site is higher than on less-fertile sites; but on less-fertile sites, the proportion of nutrients removed compared to the total ecosystem nutrient pool is higher. *The impacts on the nutrient cycle can be controlled, e.g. by site type selection, fertilisation and ash recycling* (ash from wood combustion is returned to the forest).

Soil organic matter serves both as a sink and a source of carbon and nutrients. In boreal forests organic matter accumulates on the soil surface generally forming a separate humus layer on top of the mineral soil⁴⁴. A large amount of organic

matter is removed from the site in harvested woody biomass. However, studies show that the harvest intensity has no or only a small effect on soil organic matter content in boreal^{45,46,47,48,49} or temperate forests⁵⁰.

Forests have significant influences on the hydrologic fluxes of a land area⁵¹ and they are also valuable as a sustainable source of clean water. They intercept precipitation (both rain and snow) and use water in transpiration. Snow, when intercepted by branches in cold, dry climates is mostly sublimated back to the atmosphere and does not reach the forest floor. Forest harvesting changes the dynamics of the hydrological cycle of the ecosystem. Harvesting causes higher levels of precipitation to reach the forest floor, which leads to increases in snow accumulation and subsequent melt water. Forest harvest reduces evapotranspiration⁵² and can lead to higher direct evaporation from the soil surface due to the reduction in vegetation cover which in turn allows a larger proportion of radiation to reach the surface. Increased logging residue harvests carried out with heavy machinery can cause soil compaction of wet soil and increased surface runoff⁵³ and peak flows⁵⁴. An increased amount of flowing water and a fragmented soil surface can also have a significant impact on nutrient leaching. Studies examining the effects of different harvesting intensities on the chemical composition of ground water have shown that a clear increase in nutrient concentrations can be seen, especially three to six years after the regeneration cut. When looking at the nutrient concentrations under the piles of different amounts of logging residues, it is obvious that the concentrations are higher in connection with a greater amount of needles and branches in the pile. According to recent, still unpublished studies, these impacts are reduced in a couple of years⁵⁵. The impacts may also be reduced, e.g. through proper selection of the site type, season of the year, and moisture content of the soil, as well as by selection of suitable size and type of machine used.

The importance of dead wood for biodiversity in forest ecosystems has been widely acknowledged. In Finland, at least 4 000 forest species (i.e. 20–25% of all species living in forests) are dependent on dead wood⁵⁶. The reduced amount of dead wood in forests is the main individual reason threatening endangered forest species.⁵⁷ Biomass harvesting reduces both fine and coarse woody debris. Thereby, harvesting affects population size and diversity of species, which are dependent on dead wood, such as mosses, liverworts and wood-decaying beetles⁵⁸. However, some other groups of organisms have more varied responses. For instance, diversity of ground-dwelling beetles, plants and stand structural diversity may also be positively or neutrally affected by bioenergy harvesting. Scientific evidence on the impacts of bioenergy harvesting on biodiversity is, however, still scarce. The lack of data on complex processes like population dispersal^{vi} and extinction debt^{vii} make it complicated and perhaps not

^{vi} Population dispersal refers to the process by which groups of living organisms expand the space or range within which they live.

^{vii} Extinction debt refers to the future extinction of species due to events in the past. Extinction debt occurs because of time delays between impacts on a species, such as destruction of habitat, and a species' ultimate disappearance.

even possible to define a threshold for sustainable biomass extraction in terms of biodiversity impacts. Therefore it is important to follow the precautionary principle and take care of direct conservation efforts especially on those areas where biodiversity is rich. In Finland, biodiversity hotspots have been identified and taken into account when planning forestry operations near nature reserves with high biological values associated with dead wood. *The measures to ensure biodiversity need to take place also in forests under economic use*, e.g. by leaving a sufficient amount of dead wood in forests. This can be done by following the recommendation to leave at least 25–50 big stumps per hectare and when possible leave the residual trees on the site.⁵⁵ Stumps are harvested only from spruce regeneration cut areas and the proportion of the sites from which stumps are harvested is only 15% of all regeneration cut sites.

3.2 Controlling nutrient losses when harvesting logging residues

Energy wood harvesting, where logging residues are collected in addition to stemwood, decreases the amount and changes the quality of organic matter left on a site compared to stem only harvesting. It can also have effects on soil processes such as nitrogen cycling and organic matter decomposition. Further, it can impact nutrient and carbon stocks and their availability. The effects of logging residue harvesting on site productivity or soil nutrient stocks depend on the site, species and other management practices applied^{59,60,61,62,49}. Soils on more fertile sites tend to be more resistant to nutrient losses and changes in acidity due to their higher buffering capacity^{63,64,65,66,67}. The proportion of removed nutrients in relation to nutrient storages in soil is highest on low-productivity sites. Residual tree, stump and coarse root harvesting in particular can decrease the amount of slowly decomposing organic matter in the humus layer and in mineral soil and increase soil density. Some impacts of logging residue harvesting can only be noticed after several decades but, e.g., nutrient losses or deficiencies can be seen sooner.

The impacts due to logging residue harvesting can be efficiently decreased by applying the correct measures. In the Finnish silvicultural guidelines it is suggested to utilise logging residues only from nutrient-rich forest sites, mainly from Norway spruce final fellings, and to leave at least 30% of crown biomass to the regeneration-cut area in order to avoid nutrient losses. It is also recommended to allow the logging residues to dry on the site long enough to allow most of the needles or leaves to be shed at the site. With these measures, a large proportion of nutrients can be conserved. If the harvesting of branches and needles were nonetheless applied, the growth reductions could be compensated with fertilisation. In order to close the nutrient cycles and increase material recycling, ash minerals from wood combustion use can be utilised as a forest fertiliser. Wood ash includes phosphorus and potassium in an appropriate proportion and has

therefore been found to be beneficial, particularly on peat land sites as peat itself contains enough plant-available nitrogen but not phosphorus and potassium⁶⁸. On mineral soils requiring nitrogen fertilisation, synthetic fertilisers need to be applied, when positive growth response is expected. However, in a recent study⁶⁹ it has been shown that in the long-term, also wood ash alone without simultaneous nitrogen addition can increase stem growth also on mineral lands.

In addition, harvesting of logging residues can influence positively the growth of the next tree generation. This is because soil preparation and planting is easier when the logging residues are absent, resulting in denser and more uniform stands⁷⁰. Also after stump harvesting, the regeneration may be more successful^{71,72}. The harvest of logging residues can improve the recreational value of a forest: when residue stacks are removed, walking and hiking in the forest is easier. Also, harvesting of energy wood from young stands improves visibility in the forest and makes walking and, e.g. orienteering, easier. During energy wood harvesting of young forests the stem only method is applied and all the branches and needles are left on the site.

INFOBOX 3: Forest nitrogen cycle

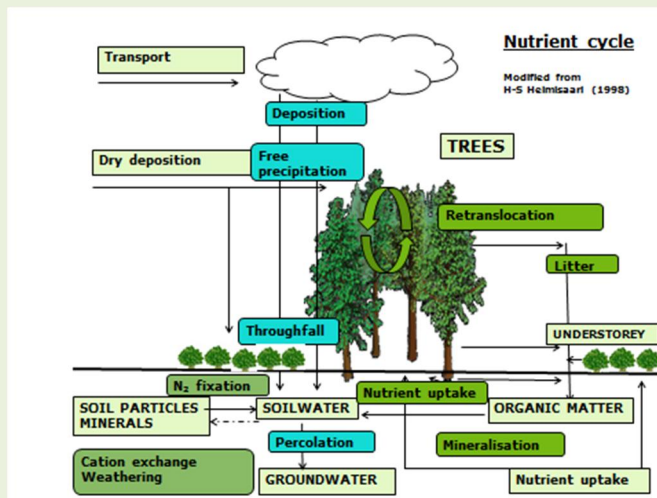


Figure 13 Nutrient cycling in, within and out of a forest ecosystem (Helmsaari 1998).

Nitrogen (N) is typically the growth-limiting nutrient in boreal zone forests^{73,74,75,76,77}, and it is efficiently cycled within forest ecosystems.^{78,79,80,81}

Biological N fixation by soil microbes and deposition within precipitation are the only external N inputs to boreal forest ecosystems. Deposition of N is spatially highly variable in Europe; ranging from 1 kg ha⁻¹ in sparsely populated areas of northern Europe to over 50 kg ha⁻¹ in areas dominated by industry or intensive agriculture⁸². Annual mean total N deposition in the Nordic countries is low, generally varying between 1 and 10 kg N ha⁻¹ in a North-East South-West gradient.^{83,84}

When a forest is undisturbed, N mainly cycles naturally in the uptake - litter fall - decomposition cycle, with relatively small leaching losses (outputs). This cycle determines the availability of N. N stored in tree biomass in mature stands accounts for 7–19% of the total ecosystem N stock.^{73,85,86} It has been reported that roughly half of the N in logging residues of Norway spruce and Scots pine is in needles and half in branches⁴². Scots pine and Norway spruce needles lose between 30–50% of their initial amount of N within six to eight years.⁸⁷ Most of the logging residues will be decomposed and the nutrients released within 10–30 years.^{88,89,90,91}

Nitrogen content in Norway spruce and Scots pine thinning residues quantitatively equal three to eight years of N input in needle litter.⁹² Thus, logging residue removal may affect the available N pool, whereas the effects may not be detected in the large N pool of old, poorly decomposable soil organic matter.^{46,63} At clear-cutting the removal of N in whole tree harvesting can be two to three times larger compared to stem-only harvest.⁹³

A large proportion of the nutrients can be conserved by leaving the needles and leaves of the logging residues on the site.⁹⁴ Also synthetic fertilisers can be used to compensate N losses.

Main messages of Section 3:

ECOLOGICAL IMPACTS OF FOREST ENERGY PRODUCTION

- Energy wood harvesting, where logging residues are also collected, can decrease the amount and change the quality of organic matter left at the site compared to the stem only harvesting.
- However, with a sufficient drying period on site, a large part of the nutrients can be returned to the soil (in the form of needles and leaves) before harvesting the logging residues. The Finnish silvicultural guidelines require leaving at least 30% of crown biomass on the harvested area.
- Nutrient losses can be compensated by nitrogen fertilisation and by recycling ash from wood combustion and returning it to forests.
- Harvesting of logging residues can increase the survival of the planted seedlings.
- In most cases logging residue harvesting has not affected tree growth of the following rotation.
- Hydrological impacts of logging residues harvesting on soil can be reduced through proper selection of site type, season of the year, and the size and type of machine used.
- Harvesting practises which reduce dead wood affect the population sizes of species which are dependent on it. Therefore, it is important to recognise and protect biodiversity hotspots, and to take care that enough dead wood is left in forests used for forestry.
- A lack of data and complex processes make it complicated and perhaps not even possible to define a threshold for sustainable biomass extraction in terms of biodiversity impacts.

4. Forest biomass in climate change mitigation

4.1 Forests in the global carbon cycle

The global carbon (C) balance is illustrated in Figure 14. Nearly half of the carbon dioxide (CO₂) emissions from fossil fuels, cement production and land use change (mainly deforestation) are compensated by ocean sink and land sink into terrestrial ecosystems. The practicable ways to improve the atmospheric CO₂ balance are reduction of fossil and land-use change emissions and increase of the C sink into terrestrial ecosystems. Also Carbon Capture and Storage (CCS) technologies can be used. The prime option is to decrease the fossil C emissions from permanent geologic reservoirs.

The role of forests in climate change mitigation is twofold:

- 1) Sustainably managed forests can serve as a continuous source of bioenergy and biomaterials to displace use of fossil resources. Utilisation of managed forests forms a closed C cycle, which does not increase the biospheric C stock, contrary to emissions from fossil fuels. This is reflected in the UNFCCC (United Nations Framework Convention on Climate Change) reporting guidelines on annual GHG inventories^{viii} where all bioenergy (including forest-based) is treated as C neutral in the energy sector.
- 2) The carbon balance of forest has a direct effect on the CO₂ concentration of the atmosphere. Decreasing of C stocks – e.g. due to deforestation or intensified harvest for bioenergy and other purposes – increases atmospheric C concentrations, and the other way around, C sequestration into growing forest stocks constitutes a C sink from the atmosphere facilitating the achievement of global emission reduction targets. The C balance of forests as a part of terrestrial ecosystems is reported in the GHG inventories to the UNFCCC under the Land Use, Land-Use Change and Forestry (LULUCF) sector.

^{viii} http://unfccc.int/national_reports/annex_i_ghg_inventories/reporting_requirements/items/2759.php

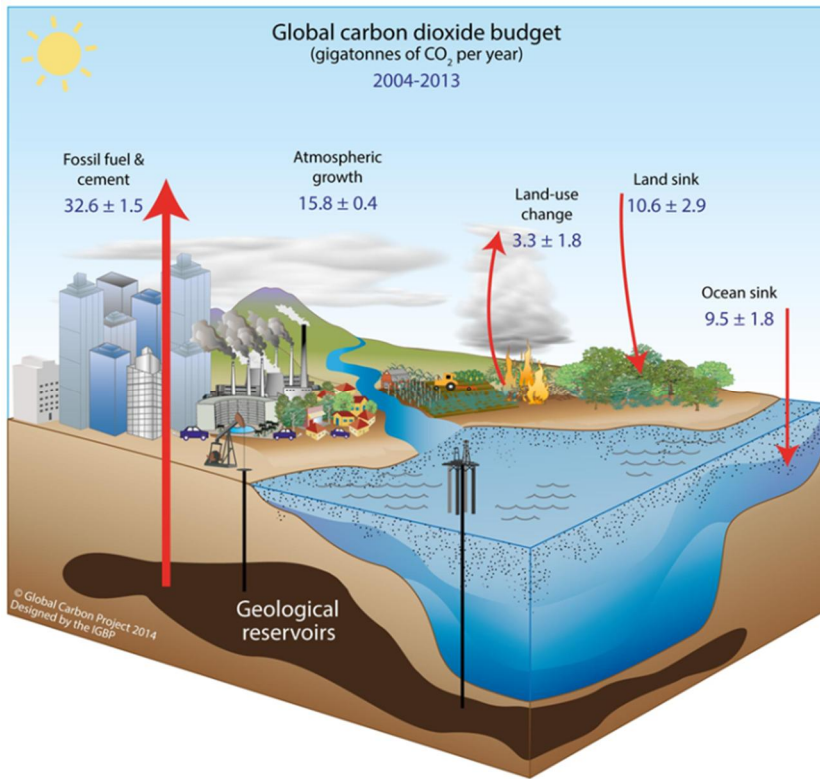


Figure 14 Global flows of CO₂ 2004–2013 (source: Global Carbon Budget 2014⁹⁵).

INFOBOX 4: Carbon sink vs. GHG emissions in Finland

In Finland, managed boreal forests serve as a source of wood for industry. Increasing demand for renewable energy has made energy use of wood from boreal forests increasingly important. As presented in Section 2, a large quantity of wood energy is produced as a side product of the forest industry. In addition, forests provide energy through targeted bioenergy harvests. The different uses of the forests for wood-based products and for energy are strongly interlinked and it is challenging to separate the climate impacts of wood use for energy from the total impacts of forestry.

The investments in forest management have resulted in increasing growth, stocking and carbon sink in the boreal forests of the Northern Europe during the last decades (Section 2). The high growth rate of Finnish forests, achieved through active forest management, makes it possible to 1) meet the demand of acquiring well-being through the forest industry, and to 2) mitigate climate change both through bioenergy and substituting for non-renewable material and through sequestering C into growing carbon stocks of forests. The climate effect of a wood-based bioenergy system depends on the type of wood biomass used and the fuels replaced. **Figure 15** shows the total forest carbon sink in Finland compared to the total emissions.

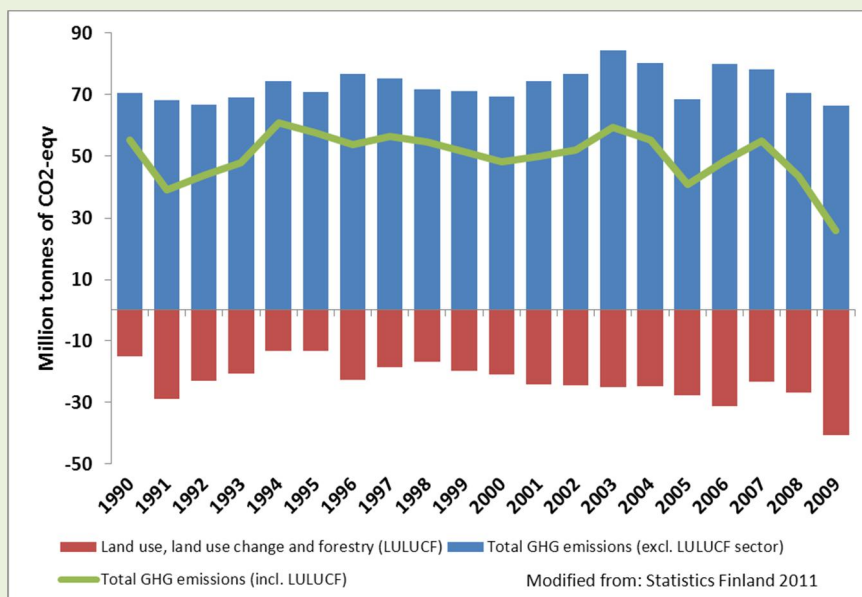


Figure 15 Greenhouse gas emissions and removals in Finland in 1990–2009 (modified from Statistics Finland⁶).

4.2 Climate impacts of using forest biomass

In this section, the on-going scientific debate regarding climate neutrality of forests is discussed. The text focusses primarily on Northern European conditions where bioenergy production (for example in the form of black liquor) is an integral part of the forest industries, and therefore a major part of wood energy cannot be treated as a separate function from wood processing and use in general. Thus, the following discussion applies to all wood use, but climate impacts are generally calculated for energy use of wood as the use of bioenergy is justified particularly by its role in climate change mitigation. The focus is on climate impacts of intensified harvest from existing managed forests, not on land use change in forms of deforestation or reforestation because they are minor factors in Finland. Section 4.2.1 concentrates on describing the impacts due to harvesting wood for energy from growing stock (e.g. roundwood from thinnings or final fellings). Section 4.2.2 focuses only on the impacts of using logging residues. The climate impacts of bioenergy need to be studied in comparison to a reference system (a counterfactual scenario), in which bioenergy production would not take place.⁹⁶ For example, one needs to ask, what would happen to a land area if not used for bioenergy production.

4.2.1 Climate impacts of wood use from growing stock

The use of renewable forest biomass is typically considered carbon neutral from the atmospheric perspective. This carbon neutrality assumption is based either on the fact that carbon released through biomass combustion or decay has once been absorbed from the atmosphere, or on the recognition that in sustainable management an equal amount of carbon will be sequestered back into growing biomass⁹⁷ during the next rotation. However, there is a scientific consensus that because there is a time lag between carbon released through harvesting and combustion of wood and its sequestration back into new biomass, a climate effect occurs due to wood use (**Figure 16**).^{98,99,100}

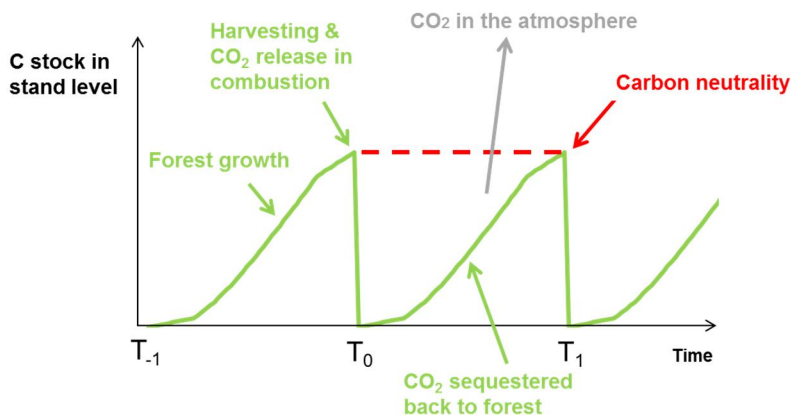


Figure 16 Stand-level illustration on the time lag between forest energy use (T_0) and carbon neutrality (T_1). Carbon neutrality on the stand level is reached when the carbon released in the combustion is sequestered back into growing forest (Figure adapted from Cowie et al. 2013¹⁰¹).

Considered at the landscape level, *more-intensive harvest has an impact on carbon balance of forest compared to a reference case with less harvest* (see **Figure 17**). On-going intensified harvest can also lead to a permanent difference in the biomass stocks between the intensive harvest scenario and the less intensive reference scenario. As harvesting of forest biomass causes a decrease in forest carbon stock and a loss in forest carbon sequestration (foregone C sequestration), an emission impact occurs. This is an important aspect to understand: when more wood is removed from the forest, the net sink becomes smaller in comparison to a situation where less biomass is removed^{102,103} assuming no other differences between the scenarios, such as fertilisation. This happens also when a forest remains a carbon sink in the intensive-harvest scenario. Although this foregone carbon sequestration is physically not an emission, it increases the atmospheric CO₂ concentration compared to the less-harvest scenario. Consequently, even if the forest carbon stock is not decreased in absolute terms, harvest of forest biomass may still cause a relative loss in forest carbon sequestration.

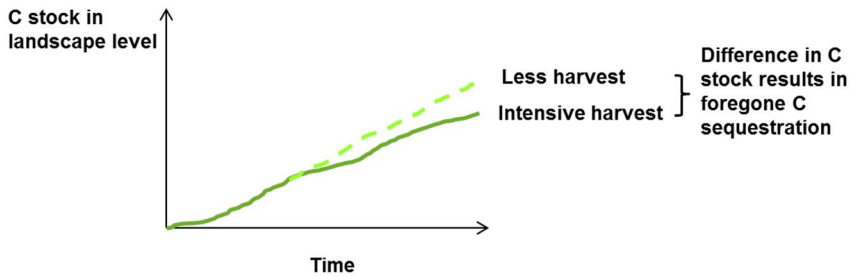


Figure 17 Illustration of a comparison between intensive- and less-intensive harvest scenarios: The C stock is increasing in both scenarios so that the forest acts as a C sink also in the intensive-harvest scenario. However, reduction of the sink in proportion to the less harvest reference has an impact on the atmospheric C balance (Figure adapted from Cowie et al. 2013¹⁰¹).

The management planning of forests is done at the landscape level, considering the total forest product portfolio¹⁷. There are alternative forest management strategies for the same forest area, all fulfilling principles of sustainable forest management but differing in rotation lengths, harvest rates and total amount of wood production. In order to compare the atmospheric impacts of these strategies, the whole life cycle of wood must be considered. In case an intensive harvest scenario (possibly with lower standing C stock) enables higher biomass production, more biomass is available (e.g. for energy, paper, packaging, and building materials) to replace fossil fuels and fossil fuel-intensive materials. Thereby more CO₂ emissions can be avoided than in the less-intensive scenario. Over time, displacement of fossil fuel emissions will eventually exceed the foregone C sequestration (**Figure 18**). How long this takes depends on the type of the biomass studied (e.g. rotation length of forest), the displaced products and the efficiency of the displacement^{104,105}.

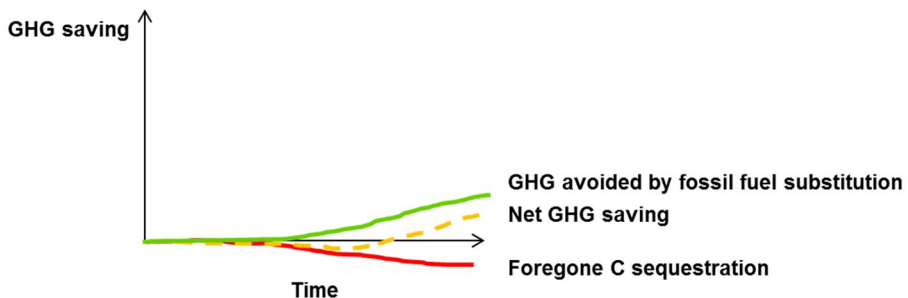


Figure 18 An illustration on how the substitution of fossil fuels eventually results in net GHG saving (Figure adapted from Cowie et al. 2013¹⁰¹).

The climate impacts of forest energy are often estimated forward in time starting from the present moment. The forward-looking perspective and consideration of marginal impact can be defended, as nothing can be done to the past, and the atmospheric carbon balance can only be influenced by *changes* to forest management practices *from now on*. Thus the past forest management and investments in forestry contributing to present forest growth are not taken into account in this perspective, which can be considered to be its weakness.

It should be noted that if forestry practices were ceased and the forest is allowed to grow on its own, we would eventually end up in a situation where the renewable resource pool provided by forests is at least partly lost. Thus, there are trade-offs between the fossil-fuel substitution and sink options of managed forests. ***Aims to maximise C stocks of long-rotation forests by decreasing harvest, would limit forests' role as a biomass source and as a substitute for fossil fuels*** in the short- and medium-term (<50–100 years). Further, concentrating on C sequestration would be a provisional, and in a way an unsustainable, option as C sinks will be saturated in the long run along with ageing forests.

4.2.2 Climate impacts of logging residue harvest and use^{ix}

During recent years several Finnish studies have brought up the impacts of harvesting logging residues, stumps and small-diameter wood on soil carbon balance.^{106,107,108,109} When residues are used for energy, the carbon contained in them is immediately released in the air. When residues are left in the forest, the carbon is slowly released in decomposition, and a decreasing carbon stock is maintained for a longer time period (the reference state). The magnitude of the impact is influenced by the length of the time period studied and the harvest strategy (single harvest, constant or increasing harvest rate).¹¹⁰ The longer the timeframe of the assessment, the greater the proportion of biomass that would have decomposed in the forest, and the lower the impact becomes. Different biomass fractions also behave differently: those that are smaller in diameter (branches, leaves) decompose faster than stumps or stems (e.g. 24% of branch and 64% of stump biomass still remains after 20 years in Southern Finnish conditions).¹⁰⁹ However, it is probable that with continuous use of logging residues C stocks may be permanently lower than in the no-use case. For stumps, the permanent C-stock loss is higher than for branches.^{107,110} But at the same time emission savings are achieved through replaced fossil products, and therefore the overall GHG balance of using logging residues becomes positive in the long run. All in all ***it is probable that emission reductions can be reached before 2050 when using fast-decomposing logging residues*** for energy.

^{ix} In this section, logging residue harvesting means additional residue harvest from fellings (final or intermediate). A normal rotation forestry is assumed, and the impact of logging residue harvesting is compared to a reference situation where residues are left in the forest.

4.3 Analysis of emissions from other life cycle phases

The whole value chain of forest biomass utilisation (cultivation, fertilisation, harvesting, transportation, storage, fuel conversion and distribution, etc.) causes emissions, including also non-CO₂ GHG emissions of methane and nitrous oxide. The emissions from these sources depend on many case-specific factors but the magnitude of these emissions is in many cases minor compared to changes in forest carbon balances.^{111,112,113,114} It has been found that the dry matter losses during storage of energy wood and logging residues can be as high as 15–24%.^{115,116} However, these losses can be effectively reduced through pre-drying the wood in smaller piles on the cutting area, and by proper covering of the piles. In favourable conditions, the logging residues can dry up to 30% in a six-week period¹¹⁵. In addition, efficient wood fuel supply chains are needed¹¹⁷.

Emissions from transportation can generally be considered negligible when talking about domestic wood and transportation distances below, e.g. 150–200 km (i.e. transportation represents less than 5% of the total GHG emissions associated with forest biomass utilization). However, if wood, e.g. pellets, were imported from overseas, the emissions from transportation would be higher. Transportation of pellets from North America to the UK has been found to typically contribute about 30% of the total GHG emissions related to the use of pellets for energy¹¹⁸. For example, the emissions associated with Canadian logging residues (40 kg CO₂/MWh) used as wood chips or pellets in the UK are two to three times greater than emissions associated with logging residues or wood processing waste from the UK (13 and 17 kg CO₂/MWh)¹¹⁹. The same impact of transporting wood from abroad can be seen in the life cycle of pellets, with higher emissions from the Baltic and Canadian sources, especially for wood processing waste.^x

The emissions due to energy requirements for fuel conversion could also play an important role, especially in biomass-to-liquid processes^{111,114}. The technologies for efficient next generation biofuel conversion are in development. When considering the direct use of wood, e.g. for electricity production, the efficiency of different conversion technologies varies significantly. The efficiency of condensing power plants can be only 30–40%, whereas the total efficiency of CHP plants can be up to 80–90% when heat is used. The possibilities to apply carbon capture and storage technologies (CCS) combined with bioenergy plants (BECCS) is also considered as an important option to reduce emissions of energy production⁹⁶.

^x This is in the same order of magnitude as the CO₂ emissions related to production of hard coal if emissions from burning the coal are excluded. For example, transportation of hard coal from Poland to Finland created about 30% of the CO₂ emissions related to the production of hard coal (Sokka et al. 2005: <https://helda.helsinki.fi/handle/10138/40482>). If also the burning of the coal is considered, then the share of transportation becomes less than 2% of the total life cycle emissions.

4.4 Other climate impacts

Besides the global warming impacts of GHGs, forests management and wood-based bioenergy have some local climate impacts. Vegetation has an influence on the solar reflectivity of the earth's surface. A forested area in general absorbs more solar radiation than a bare one, i.e. it has a lower albedo (the ability to reflect sunlight). The difference is substantial in the snowy season when the bare land's albedo is much higher than that of a forest. The warming impact of the forested area is especially high in late winter with longer daylight time. Modelling shows that afforestation in boreal and temperate regions that are seasonally snow covered decreases the land surface albedo and has a net (biophysical plus biogeochemical) warming effect, while afforestation in the tropics is likely to have a net cooling effect¹²⁰. In boreal regions, the positive forcing caused by decreases in albedo on a certain area can even offset the negative forcing that is expected from carbon sequestration in that same area¹²¹. On the other hand, forests produce aerosols that might create a cooling impact through cloud formation^{122,123}.

Incomplete wood combustion (e.g. in small-scale wood combustion, old boilers) and biodiesel are sources of black carbon particulate emissions. Black carbon particles have a warming impact by absorbing heat in the atmosphere and by reducing albedo, when deposited on snow and ice. Black carbon stays in the atmosphere for only a few days to weeks, unlike CO₂ that has an atmospheric lifetime of more than 100 years. It has been estimated that black carbon, is the second most important human emission in terms of its climate forcing in the present-day atmosphere¹²⁴. Only CO₂ is estimated to have a stronger influence on the climate.

Main messages of Section 4:

FOREST BIOMASS IN CLIMATE CHANGE MITIGATION

- Forest biomass is a renewable, domestic fuel, which advocates its use for energy. Sustainable use of forest biomass does not permanently increase the amount of carbon in the biospheric cycle, in contrast to fossil fuels.
- However, when more wood is extracted for energy use, the net carbon sink of the forest is reduced. This happens regardless of whether the forest still remains a carbon sink. This relative loss in the forest carbon sink has a similar influence on the atmospheric C balance as a carbon emission.
- By using fast decaying residual biomass either from harvests or industrial processes, emission reductions can be reached before 2050. Use of forest biomass from growing stock does not usually create emissions savings in the short- to medium-term.
- To maximise climate benefits, the harvested forest biomass should be used in the most energy and material efficient conversion processes as possible.
- In case a harvest-intensive scenario (possibly with lower standing C stock) enables higher biomass production, more biomass is available (e.g. for energy, paper, and building materials) to replace the use of fossil resources. Thereby more CO₂ emissions can be avoided in the long-term than in less-intensive harvest scenarios.
- The short-term climate aim to maximise carbon sequestration in forests is partly contradictory with the long-term aim of the bioeconomy, where forests are managed in a sustainable way to maximise continuous biomass production.
- Best practise for forestry would be to find environmentally and economically sound solutions, where the forest would be managed to produce a sustainable flow of biomass, while at the same time maintaining and increasing carbon stocks. Bioenergy production from residues is the most beneficial option.

5. Perspectives on future regulation of forest energy

5.1 Climate policy regulation of forest bioenergy

There are various alternative ways to include forest carbon balance and forest-based bioenergy in a greenhouse gas (GHG) accounting framework that could potentially serve as a basis in future climate policy – globally or within EU. Two conceivable alternatives are outlined in the following. These alternatives were chosen because they are either currently in use (approach 1) or have been actively discussed in the literature (approach 2)

- 1) Accounting zero CO₂ emissions in the energy sector due to biomass combustion, but accounting the changes of carbon stocks in forests due to biomass harvesting.
- 2) Accounting emissions in the energy sector by defining a CO₂ emission factor for forest energy based on the emissions or warming impact of the estimated future C debt or foregone C sequestration.

Approach 1 is the accounting framework applied in the IPCC Guidelines, being the basis for National Inventory Reporting (NIRs) under the United Nations Framework Convention on Climate Change (UNFCCC)¹²⁵. Each EU Member State provides its NIR on an annual basis. In the NIRs the *verified* change of C stocks in forests (ex-post) resulting from human-induced activities is reported within the Land Use, Land-Use Change and Forestry (LULUCF) sector. A negative change (decrease) of C stock is reported as an emission and positive change (increase) of C stock is reported as a removal of C from the atmosphere.

The NIRs provide information to the UNFCCC but they do not create any binding targets for emission reductions. If all countries were included in the reporting, the human-induced C balance of the LULUCF sector would be reported correctly globally. However, the change in C balance due to bioenergy would not necessarily be allocated fairly among bioenergy- or biomass-using countries, due to international trade of biomass-based fuels.

The accounting rules of the Kyoto Protocol¹²⁶ (2nd commitment period, CP2) are a kind of climate-political derivative of the IPCC framework. The Protocol (CP2)

poses legally binding emission reduction targets to its Annex I Parties until 2020 – although there are no clear sanctions if the commitments are not followed. The emission targets beyond CP2 – as well as the future of the whole Kyoto framework – are still open and this architecture will most likely not be continued in the future. The accounting rules, defining also burden sharing of emission reductions between the committed parties, are a result of a long climate negotiation process. The emissions / removals due to LULUCF are estimated based on verified changes of the C stocks ex post. However, there is a politically negotiated forest management reference level^{xi} in CP2, i.e. a baseline of C balance above which the Party will get credits in fulfilling their emission reduction targets^{xii}. In the opposite case, the C balance below the target is interpreted as an emission. The idea of the politically determined baseline is avoidance of windfall effects created, e.g., by a favourable age class distribution in forests.

There are two principal ways of causing C leakage of bioenergy emissions in the Kyoto framework:

- 1) Bioenergy is considered emission neutral in combustion. Thus, biomass imported to an Annex I country from non-Annex I countries is considered C neutral, as the C balances of the biomass producing country is excluded from the accounting. As a result, even wood coming from deforestation in a non-Annex I country preserves its C neutrality in this framework.
- 2) The C balance of the LULUCF sector in an Annex I country is not accounted on a full C basis. For instance, there is a politically negotiated national cap for the C sink / removals due to the LULUCF that can be included in accounting the C balance. When the true C sink of the LULUCF exceeds the cap, the additional C sequestration is not accounted for – thus violating the principle of full C accounting. Nevertheless, this cap can be defended by the ultimate goal of reducing emissions from fossil fuels instead of just using the LULUCF sink in fulfilling climate obligations.

Approach 2 is a possible alternative option based on a life cycle view of the biomass feedstock. The origin of the bioenergy feedstock is traced back to the site or stand from which the biomass was harvested. Development of the EU renewable energy directive (2009/28/EC)²⁴ has gone ahead according to this approach, but the treatment of solid biomass, such as forest energy, is still open. When applying Approach 2 for sustainable long-rotation forestry, it would be possible to even define an emission factor for biomass:

^{xi} Note that there are no clear scientific criteria to determine this level.

^{xii} In CP2, the ceiling value for the LULUCF CO₂ sink is 3.5% of the national emissions in 1990 (without LULUCF sector), set in COP17 in Durban. Thus, the portion of true sink that can be credited is much higher in countries with high fossil CO₂ and lower LULUCF sink. When the true sink exceeds the cap there are no incentives to increase utilisation of the sink and incentives rather to use forest biomass for energy or feedstock of forest industries.

- Based on the future (post-harvest) C debt or foregone C sequestration, it would be possible to determine an emission factor (tCO_2/TJ) for the harvested biomass – within 100 years or some other timeframe to be negotiated. This emission factor would be calculated based on the warming impact due to the C debt or foregone C sequestration (e.g. by using Global Warming Potential Bio, GWP_{bio})^{98,99}.

The principal advantage of this life cycle approach is that the sustainability of the biomass (including climate impacts) would be determined by the true origin of the biomass. For instance, biomass from deforested lands could in principle be recognised – even if coming from outside the EU area or from countries without their own emission reduction commitments. Thus, there would be no C leakage in accounting, due to biomass trade flows over system boundaries. Further, the accounting framework would treat domestic (EU) as well as imported biomass in a similar manner. This type of sorting of traded biomass would be acceptable also according to the rules of the WTO in cases where domestic biomass (i.e. within EU) would be treated by similar criteria.

However, there are also major challenges in this approach:

- One of the major principles of an international, legally binding accounting and reporting framework is that it should be based on *verified emissions* that actually took place. The major methodological flaw of Approach 2 is that it is based on a projection of future dynamic C debt (baseline C stock minus C stock of the re-growing stand after harvest) – and is thereby not compatible with the basic principles of emissions accounting.
- There is no permanent C loss in sustainably managed forest, as the biomass harvested will basically be replaced by regrowth; the period of regrowth depending, e.g., on climate conditions. Harvesting a stand causes a C debt in proportion to the no-harvest baseline – whose definition, however, is not self-evident and raises arguments. Further, one could also point out that without forest management and demand for wood the C stocks of the current forest lands would be essentially lower. Thus, according to this argument the past investments in forestry should be credited somehow in the accounting system. Another major problem would be to estimate the indirect emissions (such as iLUC).
- Sustainability certification of each biomass batch coming to the power plant would create high transaction costs for smaller players on the market.

Thus, Approach 2 and analysis of carbon balance or warming impact of alternative forest management scenarios from today forward (ex-ante) may be more useful for planning purposes than for regulation.

5.2 EU Renewable Energy Directive

As mentioned in Chapter 5.1, the current EU sustainability criteria for liquid biofuels published in the RED (2009/28/EC)²⁴ follow the life cycle assessment approach. The criteria present a method to calculate the emission savings gained by using biofuels compared to fossil fuels. This emission saving has to be 35% for old biofuel plants and 50 or 60% for new plants. In order to simplify calculations, the RED provides default emission saving values for certain biofuel chains, mostly for the agro biomass- and oil crop-based value chains. For the forest biomass-based biofuels the default values are given only for two wood classes: “waste wood” and “farmed wood”, and they vary between 70–95% emission saving. However, the biofuels planned to be produced from forest biomass do not necessarily fall under either of these classes. “Waste wood” has been traditionally understood to mean, for example, wood from construction and demolition, and not the side streams or by-products of forest industries (pulp and paper production and sawmill industry). “Farmed wood” has been understood to refer to wood plantations, and not to forestry land under traditional economic use. Studies done for hypothetical forest-based biofuels in Finland (e.g. FT-diesel from logging residues and stumps) show that the emission saving results reach 70–90% when calculated according to the RED criteria, excluding the soil carbon stock change due to logging residue harvesting (see Section 4.2.2). If the carbon stock change is included, the emission saving results likely stay below 60%, when timescales from 20 to 100 years are used for the calculation.^{113,127}

Another challenge of the RED calculation method related to the technologies generally used to convert forest biomass to biofuels is that the RED poorly recognises the nature of integrated processes. The RED does not give clear guidance on how the system boundary should be set, e.g. in cases where biofuel production is combined with a CHP plant, or when biofuels are produced in biorefineries with several other end products. It is not clear if the GHG emission calculation should be done for the whole integrated system or if the system boundary can be set separately for the biofuel process. Different interpretations on the system boundary setting can alter the results of the GHG emission calculation significantly¹²⁸, and the rules for system boundary setting should thus be clarified. In addition, the RED states that the allocation of emissions between the products inside the system boundary should be carried out in proportion to the energy content of the products, determined by a lower heating value (LHV) in the case of co-products other than electricity. This might be problematic considering co-products without lower heating value, such as heat, which can still be valuable commodities. Also, when the biofuels are produced in biorefineries with various products aimed for other than energy purposes (e.g. wood products, bio chemicals, food), the energy allocation may not be appropriate. There are other

possibilities to divide the emissions between the products, such as allocation based on the economic value of the products, better reflecting changes in market conditions and thus preventing allocating emissions to co-products that have no economic value or use.¹²⁹ Therefore, *there is clearly room for revisions to the RED methodology in relation to Northern European forest energy.*

The EU Commission is further developing the RED sustainability criteria in the so-called “ILUC directive”, which has been recently published in the official journal of the EU ((EU) 2015/1513)¹³⁰. The need for the ILUC directive arose from concern about the indirect land use impacts due to intensive production of biofuels from feedstock suitable for food production. In the directive, the so-called ILUC-factors are presented for bioenergy feedstock also suitable for food (cereals and other starch-rich crops, sugars and oil-crops). The ILUC problem is not generally connected to boreal forest energy, and no ILUC-factors are presented for forest biomass. The directive sets a limit of 7% of final consumption of energy in transport on the first generation biofuels, and an indicative target of 0.5% of the share of energy from renewable sources in all forms of transport in 2020 for advanced biofuels. The ILUC directive also provides a list of the waste and residue biomass feedstocks that can be counted as double in the national targets for biofuels for 2020 (so-called double-counting rule, where 1 MJ of biofuel from waste and residue can be counted as 2 MJ). Also the waste hierarchy and the cascading use have been mentioned as one of the criteria that Member States need to take into account (see Section 6).

After the establishment of the RED, whether similar criteria should be expanded to cover also other bioenergy applications outside the transport sector has been discussed. The EU Commission has published voluntary guidelines for the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU¹³¹. The RED calculation method for emission saving does not currently include the impacts due to changes in forest or soil carbon stocks. Only direct land use changes are considered (e.g. converting forest to agricultural land) and the impacts e.g. due to carbon debt or foregone carbon sequestration (Section 4) are ignored. In the summer 2014, the Commission published a working document on the state of play on the sustainability of solid and gaseous biomass used for bioenergy¹³². The document included a discussion on the potential climate impacts related to forest biomass use, and concluded that the majority of bioenergy used in the EU yields emissions savings. However, some bioenergy chains could lead to “negligible GHG savings or even net emissions within policy relevant periods” (such as use of stumps and stem wood). It also stated that there are differences in the results of bioenergy studies due to methodological choices, assumptions within the scenarios, site-specific characteristics of forests, and forest management practices. The results are also very sensitive to the reference scenario for land use, presenting the counterfactual scenario “without bioenergy studied”, against which the bioenergy scenario is evaluated.

In the Commission communication on a Framework Strategy for a Resilient Energy Union (COM(2015)80), one of the 15 actions announced is that the Commission will propose a new Renewable Energy Package in 2016–2017. This

package will include a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU target is met cost-effectively. It is also stated that the EU has agreed on a target of at least 27% of renewable energy by 2030, at the EU level. *If the sustainability criteria were expanded for solid and gaseous bioenergy and the biomass streams followed with the same accuracy as in the current RED criteria, a very heavy bureaucratic process might be created.* For example, in Finland there are several hundreds of power and heat production plants using some kind of wood biomass and the biomass streams in these plants are accumulated from various small sources. Thus, tracking all the biomass flows reliably would create a very significant workload for companies and administrations. The uncertainty over the final forms of the energy policy and sustainability criteria has slowed down investments in new bioenergy capacity.

Main messages of Section 5:

PERSPECTIVES ON FUTURE REGULATION OF FOREST ENERGY

- **When developing EU climate policy, an accounting system consistent with the established IPCC framework would be preferable.**
- **Analysis of carbon balance or warming impact of alternative forest management scenarios from now on forward (ex-ante), are useful for planning purposes but international commitments and regulation should be based on verified emissions (ex-post). The accounting rules, however, could be a combination of verified emissions and projected, politically negotiated baselines defining burden sharing between the parties.**
- **An accounting system based on certification of each batch of biomass feedstock would potentially create high transaction costs, penalising especially the small players in the markets. An essential issue to be considered is the treatment of international trade flows in a proposed emission accounting system.**
- **The current RED sustainability criteria should be developed to better recognise the advanced biofuels produced from forest biomass.**
- **The expansion of the RED sustainability criteria for solid and gaseous bioenergy in heat and power production would create a significant bureaucratic work load in countries like Finland, with numerous wood sources, end-use options and integrated processes.**

6. Cascading principle as a way to improve circular economy

The cascading use of wood has recently been increasingly emphasised in the EU. For example, in the currently published ILUC directive ((EU) 2015/1513)¹³⁰, the waste hierarchy and cascading use have been mentioned as principles that Member States need to take into account, by taking into consideration the regional and local economic and technological circumstances. The cascading principle has also been discussed in the Commission strategy for a circular economy¹³³ (Figure 19), and in the EU Forest Strategy¹³⁴. In addition, the European Commission is currently (2015) carrying out a 'Study on the optimised cascading use of wood'. The cascading principle is important, as woody biomass is a limited resource, and its use and *the service life of wood fibres should be optimised*. Similarly, the cascading principle could be discussed in relation to other limited resources, such as other biomass or fossil resources.

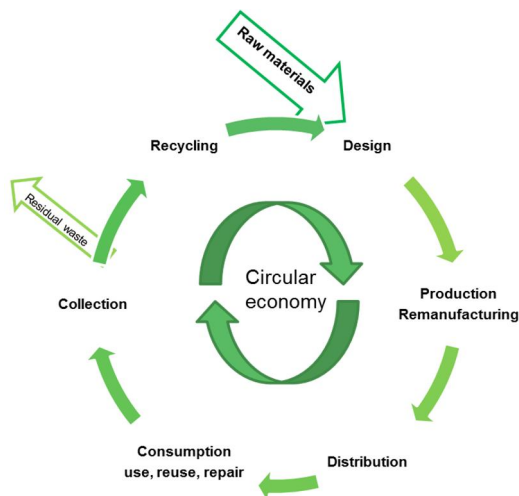


Figure 19 Simplified illustration of the use of resources in a circular economy (Figure adapted from COM(2014) 398)¹³³.

Simply put, cascading use of biomass means that biomass is used (and reused or recycled) at least once or several times as a product before its end-of-life (e.g. energy use or landfill) (Figure 20). The concept of cascading use has been presented in many studies and reports, but the definitions used in these publications differ. So far there seems to be no full consensus on what is meant by “cascading”. Some define cascading use as use that occurs only when final material products are reused at least once or several times as products before their energy recovery (Carus et al. 2014)¹³⁵. According to this definition, all forms of intermediate products without a real material use by private or industrial consumers are excluded from the definition of cascading use. On the other hand, some have defined cascading so that also direct energy use of forest industry residues can be considered as cascading use (Mantau 2012)¹³⁶.

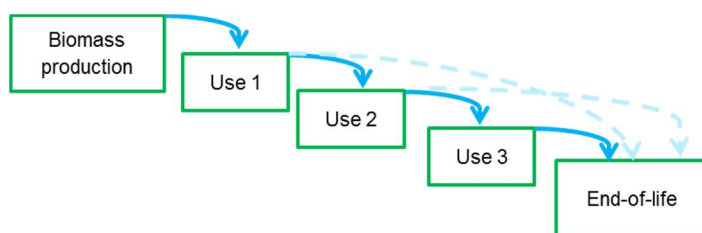


Figure 20 Simplified presentation of cascading use (Figure adapted from Odegard et al. 2012¹³⁷).

The resource use hierarchy of the principle of cascading can be considered to have its roots in the waste hierarchy of the Waste Framework Directive (2008/98/EC)¹³⁸. According to the waste hierarchy, waste prevention, re-use and recycling go over energy recovery (Figure 21). However, the Member States can also encourage options where the use of waste does not follow the hierarchy but delivers the best overall environmental outcome justified by life-cycle thinking. One view point to the cascading discussion asks whether the different types of energy use are considered to have the same value. For example, does refining of wood for transportation biofuels have the same value as using wood directly for electricity or heat production? Refined biofuel products could also be considered to be on a same level of the hierarchy, as other biochemistry products substituting fossil resources. To value the different uses of biomass, several principles could be used, for example: added value, environmental impacts, greenhouse gas emissions, or societal value of the product (e.g. for food).

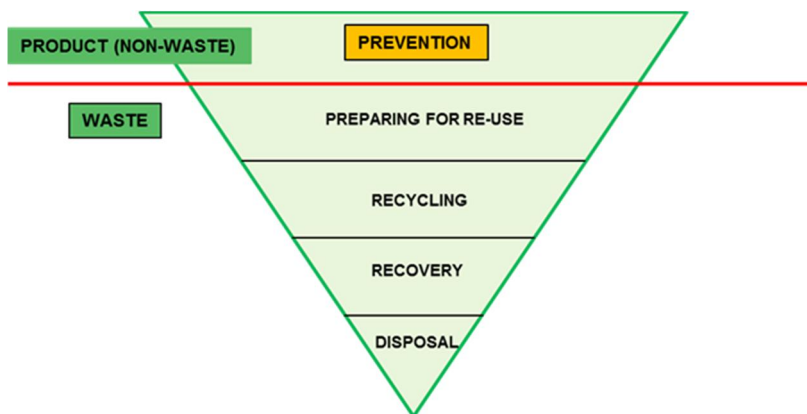


Figure 21 The waste hierarchy according to the Waste Framework Directive (Figure adapted from the European Commission 2015¹³⁹).

The cascading wood flows for the EU are presented in **Figure 22**, and for Finland in **Figure 23**. The figures show that the Finnish wood flows differ significantly from the average European wood flows presented by Mantau (2012). First, the direct use of wood for energy is relatively much lower, and the use of wood for the pulp industry much higher, in Finland than in the EU. Second, *as Finland exports a significant part of its wood biomass in product-related value chains (as pulp, paper and board, timber and plywood), the cascading cycles of wood products take place outside Finnish borders*, e.g. in the other Member States. This limits the cascading cycles inside Finland^{xiii}. Therefore, at the EU level, the cascading should be considered from the perspective of the whole wood use cycle, where the role of the wood producing countries supplying virgin fibre differs from the consumer countries with more recycling.

^{xiii} A separate study on the cascading use of wood in Finland with in comparison to selected EU countries available: <http://www.vtt.fi/inf/julkaisut/muut/2015/VTT-R-03979-15.pdf>

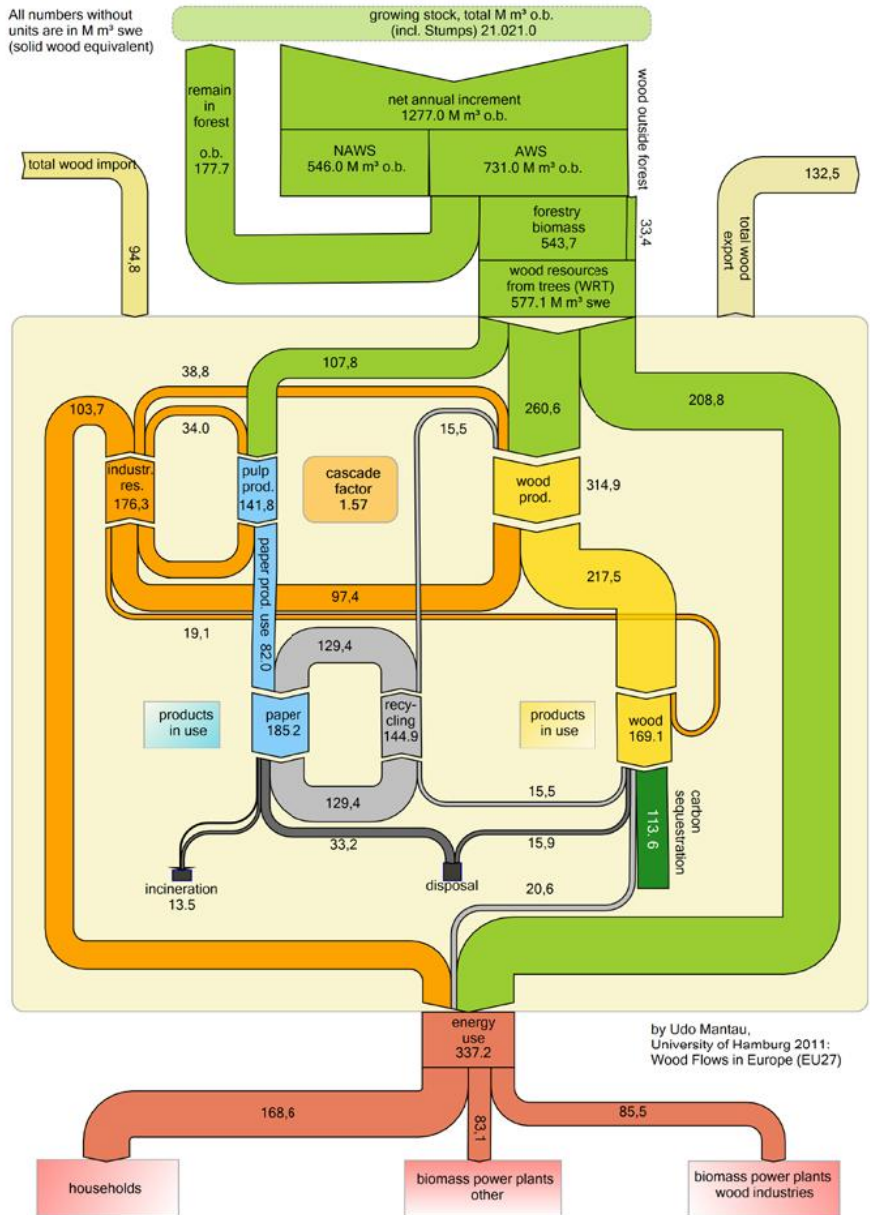


Figure 22 Wood flows in the EU, according to Mantau 2012¹³⁶.

Wood flows in Finland, 2013

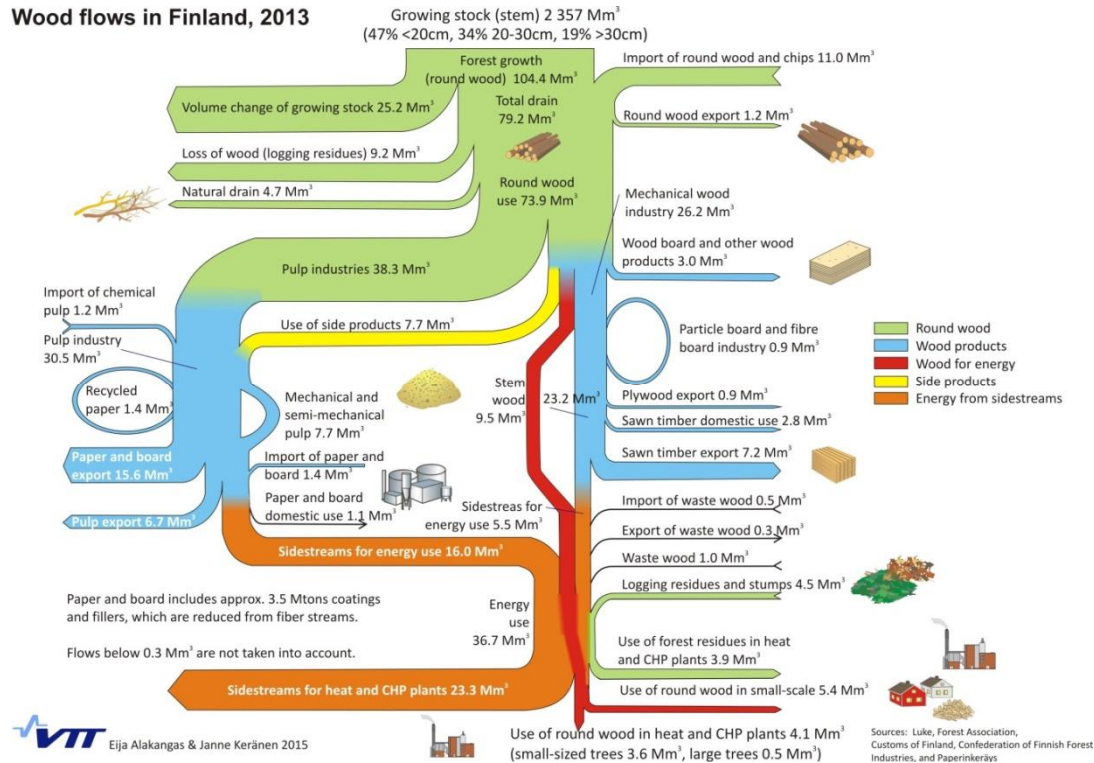


Figure 23 Wood flows in Finland (VTT 2015⁵). The threshold value for showing the streams is 0.3 million m³. The flows are described in detail in Appendix I.

In addition, the figures show that the energy use of wood industry side streams is very significant in Finland. The Finnish forest industry has built optimised wood use cycles over many decades. The direct energy use of streams like black liquor or bark can be considered reasonable in the pulp and paper industry with highly developed facilities and elevated self-sufficiency in energy use. ***A strictly defined cascading principle should not be seen as the only option to promote resource efficiency***, and it could be partly in contradiction with the present energy and material efficient solutions of the forest industry.

Main messages of Section 6:

CASCADING PRINCIPLE AS A WAY TO IMPROVE CIRCULAR ECONOMY

- **The cascading should be considered from the perspective of the whole wood use cycle, where the role of the wood producing countries supplying virgin fibre differs from the consumer countries with more recycling.**
- **Cascading hierarchy should be applied prudently, considering national and regional circumstances. It may be very difficult to find a uniform principle for cascading use of wood that would lead to the best possible solutions in countries under various circumstances.**

7. Economics of forest energy

7.1 Forest biomass as part of the EU's and Finland's economies

In Europe, forest biomass for energy is largely produced as a complementary by-product of wood material and the fibre product industry, which makes it challenging to separately evaluate the impacts of forest energy on the EU's economy and national economies. Additional benefits of bioenergy on national economies may be observed if the use of bioenergy has a positive impact on the EU's balance of current payments and trade. The bioenergy sector may also have many indirect impacts, which makes the analysis even more complicated.

The employment potential of forest energy and other bioenergy sectors is high compared to other renewable technologies due to feedstock production, supply, handling and logistics. According to the EurObserv'ER statistics, the number of employees in the bioenergy sector in 2012 was estimated as 489 790 and the gross value added in the bioenergy industry was estimated at 47 887 million EUR. This number includes both the direct and indirect jobs^{xiv}. **Figure 24** shows the job distribution of the bioenergy sector in the EU in 2012.

^{xiv} Direct and indirect employment number includes RES production, equipment and component supply, onsite installation, operation and maintenance, but does not take into account job losses in other industrial sectors due to expenditure and investment in sectors.

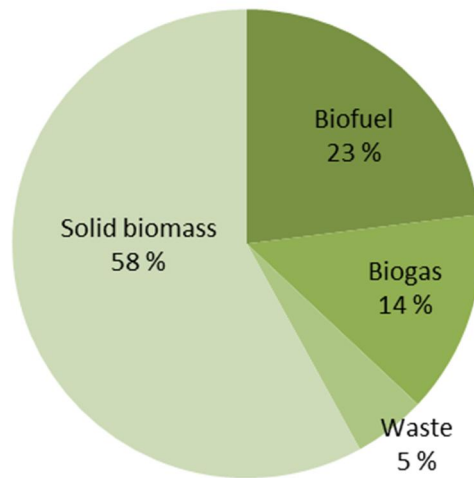


Figure 24 Job distribution of the bioenergy sector in 2012 based on the EurObserv'ER data (source: AEBIOM 2014²⁸).

The total employment of the forest industries as a whole in 2010 was about 2.6 million employees and the gross value added nearly 100 billion EUR (**Table 4**). Among the EU-28 countries, the impact of the forest sector on gross value added is clearly the highest in Finland. Also in Latvia, Sweden, and Estonia the impact of the forest sector on national economies is high. In 2013 the share of the forest industry was about 4% of Finland's GDP³. The seven most forested countries in the EU (Sweden, Spain, Finland, France, Germany, Italy and Poland) produce 68% of the total gross value added in the forestry and wood industry in Europe.

Table 4 Employment and gross value added of the forestry sector in 2010 (source: State of Europe's Forests 2011¹⁹).

Country	Gross Value Added 2010								Employment 2010				
	million Euro				% of total GVA				Total [thousand full time equivalents]				
	Forestry	Wood-products industries	Pulp and paper industries	Total	Forestry	Wood-products industries	Pulp and paper industries	Total	Forestry	Wood-products industries	Pulp and paper industries	Total	% of total employment
Finland	3 562	1 248	3 401	8 211	2.2	0.8	2.1	5.1	23	26	21	70	2.8
France	3 185	3 556	5 065	11 805	0.2	0.2	0.3	0.7	25	83	68	175	0.7
Spain	-	3 247	-	-	-	0.3	-	-	38	110	43	191	1.0
Sweden	2 707	2 956	3 560	9 223	0.9	1.0	1.2	3.1	26	39	35	100	2.2
Germany	2 650	7 560	10 560	20 770	0.1	0.3	0.5	0.9	43	147	146	336	0.8
Austria	1 137	2 280	1 577	4 993	0.5	0.9	0.6	2.0	11	45	18	74	1.8
Poland	994	2 172	1 270	4 437	0.3	0.7	0.4	1.4	44	143	38	225	1.5
Czech Republic	804	1 126	570	2 500	0.6	0.8	0.4	1.8	18	67	25	110	2.2
Portugal	624	796	728	2 149	0.5	0.6	0.5	1.6	13	66	14	93	1.9
United Kingdom	585	3 810	3 502	7 897	0.0	0.2	0.2	0.4	16	84	83	184	0.6
Romania	442	1 076	453	1 971	0.4	1.0	0.4	1.8	44	128	19	190	2.1
Italy	387	6 437	5 037	11 861	0.0	0.5	0.4	0.9	43	166	88	298	1.2
Latvia	266	384	28	679	1.3	1.8	0.1	3.2	24	31	1	56	6.6
Denmark	230	841	576	1 646	0.1	0.4	0.3	0.8	3	14	6	22	0.8
Slovakia	222	242	178	642	0.4	0.4	0.3	1.1	24	34	8	67	3.1
Slovenia	179	244	155	578	0.5	0.7	0.5	1.7	3	15	7	25	2.5
Ireland	163	454	194	811	0.1	0.3	0.1	0.5	2	8	2	12	0.6
Croatia	157	176	105	438	0.4	0.4	0.3	1.1	14	19	5	38	2.5
Lithuania	143	345	74	562	0.5	1.2	0.3	2.0	12	32	3	47	3.7
Hungary	143	286	251	680	0.2	0.3	0.3	0.8	14	38	14	66	1.6
Belgium	142	991	1 125	2 257	0.0	0.3	0.4	0.7	3	24	16	42	0.9
Estonia	104	195	35	334	0.9	1.6	0.3	2.8	5	17	2	24	4.3
Bulgaria	97	-	-	-	0.3	-	-	-	23	27	11	61	1.7
Greece	63	205	359	626	0.0	0.1	0.2	0.3	5	28	9	43	0.9
Netherlands	54	1 233	1 528	2 815	0.0	0.2	0.3	0.5	2	23	23	47	0.5
Luxembourg	8	32	-	-	0.0	0.1	-	-	n.s.	n.s.	n.s.	-	-
Malta	0	5	6	11	0.0	0.1	0.1	0.2	-	n.s.	n.s.	-	-
Cyprus	-	-	-	-	-	-	-	-	1	4	n.s.	-	-
EU-28	19 045	41 897	40 335	97 893					477	1416	705	2594	1.2

7.2 Trade of wood for energy

Even though the role of imported energy biomass is marginal in the Nordic Region, the situation in many Central European countries and also in the United Kingdom is very different: the majority of energy biomass is imported from overseas, e.g. from North America (mainly wood pellets). Global trade in liquid and

solid biomass and processed bioenergy carriers has been growing rapidly, boosted by national policies to reach the national renewable energy targets set by the EU. Also the trade in solid biomass feedstocks (e.g. wood chips and wood pellets) has followed the same trend. Especially the direct trade of solid biofuels, like pellets, has grown rapidly but the indirect trade through the trading of industrial roundwood and material by-products has been relatively stable over the past years. However, trade in wood chips for energy (virgin and/or from residues) is practically limited to Europe, Turkey, and Japan, being less than 20 PJ annually. The direct trade of wood chips for energy purposes is thus about 10% of the indirectly traded volume (in terms of calorific value)²¹.

Wood-based bioenergy is the most competitive when it is a by-product of forest industry. The biomass price at mill sites can even be negative if biomass creates waste handling costs, when not used for bioenergy. **Figure 25** shows the development of fuel price in heat production in Finland. It can be seen that the price development of the forest biomass has been more stable than that of fossil fuels. However, during recent years the price of coal has decreased due to lower demand, especially in the United States. Combined with the low emission allowance price levels, the cost competitiveness of coal compared to biomass has increased, which has led to increased coal use in some heat plants in Finland.

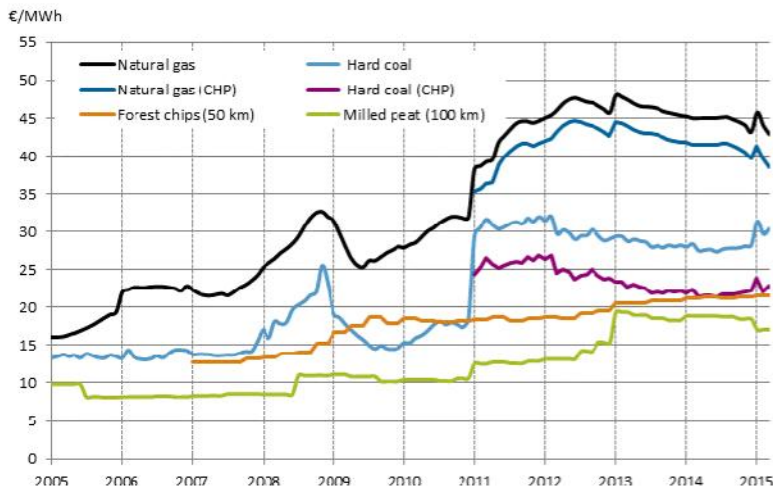


Figure 25 Fuel prices in heat production in Finland (Statistics Finland 2015¹⁴⁰). The change in prices in 2011 is due to changes in world market prices and due to changes in Finnish taxation system. A separate CO₂ tax level¹⁴¹ was set for fuels used in CHP plants, so the prices for gas and coal used in CHP plants are separated after 2011.

INFOBOX 5: Forest owner's perspective – case of Finland

Over 60% of Finland's commercial forests are owned by non-industrial private forest owners. The average size of these, altogether about 347 000 small family forest holdings, is 30.3 ha. For forest owners, pre-commercial thinnings are not profitable to conduct due to high per-unit costs related to dense stand structure and small average piece size. Therefore, the harvesting of energy wood from young forests ready for thinning can be encouraged by state subsidies that are designed to increase the use of energy wood through promotion of silvicultural activities in young forests; thereby boosting employment and the national economy¹⁴². Only a small proportion of forest owners' income is based on energy wood harvesting. From the perspective of forest owners, energy wood has the lowest value in terms of stumpage prices. In recent years, the stumpage prices of pulpwood and sawlogs have been relatively stable. However, the price level is lower than in the beginning of this millennium. The unit stumpage prices of harvested pine saw logs, pulpwood and energy wood were 56, 16, and 4 €/m³, respectively in 2013. Presently, the share of energy biomass is only 1.5% of the total sales value of biomass sold annually from Finland's forests (Figure 26). As a result, it is considered as a by-product of silvicultural and logging operations also from the forest owner's perspective and forest management practices are targeted toward the production of industrial roundwood.

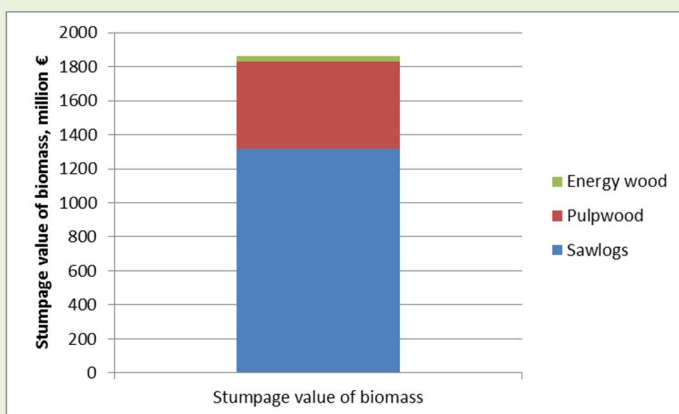


Figure 26 Shares of sawlogs, pulpwood and energy wood in the value of annual sales of biomass in Finland (Statistical Yearbook of Forestry 2014³).

Growing forests in Nordic conditions requires long-term commitment: the time lapse between the establishment of a stand (planting of trees) and final harvest is typically 55–85 years. Energy wood is harvested in connection with the first thinning as the stand reaches the age of 30 years. If e.g. 50 m³/ha energy wood is harvested in first thinning, the income totals 175 €/ha. For the extraction of wood for energy from young forests the forest owner can get a subsidy of 450 €/ha. When logging residues and stumps are harvested in connection with the final harvest, forest owner gets c.a. 200 €/ha extra income from the energy biomass. In addition, he may get reduced cost for the soil preparation (c.a. 100 €/ha), because stump removal decreases the need and costs of soil preparation for promoting the regeneration of the stand, and planting of trees becomes easier.

7.3 Impact of EU 2030 climate and energy policies on the role of forest energy in the future

On 22 January 2014, the European Commission published a policy framework for climate and energy in the period from 2020 to 2030¹⁴³. The Commission set a 40% reduction target for domestic EU greenhouse gas (GHG) emission in 2030, relative to emissions in 1990. This will ensure that the Union continues to follow the least cost pathway to a low-carbon economy. Unlike in the 2020 climate and energy policy framework, the Commission did not set binding national targets for the use of renewable energy resources but an EU-level renewable energy target of 27% by 2030. In addition, the Commission proposes that the EU's ETS sector will have to deliver a reduction of 43% in GHG emissions in 2030 and a reduction of 30% in the GHG emissions excluded from the ETS (i.e. non-emissions trading sector, non-ETS) both compared to 2005. The non-ETS target will be allocated amongst Member States but the Commission has not yet specified any exact effort sharing between the Member States.

According to Finnish scenario studies¹⁴⁴, the alternative scenarios up to 2050 for Europe and for Finland show the development of different renewable energy sources for primary energy production (**Figure 27** and **Figure 28**). In the Baseline scenario, only the current EU 2020 energy and climate policies for Europe were assumed, without any new climate policies for the rest of the world. In the other scenarios the EU's 2030 policy framework was taken into account by setting the above-mentioned EU GHG mitigation targets to both ETS and non-ETS. For Finland, also a national-level non-ETS target was set according to the same burden sharing rules as in the 2020 policy framework. Three different scenarios were examined, where two main dimensions were selected: growth in energy demand and growth focusing either on solar or bioenergy. The three scenarios are called "Crunch", "Bio-Inno", and "Bio-Stor". In the Crunch scenario, climate policies are not priorities, technology development is conservative, and prices of fossil fuels return to high levels. In the Bio-Inno scenario, "centralised bio-policies" are assumed, and bioenergy has a strong position in the focus of European research and development. In the Bio-Stor scenario, bioenergy supports other renewables, especially solar, and bioenergy storage systems evolve to balance the intermittent energy production. In both, the Bio-Inno and Bio-Stor scenarios, the global 2 degree mitigation target was assumed resulting in moderate fossil fuel prices (i.e. price of crude oil remains below 100 USD/bbl). On the European level, the use of agro biomass sources (i.e. energy crops, agricultural residues and wastes, etc.) is expected to grow much more than forest bioenergy (**Figure 27**). In Finland, the situation is vice versa, i.e., forest energy is expected to remain the major renewable energy source (**Figure 28**).

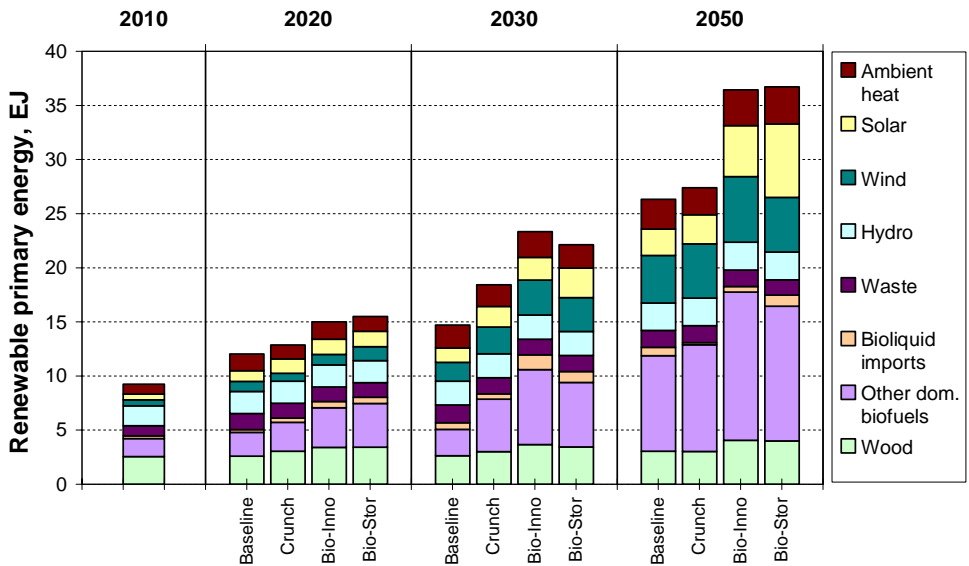


Figure 27 Supply of renewable primary energy in Europe (includes all municipal waste) (source: Kallio et al. 2015¹⁴⁴).

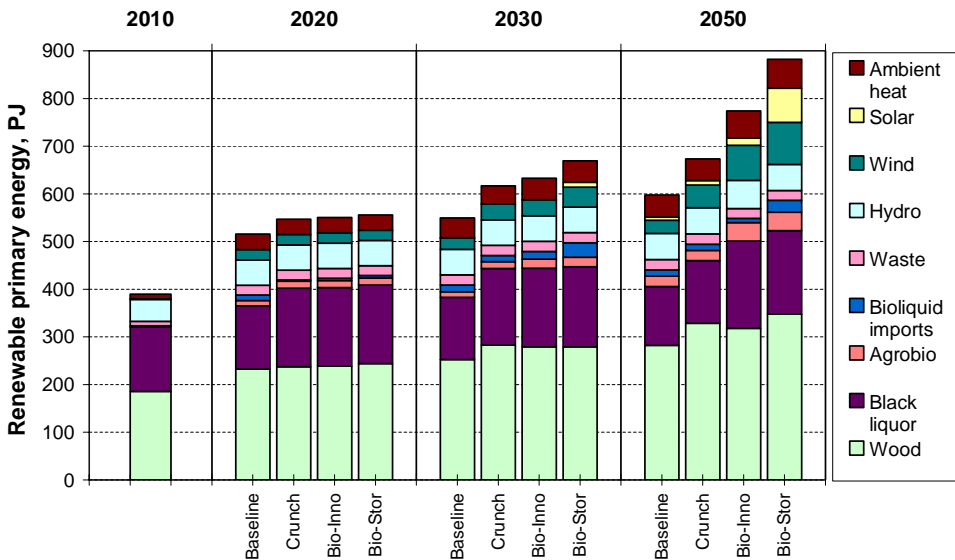


Figure 28 Supply of renewable primary energy in Finland (source: Kallio et al. 2015¹⁴⁴).

The scenarios propose that the EU 2030 climate and energy policies will have an impact on biomass demand and its competition in different energy sectors. The highest increase in bioenergy demand is shown in the transport sector, which is among the largest non-ETS sectors in the EU (**Figure 29**). However, it should be noted that there are significant uncertainties especially related to the transport sector, due to the uncertainty related to the speed of penetration of alternative vehicle technologies, such as electric and hybrid vehicles, the level of modal shift, and consumer behaviour. In the scenario assessments presented here, the 2nd generation biofuels are so-called drop-in fuels, which may be used in the existing vehicle fleet. On the other hand, there are large uncertainties related to the costs of large-scale biorefineries, which should be taken into account as well (see e.g. Infobox 6 below).

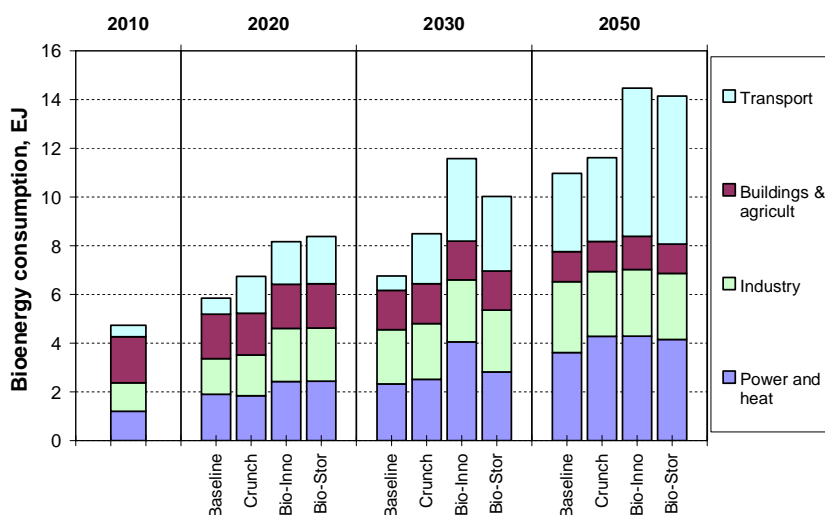


Figure 29 Bioenergy use by sector in Europe (source: Kallio et al. 2015¹⁴⁴).

In addition to new targets for the ETS and non-ETS sectors for 2030, an open question is also how the agriculture, land use change and forestry sectors will be treated in the 2030 policy framework (i.e. AFOLU and LULUCF sectors). The Commission has proposed that to ensure that all sectors contribute in a cost-effective way to the mitigation efforts, agriculture, land-use, land-use change and forestry should be included in the GHG reduction target for 2030. However, the architecture of the implementation of these sectors is still open and further analysis will be undertaken with the aim of assessing the most appropriate policy approach.

INFOBOX 6: The impacts of the EU's 2030 climate and energy policies on Finland's energy economy.

According to the impact assessments of the EU 2030 climate and energy framework on Finland's energy systems and national economy, the largest challenges for Finland would be the 2030 non-emission trading sector target, which could be tightened from the existing -16% in 2020 up to 35–40% in 2030 compared to the 2005 emission levels¹⁴⁵. The results of the impact assessment showed that in the cost-optimal solution the emission reduction is the highest in the transport sector (Figure 30), where GHG emissions may be reduced by rapid renewal of the vehicle fleet, by electrification of the transport sector and by increased use of biofuels as a drop-in solution to the existing transportation infrastructure. In the 2030 impact assessments the replacement of diesel and gasoline by 2nd generation biofuels seems to be the most cost efficient way to reduce the GHG emissions in transport, which would lead to 40% biofuel use from total energy in road transport by 2030 (when these fuels are considered carbon neutral). In addition, the GHG emissions of the machinery and space heating sectors are reduced due to replacement of mineral oil by biofuels.

The 2nd generation biodiesel may be flexibly used up to 100 percent in the existing vehicle fleet, which means that the direct costs would be focused on new investments on biorefineries, which would use domestic wood as a raw material. Also the use of bioethanol increased in the assessments, but not as much as the use of biodiesel. One option is also to increase the imports of biofuels. However, it should be noted that because the technology of the 2nd generation biofuel production is not commercially mature yet, it was assumed that before the year 2030 the 2nd generation biorefinery investments would be realised with help of public risk money and other support, especially for the first investments of biorefineries. In addition, it was assumed that there is enough wood available for the biorefineries in Finland.

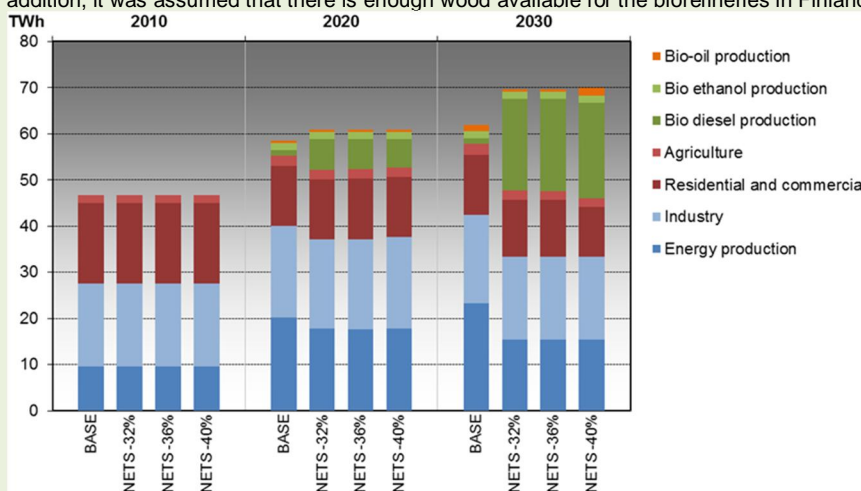


Figure 30 The sectoral use of solid wood biomass (excluding black liquor) in the Baseline (Base) and alternative policy scenarios with non-emission trading sector targets -32%, -36% and -40%, in Finland (source: Koljonen et al. 2014¹⁴⁵).

Main messages of Section 7:

ECONOMICS OF FOREST ENERGY

- **Wood-based bioenergy is the most competitive, when it is a by-product of forest industry or/and used in bio-refineries. The biomass price at a mill site can even be negative if biomass creates waste handling costs when not used for bioenergy.**
- **Forest management practices are mainly targeted at the production of industrial roundwood. For the forest owner, the harvesting of energy wood creates added value, but compared with the income from the selling of sawlogs and pulpwood, its economic importance is small.**
- **On a European level, the use of agro biomass (i.e. energy crops, agricultural residues and wastes, etc.) is expected to grow much more than the use of forest bioenergy. In Finland, the situation is vice versa, i.e., forest energy is expected to remain the major renewable energy source.**

8. Conclusions and recommendations

Nordic forests provide a variety of valuable, monetary and non-monetary, services. In Finland, over 10% of the gross value added to forestry (or 15% of the value of traded timber) is re-invested by forest owners into the forest resource. This re-investment has enabled enhancement of biomass production, improvement of plant material, maintenance of forest roads, efficient forest fire and forest damage control and maintenance of waters and watersheds located in forests. In recent years, the stemwood removals from Finnish forests have been only 60–70% of the net annual increment, resulting in increasing growth of forests. For example, since the 1950s in Finland, the growth of forests has doubled from 50 million m³/a, to the current level of 104 million m³/a. Lately, the growth has exceeded the total biomass removal by 30 million m³ annually leading to an increase of growing stock from 1 500 million m³ to 2 400 million m³ between 1950 and 2014, even though simultaneously nearly 3 500 million m³ stemwood has been cut. The forest sink in Finland has also been steadily growing during the past decades. The magnitude of the sink is substantial: its size has been more than 40% of the national GHG emissions during 1990–2012. Also, future scenarios indicate that the planned use of wood does not threaten the increasing trend of the forest sink. This development should be ensured by continuous investment in forest resources and by good forest management practices.

80% of Finnish wood-based energy is produced using by-products and residues from the forest industry, of which 64% (61 TWh, 220 PJ) is in the form of black liquor, bark, sawdust, and other industrial wood residues, and 16% (15 TWh, 54 PJ) is composed of logging residues, stumps and small-diameter trees combusted in combined heat and power plants. However, scenarios to increase production of bioenergy to a level that would require primary wood resources to be used for energy production has led to a critical discussion on the use of forest resources, the stability of forest sinks and the climate-neutrality of using biomass for energy. Even though the future scenarios for Finland predict that it is possible to produce forest energy and have a growing carbon sink at the same time, more-intensive harvest scenarios reduce the growth of the carbon sink compared to less-intensive harvest scenarios. This relative loss in the forest carbon sink is equal to a carbon emission. Therefore, the use of growing forest biomass for energy usually only creates emission savings in the long run, not in the short to medium term.

However, by using fast decaying residual biomass either from harvests or industrial processes, emission reductions can be reached already before 2050.

Moreover, if the only goal was to increase carbon sequestration in the forests, and the harvests were minimised in the short to medium term, forests would eventually end up in a state, where forests as a continuous productive source of renewable energy and materials would be lost. In the long run, ceasing forest harvesting drives sequestration to a halt. Thus, in the long-term harvesting for bioenergy is often a better choice from the point of view of climate change mitigation. Forest biomass is a renewable, domestic fuel, which advocates its use for energy. Sustainable use of forest biomass does not permanently increase the amount of carbon in the biospheric cycle contrary to fossil fuels. The best combination for effective climate and forest economic policy would therefore be to find environmentally and economically optimal solutions, where the forests would be used in the best possible way to produce a sustainable flow of biomass while maintaining and increasing the carbon stocks at the same time.

When the Finnish silvicultural guidelines (Infobox 2) are followed, the negative effects of harvesting on the growth of the forests can be reduced. For example, allowing needles to fall onto soil before biomass transport reduces the risks for nutrient losses. The guidelines demand leaving at least 30% of crown biomass at the harvest area. On the other hand, the removal of logging residues facilitates site preparation and planting and allows for fast establishment of the subsequent stand, and therefore seedling survival is increased on sites where logging residues are collected. Conservation efforts should be concentrated on those areas where biodiversity is rich. In Finland, biodiversity hotspots have been identified and protected. Care must be taken when harvesting energy wood near nature preserves with high biological values associated with dead wood.

Finland's forest industry, wood-refining industry and integrated bioenergy production are not typical in the EU. Similar circumstances can be found in only a few Member States, such as Sweden and Austria. The forest area in the EU is 180 million ha, of which more than 70% is in seven countries: Sweden, Spain, Finland, France, Germany, Italy and Poland. These countries also produce almost 70% of the total gross value-added products of the forestry and wood industry in the EU. The EU-level policy frameworks and legislation should take into account the specific features of these forest-intensive Member States, and ensure the operational prerequisites for sustainable bioenergy production, which have been developed during decades of sustainable forest management. For climate impacts of forest bioenergy, an accounting system based on the established IPCC framework would be preferable in future climate commitments instead of creating inconsistent frameworks within the EU climate policy. The expansion of the EU renewable energy sustainability criteria based on life cycle analysis for solid and gaseous bioenergy in heat and power production could create a significant bureaucratic work load in countries like Finland with numerous wood sources, end-use options and integrated processes.

The Finnish forest industry has built optimised wood use cycles and recycling practises over the course of many decades, and for example, the direct energy

use of streams like black liquor and bark provides an elevated self-sufficiency and cost-efficiency of energy use in highly developed facilities. As Finland exports a significant portion of its wood biomass in product value chains (as pulp, paper and board, timber and plywood), the cascading cycles take place outside Finnish borders. These national circumstances need to be considered, when discussing the principles of cascading use.

Growing of forests in Nordic conditions requires long-term commitment: The time between the establishment of a stand (planting of trees) to the final harvest is typically 55–85 years. Forest management practices are mainly targeted toward the production of industrial roundwood, and forest owners' income from energy wood compared to sawlogs and pulpwood is small. Wood-based bioenergy is the most competitive, when it is a by-product of the forest industry and used in highly efficient conversion plants (e.g. in combined heat and power production and biorefineries). Bioenergy is the largest renewable energy source in the EU currently and will be in the near future. On the European level, the use of agro biomass (i.e. energy crops, agricultural residues and wastes, etc.) is expected to grow more than the use of forest bioenergy. In Finland, the situation is vice versa, and forest energy is expected to remain as the major renewable energy source also into the future, as a part of forest industry renewal.

RECOMMENDATIONS:

- **The operational prerequisites of forestry need to be maintained. Forestry should be considered from a long-term perspective, as the rotation period of Nordic forest can be 80 years.**
- **Continuous growth of forests needs to be ensured by sufficient investments in the forests. This benefits both the bioeconomy and climate change mitigation.**
- **Growing stock ensures a sustainable flow of wood for energy and material purposes.**
- **The increasing level of annual growth and maintenance of the forest carbon stock supports climate change mitigation efforts by removing carbon from the atmosphere.**
- **Wood-based bioenergy is the most competitive, when it is a by-product of the forest industry and used in highly efficient conversion plants. The competitiveness of forest biomass-based energy production can be further improved by better integration into industrial infrastructures of wood processing industries, including their feedstock supply systems.**
- **Wood biomass should be used where high emission intensive non-renewable products and energy can be substituted or where carbon can be stored.**
- **To mitigate climate change, the use of residual forest biomass is the most beneficial. In short time periods, fast decomposing wood residues are more beneficial for climate change mitigation than slowly decaying ones, or wood from growing stock.**
- **Analysis of carbon balances and warming impacts of alternative forest management scenarios is necessary for planning purposes but international commitments and regulation should be based on verified emissions (ex-post).**
- **Cascading should be considered from the perspective of the whole wood utilisation cycle, where the role of the wood producing countries supplying virgin fibre differs from the consumer countries with more recycling.**
- **It may be difficult to find a uniform definition for cascading use of wood that would lead to the best possible solutions in countries characterized by various circumstances. EU Member States should therefore be able to choose the optimal wood use cycles inside the country.**

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Appendix I: Finnish wood flows

Table I Short explanation of the wood flows and their estimated volume (at year 2013), as presented in Figure 23.

Term in English	Term in Finnish	Mm ³	Explanation
FOREST RESOURCES			
Growing stock (stemwood)	Metsävarat	2357	Total forest resources; stemwood with bark altogether 2 357 Mm ³ . "Stemwood" stands for the volume of the stem with bark starting after stump and ending up to the top. The branches, stump and roots are not included in the figure.
Forest growth	Puuston kasvu	104.4	The yearly growth of forests is 104.4 million cubic meters of stemwood. From this, 99.1 Mm ³ is situated on forest land that can be used for industrial purposes.
Total drain	Puuston poistuma	79.2	In 2013, 79.2 Mm ³ of roundwood was removed from forests. The total drain is evaluated by adding to the total roundwood removal the estimates of loss of wood and the natural drain of wood.
Volume change in growing stock	Puuston tilavuuden muutos	25.2	The difference of growth and stock drain is 25.2 Mm ³ , which is accumulated to the growing stock in forest.
Roundwood import	Raakapuun tuonti	11	Import of roundwood and chips. Most of wood imported to Finland is bought from Russia (73%).
Roundwood export	Raakapuun vienti	1.2	The total roundwood removal (65.3 Mm ³) is divided to domestic use (64Mm ³) and exports (1.2 Mm ³). From total roundwood removal 23.8Mm ³ is sawlogs and 32.2 Mm ³ pulpwood
Natural drain	Luonnon-poistuma	4.7	The natural drain (natural mortality) of wood. A small part of natural drain and logging losses are used, and classified as waste wood.
Loss of wood	Metsähukkapuu	9.2	Part of wood harvested (unused logging residues, tops, unfound logs, etc.) stays in forest as "loss of wood". Figure presents an estimate of this amount.
Forest residues and stumps	Metsätähde (hakkuutähteet ja kannot)	3.9	Use of logging residues (2.8 Mm ³) and stumps (1.2 Mm ³) for energy (altogether 3.9 Mm ³).
WOOD PRODUCTS			
Roundwood use in Finland	Raakapuun käyttö kotimaassa	73.9	Roundwood use in Finland was 73.9 Mm ³ . Total use of wood (including also logging residues and stumps) was 77.9 Mm ³ in wood industry, pulp industry and direct wood use for energy (energy wood, logging residues, stumps).

“Roundwood inventory 2013” (not in figure)	Raaka-puubarasto	1.2	Computational difference between the total roundwood removed from forests ($79.2+11-1.2-4.7-9.2=75.1 \text{ Mm}^3$) plus the removal of logging residues and stumps 3.9 and the total use of wood $\rightarrow 75.1+3.9-77.9=1.2 \text{ Mm}^3$. The difference occurs, for example, due to over year stocking of wood, etc. No public statistic available on roundwood stocks.
Mechanical wood industry	Puutuote-teollisuus	26.2	The use of roundwood in wood industry was 26.3 Mm^3 . Sawmill industry used 89% and board and other wood products industries 11%. Particle- and fibreboard industry mostly use sidestreams.
Board and other wood products	Puulevy- ja muu puutuote-teollisuus	3	Use of roundwood in board and other wood products.
Particle board, fibreboard and pellet industry	Lastulevy-, kuitulevy- ja pellettiteollisuus	0.9	Particle board, fibreboard and pellet industry mostly uses residues from other mechanical industry processes. Pellet production in 2013 was 300 000 tonnes.
Plywood, domestic use	Vaneri, käyttö kotimaassa	2.8	Domestic use of plywood
Plywood, export	Vaneri, vienti	0.9	Export of plywood
Sawmill industry	Sahateollisuus	10	Use of roundwood in sawmill industry.
Sawn timber, export	Sahatavara, vienti	7.2	Export of sawn timber
Sawn timber, export	Sahatavara, käyttö kotimaassa	2.8	Domestic use of sawn timber
Use of side products for mechanical and semichemical pulp industry	Mekaaninen ja puolikemiallinen massateollisuus	7.7	Use of by-products in pulp industry (5.9 Mm^3 for chemical pulp, 1.6 Mm^3 for to mechanical pulp)
Pulp industry	Massateollisuus	38.3	Wood used in pulp industry. 30.5 Mm^3 for chemical pulp.
Pulp import	Sellun tuonti	1.2	Import of pulp
Paper and board import	Paperin ja kartongin tuonti	1.4	Import of paper and board
Pulp domestic	Sellu kotimaan kulutus	1.9	Domestic use of pulp
Pulp export	Sellun vienti	6.7	Export of pulp
Recycled paper	Keräyspaperi	1.4	Recovery of paper 0.71 Mt (with filling materials)
Paper and board, domestic use	Paperi ja kartonki kotimaan kulutus	1.1	Domestic use of paper and board.

Paper and board, export	Paperi ja kartonki vienti	15.6	Export of paper and board. (Paper and board includes approx. 3.5 Mt coatings and fillers which are reduced from fibre streams)
Waste 0.27 Mm³ (+to water systems 0.02 Mm³) (not in figure)	Jätteet 0.27 Mm ³ (+vesistöihin 0.02 Mm ³)	0.29	Waste from paper and board industry to landfills and water systems.
ENERGY USE			
Wood industry sidestreams for energy use	Saha-teollisuuden sivutuotteiden energiakäyttö	5.5	Energy use of by-products
Stemwood for energy	Puun suora energiakäyttö	9.5	Direct use for energy
Sidestreams for energy in pulp industry (black liquor)	Energia selluteollisuudessa (mustaliipeä)	16	The by-product of chemical pulp industry (mostly back liquor from the production of sulphate pulp) is used for energy.
Waste wood import	Jätepuun tuonti	0.5	Waste wood used mostly in energy production and some also in industry
Waste wood	Jätepuu	1	Domestic waste wood for energy
Waste wood export	Jätepuun vienti	0.3	Exported waste wood
Energy use	Energiakäyttö	36.7	Total energy wood use
Side streams for heat and CHP-plants - energy production in forest industry	Energiantuotanto metsäteollisuudessa ja CHP-laitoksilla	23.3	Use of black liquor as energy and the heat plants mostly combusting forest chips, by-products (chips, sawdust, and bark) and recycled wood.
Use of stemwood in heat and power plants	Lämpö- ja voimalaitosten polttopuu	4.1	Use of small-dimensioned wood (delimbed logs, other small dimensioned wood total 3.6 Mm ³ , roundwood 0.5 Mm ³) at heat and power plants.
Small-scale use of wood	Pientalojen polttopuu	5.4	The small-scale use of wood mostly includes use in households, farms and in the service sector (e.g. use of chopped firewood, 4.7 Mm ³ and wood chips 0.7 Mm ³). No annual information is available on all streams, for example the statistics for small-scale use of saw mill industry and family houses are gathered every 5-10 years.
Flows below threshold of 0.3 Mm³ not included	Alle 0.3 Mm ³ virtoja ei ole huomioitu		

Title	Sustainability of forest energy in Northern Europe
Author(s)	Kati Koponen, Laura Sokka, Olli Salminen, Risto Sievänen, Kim Pingoud, Hannu Ilvesniemi, Johanna Routa, Tanja Ikonen, Tiina Koljonen, Eija Alakangas, Antti Asikainen & Kai Sipilä
Abstract	<p>Increased demand for wood in the bioeconomy and bioenergy production means increased pressure on forest resources. Policies emphasising the targets for bioenergy, such as the European Union 2020 targets for renewable energy, have evoked concern on the sufficiency of biomass resources. As forests have multiple roles in supplying raw materials for industry and energy production, climate change mitigation, and in provision of ecosystem and recreational services, comprehensive assessments are needed to reach balanced and sustainable use of forests. Careful management and sustainable use of forest resources can lead to greater climate benefits in the long run by preserving forests as a continuous storage of carbon, and a source of renewable materials and energy.</p> <p>This report summarises the research-based results of the use of forest biomass for energy in Northern European conditions. It discusses the trade-offs and win-win situations of growing forests, sequestration of carbon and using the wood also for energy – in an economically viable and ecologically sustainable manner. The topic is approached from several viewpoints: First, development of forest resources in the EU and in Finland is presented, and a background for the discussion on how much and what kind of wood is used for energy production is provided (Section 2). Second, ecological and climate impacts of the use of forest energy are discussed (Sections 3 and 4). Third, the role of forests in international climate policy and future EU regulations (Section 5), and the specific features of cascading use of wood in fibre producing countries (Section 6) are discussed. In addition, remarks on the economics and the future role of forest energy in low-carbon scenarios are presented (Section 7). Finally, the conclusions and recommendations concerning forest energy use are provided (Section 8).</p>
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