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Abstract

Introduction of second-generation biofuels is an essential factor for meeting the EU's 2020 targets for renewable energy in the transport sector and enabling the more ambitious targets for 2030. Finland's forest industry is strongly involved in the development and commercialising of second-generation biofuel production technologies. The goal of this paper is to provide a quantified insight into Finnish prospects for reaching the 2020 national renewable energy targets and concurrently becoming a large-scale producer of forest biomass based second-generation biofuels feeding the increasing demand in European markets. The focus of the paper is on assessing the potential for utilising forest biomass for liquid biofuels up to 2020. In addition, technological issues related to the production of second-generation biofuels were reviewed. Finland has good opportunities to realise a scenario to meet 2020 renewable energy targets and for large-scale production of wood based biofuels. In 2020, biofuel production from domestic forest biomass in Finland may reach nearly a million ton (40 PJ). With the existing biofuel production capacity (20 PJ/yr) and national biofuel consumption target (25 PJ) taken into account, the potential net export of biofuels from Finland in 2020 would be 35 PJ, corresponding to 2–3% of European demand. Commercialisation of second-generation biofuel production technologies, high utilisation of the sustainable harvesting potential of Finnish forest biomass, and allocation of a significant proportion of the pulpwood harvesting potential for energy purposes are prerequisites for this scenario. Large-scale import of raw biomass would enable remarkably greater biofuel production than is described in this paper.

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APPENDICES

1. Introduction

The European Union (EU) has set itself an ambitious target of reducing overall emissions of greenhouse gases in the union and increasing the proportion of renewable energy in gross final consumption of energy by 2020[1]. The renewable energy directive of the EU (RES Directive) includes country-specific targets (13–49%) for renewable energy sources as a proportion of the final consumption of energy in 2020 and a uniform target of 10% for renewable energy's share in transport for all Member States[2]. The expected total energy demand in the EU's transport sector in 2020 is vast, at approximately 18 EJ, of which the road transport sector accounts for approximately 80%[3].

The commercialisation of second-generation biofuels[1] has been recognised as a prerequisite for meeting the EU's 2020 target and allowing more ambitious targets looking toward 2030 for renewable energy [2, 4]. The major advantage of second-generation biofuels is that lignocellulosic raw materials such as forest biomass and dedicated energy crops can be used as their raw material. In the EU area, production costs of dedicated energy crops and forest biomass are lower and the production potential higher than those of oil crops or sugar crops [5, 6]. In addition, synthetic second-generation biofuels offer a better energy balance and greater reduction in CO_2 emissions than do conventional biofuels[7]. However, the commercialisation of second-generation biofuels' production technologies has several techno-economic challenges to overcome, mainly related to gas cleaning and costs [8]. Conventional biofuels dominate the early biofuel market, but the market penetration of second-generation biofuels is expected to take place by 2020 in favourable conditions [6].

Over the past few years, the European pulp and paper industry has suffered from overcapacity in production, stemming from the weakened global economy, success of electronic communication, and stagnating European paper markets [9, 10]. In Finland too, the forest industry was harmed by the weak global economy. The Finnish forest industry is now undergoing major structural change, and the volume of the industry's production is forecast to drop remarkably toward 2020 in comparison to 2007's all-time peak figures [11, 12]. The industry is in a situation where new business opportunities are seen as a solution to improve the sector's long-term competitiveness [10, 13].

The forest-industry cluster has several interesting opportunities for the production of second-generation biofuels, such as options for process integration and utilisation of existing raw material sourcing organisations and facilities [13-15]. Synthetic diesel production with gasification and Fischer-Tropsch (F-T) synthesis, dimethylether (DME) production at pulp mills, and bio-oil production with integrated fast pyrolysis (ITP) are regarded as most promising technologies for producing liquid fuels from woody biomass within the forest industry [13, 14]. The price developments for energy and forest products have increased the forest industry's interest in the production of second-generation biofuels. The price of energy is increasing whereas prices of paper and paperboard have been declining [10]. For example, in Finland in 2000–2007, the price index for energy increased by 53% [16]. In the same period, the unit price of exported paper products fell by 20% [16]. Recent studies indicated that second-generation biofuels made from forest biomass will become economically attractive by 2020 when compared to conventional biofuels [17-20]. As an EU member state, Finland has committed itself to the 10% biofuel target. However, its cold climate has given Finland unfavourable conditions for cultivation of the oil and sugar crops used for the production of conventional biofuels.

[1] Future biofuels that were not on the market (or were on the market in only negligible quantities) in January 2008, such as ethanol, dimethylether, diesel fuel, and methanol made from wood or straw.[2]

Production of second-generation biofuels from forest biomass by 2020 is defined as one target in the Finnish Climate and Energy strategy [21].

The aim of this study is to provide a quantified insight into Finnish prospects for meeting the national 2020 renewable energy targets and concurrently becoming a large-scale producer of forest-biomass-based second-generation biofuels for feeding increasing demand in European markets. The focus of the paper is on assessing the potential for utilising forest biomass for liquid biofuels up to 2020. In addition, technological issues related to the production of second-generation biofuels within the forest industry are reviewed. The paper is established initially via a review of Finnish renewable energy targets and the outlook for the forest industry. The dynamics of future forest biomass supply and demand will be examined on the basis of reviews of projections of the production and wood sourcing for the Finnish forest industry. The basic projection is derived from the recently published forecast by the Finnish forest research institute (METLA) for the state of Finland's forest industry in 2020 [11]. Next, a comprehensive picture of wood streams, covering the chain from forest increment to end use of wood as raw material and energy, and raw wood[2] import, is composed. Then, the technological prospects and plans for second-generation biofuels in the Finnish forest industry are reviewed. The results are presented and evaluated, and, finally, conclusions and recommendations based on the findings presented are given.

[2] Raw wood refers to round wood (domestic and imported) and imported (non-domestic) wood chips used as raw material in the forest industry.

2. Finnish targets for renewable energy and transport biofuels in 2020

The RES Directive has set 38% as a target for the share of renewable energy in final energy consumption in Finland in 2020 [2]. In 2005, the realised share of renewable energy was 29% [2]. The use of renewable energy in 2007 and Finnish renewable energy targets by energy source for 2020 are presented in Table 1.

Table 1. Renewable energy consumption by energy source in 2007 in Finland and the targets for 2020

Source of renewable energy	Year 2007[a] (PJ)	Target level for 2020[b] (PJ)	Increment (PJ)	Relative change
Black liquor	153	137	-16	-10%
Solid wood processing industry by-products and residues	68	68	0	0%
Hydropower	50	50	0	0%
Firewood	46	43	-3	-7%
Forest fuels (in heat and power generation)	22	97	75	349%
Recycled fuels	7	7	0	0%
Heat pumps	10	29	19	190%
Other renewable energy (includes, e.g., solar energy and agro-biomass)	3	1	-2	-67%
Biogas	2	4	2	100%
Wood pellets	2	7	5	250%
Wind power	1	22	21	2,100%
Liquid biofuels	0	25[c]	25	-
Total	364	490	126	35%

[a] *Data obtained from energy statistics [22].*
[b] *Source: NREAP Finland [23].*
[c] *The figure corresponds to approximately 15% of the projected fuel consumption in the transport sector in 2020.*

Forest biomass is the most important source of renewable energy in Finland, covering approximately 80% of the renewable energy used. Most forest-based bioenergy (over 75%) is generated from by-products of the forest industry (black liquor, bark, and sawdust). The rest of the wood energy is generated from wood biomass that is sourced from forests for energy purposes (firewood and forest chips). The proportion of wood pellets has been negligible. The volumes of the forest industry's energy by-products vary with the production of pulp and paper. In the Finnish Climate and Energy Strategy, only a minor decline was estimated for forest-industry production up to 2020, and the utilisation of solid forest-industry by-products for energy in 2020 will be approximately at the same level as in 2007.

In the current energy policy,[21, 23, 24] the target for the use of forest chips (logging residues, stumps, and energy wood[4]) in 2020 has been set at 13.5 million solid cubic metres (equalling approximately 97 PJ). Forest chips will account for most future growth in renewable energy production. Industrial energy plants and the district heating sector will be the major user of forest chips. Forest chips are expected to become an important raw material in the production of liquid biofuels. The government is striving for a 20% blending obligation for biofuels in road transport

[4] In this paper, energy wood refers to trees that are harvested for energy purposes.

by 2020. Some of the target volume of biofuel is expected to be covered by second-generation biofuels, whose consumption is counted at twice the volume of other biofuels in the RES Directive [24]. Therefore, the target volume for biofuels in energy terms corresponds to less than 20% estimated fuel consumption in road transport in 2020.

In recent years, significant capacity for production of biofuels has been constructed in Finland, covering bio-ETBE,[5] hydro-treated biodiesel (NExBTL), and bio-ethanol. The production of ETBE and NExBTL is based on imported raw materials (bio-ethanol and palm oil). Finnish bio-ethanol is produced from non-cellulosic raw materials such as by-products and waste streams of the food industry; see also Table 2. Compared to the current use of transport biofuels in Finland, the existing production capacity is large, at almost 20 PJ/yr. The existing production capacity will not meet the target level set for biofuels in road transport in 2020, and either more domestic capacity is required or biofuel import has to be increased (see Figure 1). On the other hand, most biofuels produced have been exported so far, and, depending on the development of the market, some of the domestic production might be exported in the future as well.

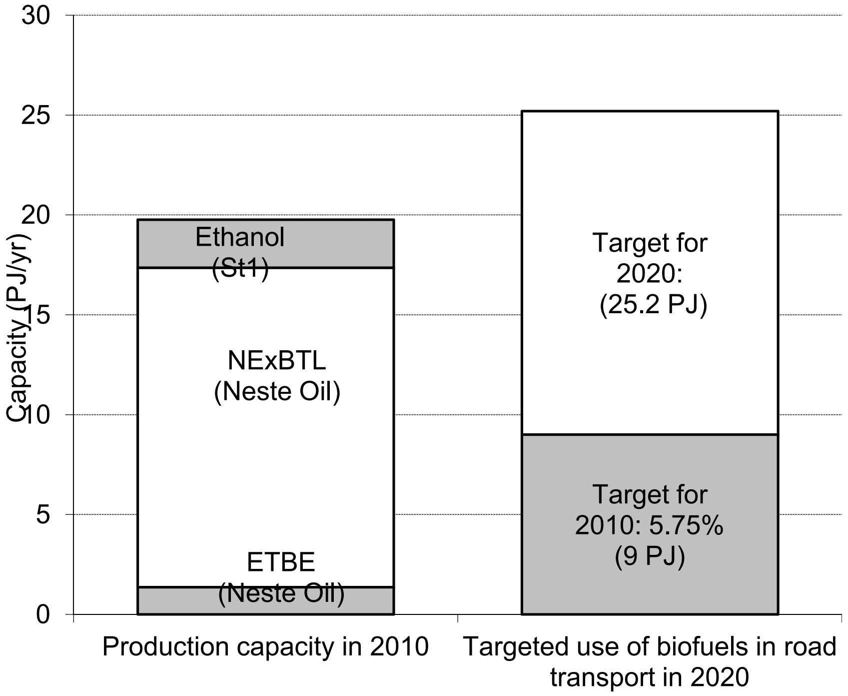

Figure 1. A comparison of existing biofuel production capacity and the 2020 biofuel target set by the government. The projected fuel consumption in road transport in 2020 is approximately 150 PJ.[21] The capacity for production of ETBE includes only the proportion of bio-components (50% of the total calorific value).

[5] ETBE (ethyl-tertio-butyl-ether) is an additive that enhances the octane rating of petrol (replacing lead and benzene in unleaded petrol) and reduces emissions. Bio-ETBE is produced by combining bio-ethanol and fossil isobutylene [25].

3. The state of forest industry in Finland

In the last five decades (from the mid-1950s to 2005), the forest industry grew rapidly in Finland and annual production of major forest-industry products (pulp, paper, paperboard, and sawn timber) has generally at least doubled (see Figure 2). Since the 1980s, raw wood import has been an important factor enabling growth in the forest industry's production. Russia has been the most important source of foreign raw wood in Finland. The strongest growth in total wood use and raw wood import took place in the 1990s. Raw wood import to Finland peaked in 2005 at 21 million m^3, corresponding to about 25% of the forest industry's raw wood use [26].

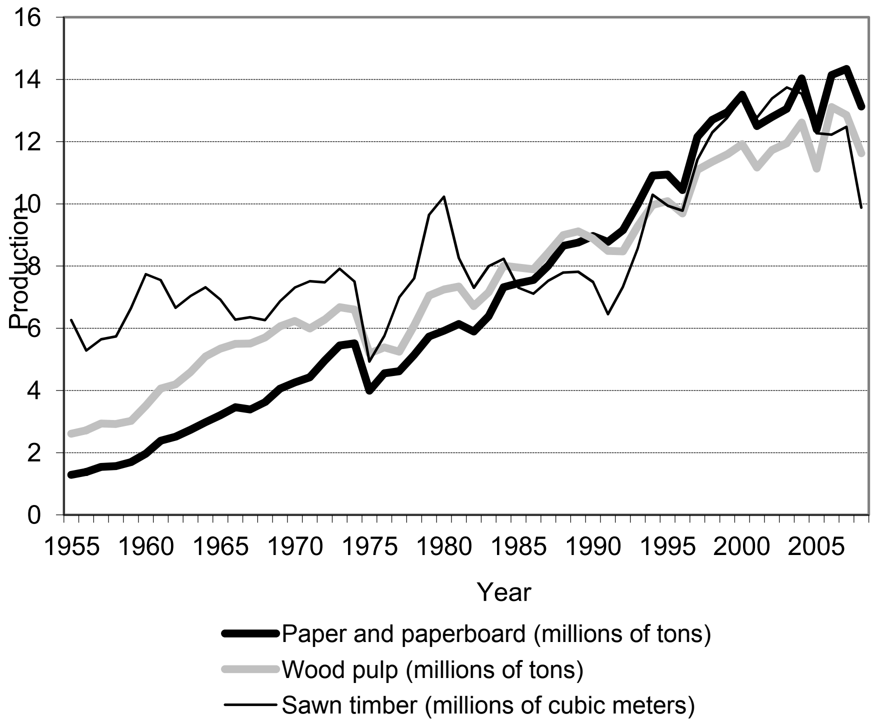

Figure 2. The production of the major products of the Finnish forest industry in1955–2008 [26].

The last few years have seen the Finnish forest industry affected greatly by the weak global economy, and the continuous growth of the industry came to an end. In 2006–2010, approximately three million tons of pulp, paper, and paperboard capacity was permanently closed in Finland [12, 27, 28]. Simultaneously, raw wood import from Russia dropped dramatically, to only seven million cubic metres in 2009 [29]. A rise in the Russian export duty for round wood increased the costs of Russian wood, which was the key reason for the decrease in the use of Russian raw wood in Finland.

In the light of recent capacity cuts, and in view of the fact that the forest industry has published no plans to create new pulp and paper capacity in Finland, the outlook for traditional branches of the forest industry does not seem auspicious. The focus of forest-industry companies seems to be more on surviving economic depression than on planning new capacity for stagnating paper markets. Recently, several forecasts considering the production and raw wood use of the Finnish forest industry (looking toward 2020) were published; see, for example, sources [11, 12, 30].

4. Methods and material

4.1 Projections for wood use and sourcing for the forest industry

Next, three projections for the raw wood use and sourcing of the Finnish forest industry in 2020 are discussed. The first is the basic projection entitled ‘2020 METLA’, derived from an extensive study carried out in METLA by Hetemäki and Hänninen in 2009 [11]. The estimations made in the study are based on statistical trends and qualitative analysis of the operating environment and competitiveness. The study painted a gloomier outlook for forest-industry production in Finland than the other predictions did. According to METLA’s forecast, annual production of paper and paperboard will decline by nearly four million tons from 2008 by 2020, ending up at almost the same level as in the early 1990s. Production of sawn timber has been forecast to be about 10 million m^3 in 2020, equalling roughly the figure from 2008. METLA’s paper includes also estimates for round wood and pulp chip import volumes. The basic projection is supplemented by the projections ‘2020 b’ and ‘2020 c’, which are more optimistic with regard to forest-industry production, assuming the wood use and production of the forest industry to be at the same level in 2020 as in 2007. The idea of these two projections is to illustrate boundary conditions and supply–demand dynamics related to forest biomass. In the projection 2020 b, raw wood import was set at the 2007 level. In the projection 2020 c, imported round wood is replaced with domestic round wood (no import of round wood) but import of pulp chips remains at the same level as in 2007.[6] Actual forest-industry production in 1990–2008, estimates of forest-industry production until 2020, and the projections are presented in Figure 3.

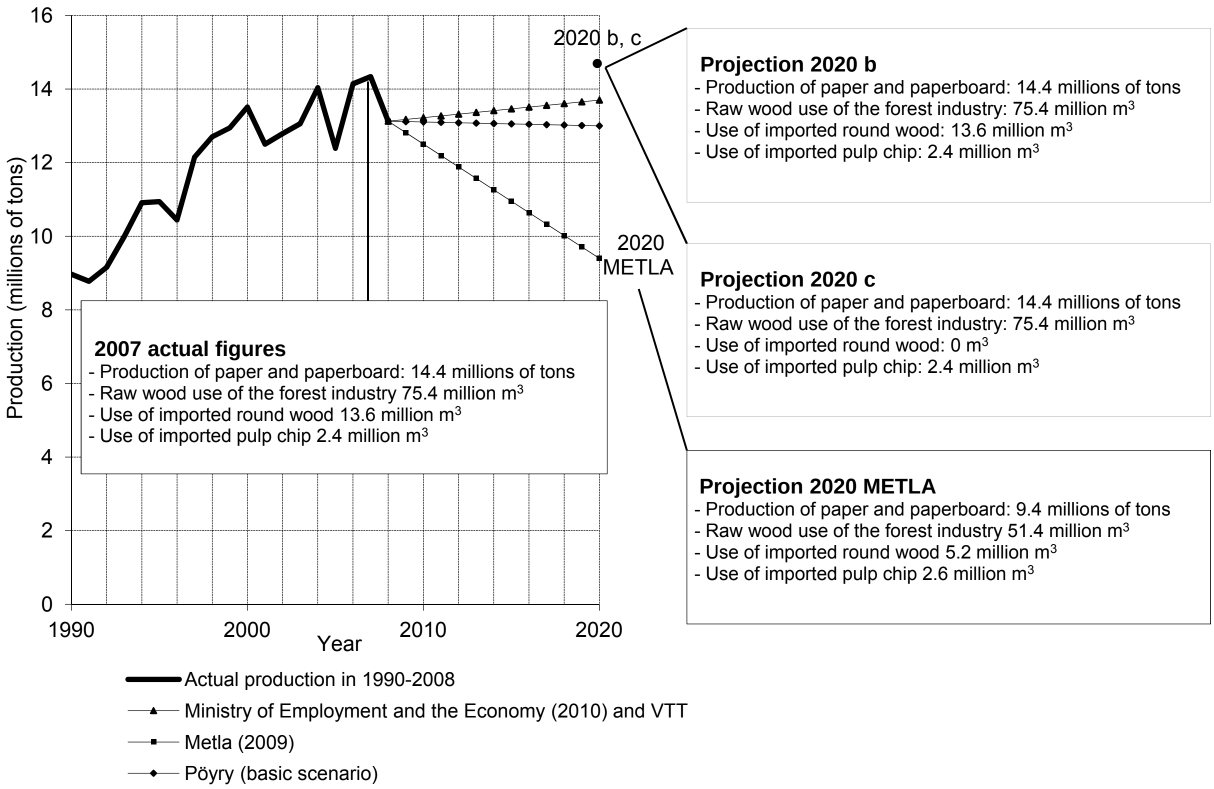

Figure 3. Production of paper and paperboard in Finland in 1990–2008, forecast to 2020, and the projections used in this paper [11, 21, 31].

[6] The estimate is based on the fact that the Russian export duty for processed wood such as pulp chips is lower than for unprocessed raw wood.

4.2 Wood streams from forest growth to forest products and energy

4.2.1 Review of wood streams

For shedding light on the dynamics of supply and demand related to forest biomass, wood streams from annual increment of forests into forest products and energy are reviewed. The components included in the review are:

1) Forest-industry wood streams,
2) Forest growth and forest biomass harvesting potential, and
3) Forest biomass harvested for energy.

In the review, streams of stem wood and crown biomass and root wood are distinguished. In addition, raw wood import (and export) is included (in Figure 4). The import of wood for energy in Finland has been negligible – e.g., approximately 0.2 million m^3 in 2007[32] – as compared to total wood use; therefore, the import of wood for energy is not considered. Key assumptions in the wood stream calculations are:

- The growth of forest biomass and sustainable harvesting potential of logs and pulp will increase as estimated in the latest national forest inventory [33].
- The use of forest chips and firewood in 2020 is set according to government targets at 13.5 million solid cubic meters for forest chips and five million for firewood [23].
- Technical harvesting potential of logging residues and stumps increases by 4 million solid cubic metres in compared to level in 2007 [30].

A detailed description of the components of the review, calculation steps, and initial data of the review are described in detail in Appendix I.

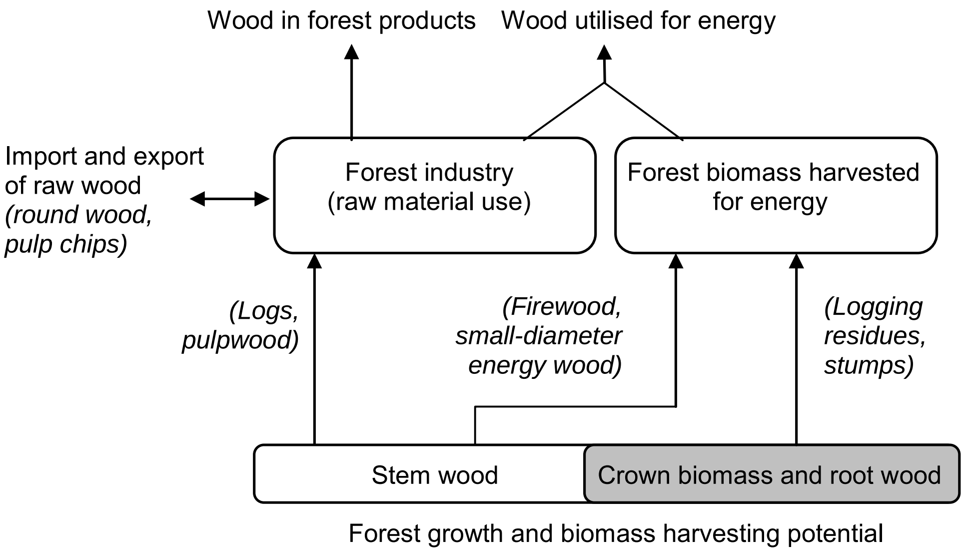

Figure 4. The components of wood stream review. The timber assortments included in the review are presented in brackets.

4.3 Technological prospects and plans for large-scale production of biofuels in the forest industry

A separate (standalone) biomass-to-liquid (BTL) plant, such as an F-T plant, can convert approximately half of the raw material's calorific energy into fuel and electricity [34, 35]. The rest of the raw material's calorific value is converted into heat. Integrating a BTL plant with a pulp and paper mill offers high overall efficiency, as excess heat from the BTL process can be utilised for power generation and process heat on-site. Efficient integration of the processes allows even greater than 80% efficiency in conversion from feedstock energy into biofuel [14, 15]. In addition, forest-industry mills' raw wood procurement organisation and wood-handling facilities can be utilised for the raw material sourcing of BTL production.

Options for integration ofr BTL plants with pulp and paper mills have been studied intensively in recent years; see, e.g., [13-15, 20]. The emphasis in the design of the integration of a BTL plant with a pulp and paper mill can be on the minimising of either additional biomass demand or external electricity purchasing [15]. Figure 5 depicts the changes in raw material and energy balance of a typical pulp and paper mill that result from integration of a BTL plant for both of the above cases. When demand for external electricity is minimised, approximately 75% total conversion efficiency can be achieved. A BTL plant in a forest-industry environment can convert roughly one million solid cubic metres of forest biomass into 120,000 t (5.4 PJ)[7] of products, such as synthetic biodiesel.

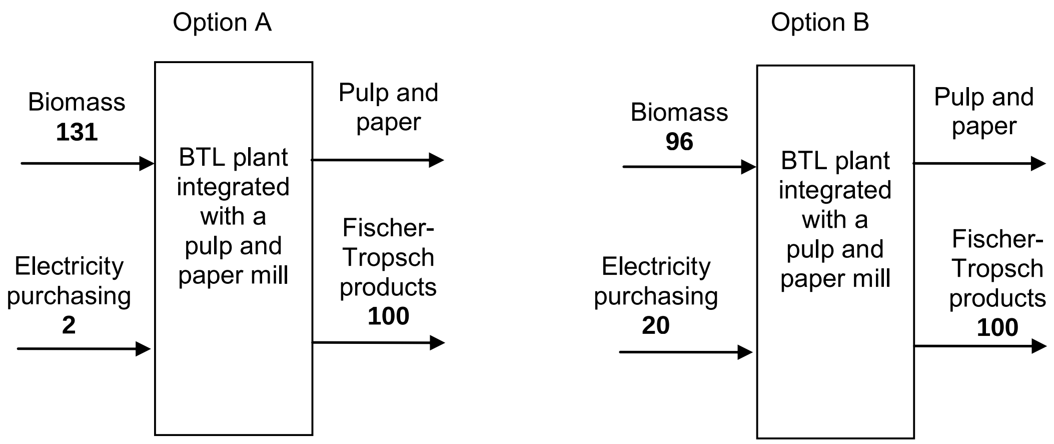

Figure 5. Examples of integration options for F-T products with a pulp and paper mill and the changes in energy balance. The numbers in the figure are energy-based. Option A minimises purchasing of external electricity, and option B minimises that of biomass. Data obtained from sources [15, 20].

In a recent study, the Technical Research Centre of Finland (VTT) and Pöyry evaluated the market potential of liquid biomass fuel technologies in the European forest industry by 2020 [13]. In the analysis, mill-level information on existing power and recovery boilers, including data on boiler size and age, was utilised. The idea was to replace old boiler capacity that is coming to the end of its technical service life with new bioenergy technologies while taking technological limitations such as boiler size and the heat demand of the mill into account. The liquid biofuel production technologies included in the study were ITP, F-T diesel, and black

[7] Conversion efficiency: 75% and calorific value of F-T products: 44 GJ/t.

liquor DME. According to the study, the greatest country-specific potential for liquid biofuel production within the forest industry lies in Finland, at approximately 60 PJ/yr, equalling 1,400,000 tons of biofuels per year [13].

All of the large Finnish forest-industry companies have been involved in the development and commercialisation of BTL processes with their technology partners. A summary of the present state of liquid biofuel production and projects involving BTL production in Finland is presented in Table 2. In addition, the forest industry companies have several alternative locations for BTL plants abroad. The capacities given for planned F-T biodiesel projects are the maximum production capacities used in environment impact assessment (EIA) plans. Investment decisions on BTL plants are expected during the second half of the year 2012 [36].

Table 2. Summary of biofuel production and planned projects in Finland [27, 37-43]

Company	Location	Product or technology	Raw material	Production capacity (t/yr)	Status / Other
Neste Oil	Porvoo	ETBE	Ethanol	100,000	Production started in 2004
Neste Oil	Porvoo	Hydro-genated biodiesel, NExBTL process	Tri-glycerides (mainly palm oil)	380,000	Two production plants, production started in 2008
St1	Hamina (dehydration plant), with ethanol production units in Lappeenranta, Närpiö, Hamina, Vantaa, Lahti, and Hämeenlinna	Ethanol, Etanolix technology	Food-industry waste, scraps, and by-products	88,000 (dehydration capacity)	Production started in 2008
Realised plants↑		Status in late 2010			Planned plants↓
UPM	Rauma	Second-generation biofuels (biodiesel), with gasification and Fischer-Tropsch synthesis	Lignocellulosic biomass (wood)	300,000 (per plant)	Environmental impact assessment (EIA) completed in December 2009.
UPM	Several alternative locations	Pyrolysis oil, fast pyrolysis / ITP process (process integrated with a fluidised bed boiler)	Lignocellulosic biomass (wood)	n.a.	Joint development project with UPM, Metso, Fortum, and VTT.
Vapo and Metsäliitto	Kemi or Äänekoski	Second-generation biofuels (biodiesel), with gasification and Fischer-Tropsch synthesis	Lignocellulosic biomass (wood, field biomass, and peat)	200,000 (per plant)	EIA completed in December 2009.
NSE Biofuels[a]	Imatra or Porvoo	Second-generation biofuels (biodiesel), with gasification and Fischer-Tropsch synthesis	Lignocellulosic biomass (wood)	200,000	EIA will be completed in April 2011. Products of BTL process can be used as raw material in the NExBTL process.

[a] *A joint venture of Neste Oil and Stora Enso.*

5. Results and discussion

5.1 Streams of forest biomass in Finland in 2007 and 2020

The figures calculated for conversion of wood into fuels (black liquor and solid biofuels) in the Finnish forest industry in 2007 and in the various projection to 2020 are shown in Table 3. In the basic projection (2020 METLA), the volumes of forest-industry by-products that are utilised for energy will decrease markedly in comparison to the 2007 figures. The streams of forest biomass in Finland were calculated for 2007 and for the various projections to 2020. The wood streams for which calculations were performed are depicted in Figure 6.

Table 3. Conversion of wood into (by-product) fuels in the Finnish forest industry in 2007 and in 2020 in various projections in terms of absolute volume

Branch of the forest industry	Year and projection			
	2007 (millions of solid m^3)	2020 METLA (millions of solid m^3)	2020 b (millions of solid m^3)	2020 c (millions of solid m^3)
▪ Sawmills	5.1	7.0	5.1	5.1
▪ Plywood mills	1.3	1.4	1.3	1.3
▪ Particle-board and fibreboard mills	0.0	0.0	0.0	0.0
▪ Other wood-product industry	0.1	0.0	0.1	0.1
▪ Chemical pulp mills	21.3	12.3	21.3	21.3
- *black liquor*	*17.7*	*10.2*	*17.7*	*17.7*
- *solid biofuels*	*3.6*	*2.0*	*3.6*	*3.6*
▪ Mechanical and semi-mechanical pulp industry	2.7	1.4	2.7	2.7
Total	30.4	22.2	30.4	30.4
- *Domestic wood*	*22.9*	*18.9*	*22.9*	*29.4*
- *Foreign-origin wood* (imported raw wood)	*7.5*	*3.3*	*7.5*	1.0

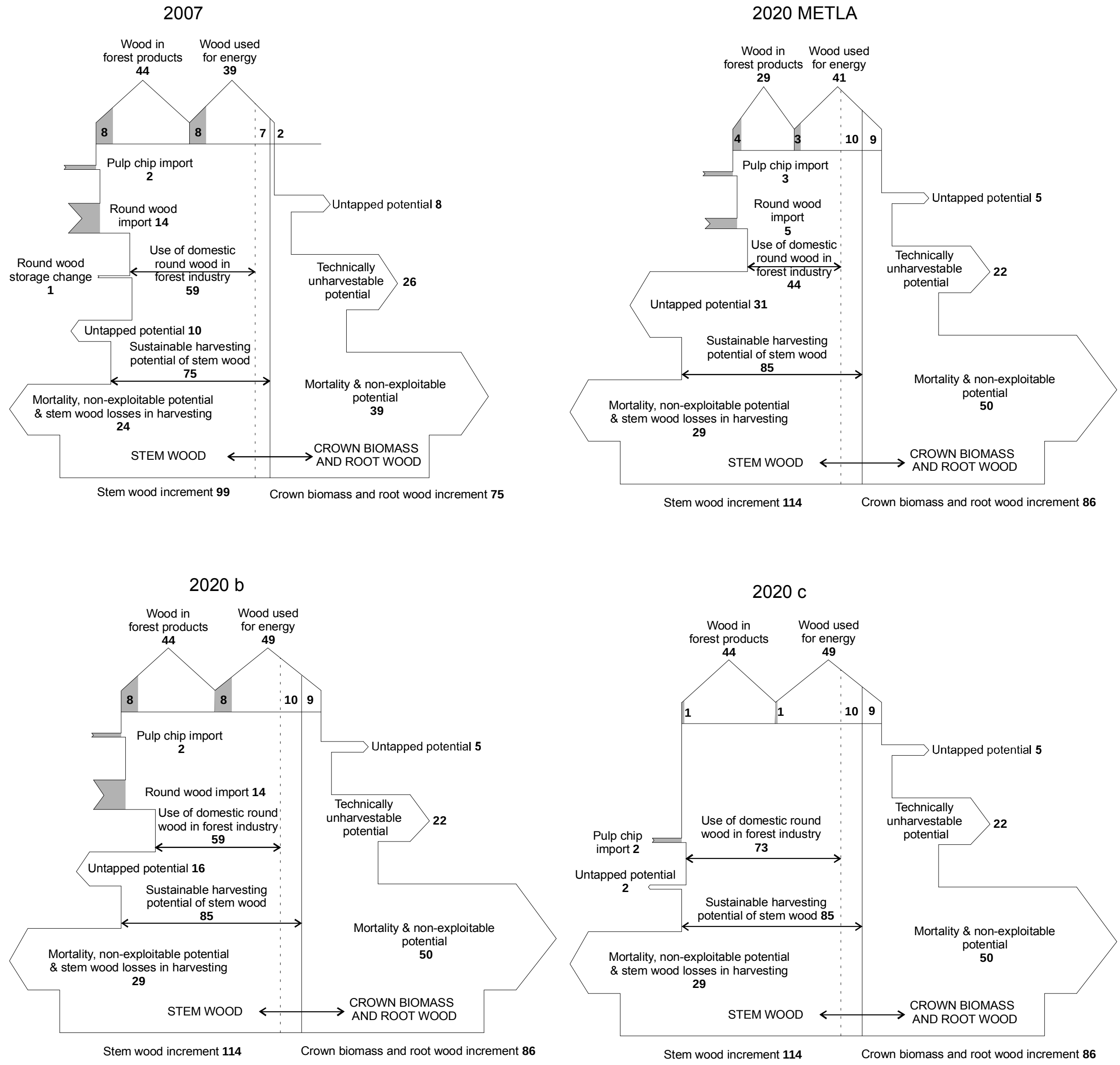

Figure 6. Illustration of forest biomass growth and utilisation in Finland in 2007 and in 2020 in the projections 2020 METLA, 2020 b, and 2020 c. The numbers in the figure are in million of solid cubic metres, including bark. Grey parts of the figure illustrate imported raw wood (round wood and pulp chips). To the right of the dashed lines is stem wood that is harvested for energy (energy wood and firewood).

For clarification of foreseeable major changes in streams of forest biomass, key figures for utilisation of forest biomass and energy generation from forest-industry by-products in 2007 and 2020 in the various projections were defined. The key figures for utilisation of forest biomass were obtained by means of the reviewing of wood streams; they are presented in Table 4. The figure for generation of energy from forest-industry by-products in the basic projection (2020 METLA) was defined by way of the figures for energy production from by-products (black liquor and solid wood processing residues) and the wood volumes calculated for by-products.[8]

[8] In 2007 – energy derived from black liquor: 153 PJ, wood in black liquor: 17.7 M m^3, energy derived from solid processing residues: 68 PJ, wood in solid processing residues: 12.7 M m^3; 2020 projection – wood in black liquor: 10.2 M m^3, wood in processing residues: 12.0 M m^3.

Table 4. Key ratios related to utilisation of forest biomass in 2007 and 2020

Key ratio / year and projection	2007	2020 METLA	2020 b	2020 c
Harvesting of stem wood / sustainable stem wood harvesting potential	87%	64%	81%	98%
Harvesting of crown biomass and root wood / technical harvesting potential for crown biomass and root wood	20%	64%	64%	64%
Total utilisation of domestic forest biomass / total increment of forest biomass	39%	32%	39%	46%
Foreign-origin wood as a proportion of total energy use of wood (in terms of volume)	21%	7%	16%	2%
Energy generation from forest-industry by-products (black liquor, bark, and sawdust) **(note: the government target for 2020 is 205 PJ)**	221 PJ	153 PJ	221 PJ	221 PJ
Untapped harvesting potential of forest biomass (harvesting potential less harvesting), in millions of cubic metres				
▪ Logs	4	8	3	1
▪ Pulpwood and energy wood (including firewood)	6	23	13	1
▪ Logging residues and stumps	8	5	5	5

Next, the actual wood streams in 2007 and wood streams in the basic projection (METLA 2020) are compared. The following observations on forest biomass supply and demand can be made. First, in 2007–2020, the forest industry’s use of domestic pulpwood will decrease by ten million cubic metres. At the same time, the annual sustainable harvesting potential of pulpwood will grow by nine million cubic metres. This development leads to a situation wherein a marked surplus (or oversupply) of pulpwood exists in Finnish forests in 2020. Parallel to this, volumes of forest-industry by-products decrease, especially that of black liquor, which will almost halve, and this will reduce energy production from by-products by nearly 70 PJ by 2020. According to assumptions presented in the Climate and Energy Strategy, energy derived from black liquor and solid by-products will fall by only 16 PJ by 2020 (Table 1). For reaching the government’s total target for renewable energy in 2020, the use of other renewable energy sources – e.g., forest biomass directly sourced for energy (forest chips) – has to be increased by 52 PJ in comparison to the figures set in the energy strategy. That amount of energy corresponds to about seven million solid cubic metres of forest chips. In addition, one should note that by 2020 energy generation will surpass forest products as a destination of forest biomass (in terms of volume). Furthermore, the importance of foreign-origin wood as a renewable energy source will decrease.

From comparison of the actual wood streams in 2007 and supplementary projections (2020 b and 2020 c), the following conclusions can be drawn. Projection 2020 b, which relies on the continuation of large-scale import of raw wood, indicates that the import of raw wood would enable strong production by the forest industry and reaching (and even surpassing) the wood energy targets. Furthermore, it shows increased theoretical availability of domestic forest biomass for biofuels. Projection 2020 c, striving for the same production by the forest industry as in 2007 and surpassing the wood energy targets without import of round wood, requires that domestic pulpwood harvesting potential, which is currently under-utilised, be allocated almost fully as forest-industry raw material. Realisation of the projection would require nearly full utilisation of stem wood harvesting potential, which may be an unrealistic target.

5.2 Options for large-scale biofuel production

According to the basic projection (2020 METLA) and despite significant growth in wood's use for energy, the utilisation of forest biomass will decrease toward 2020. The estimated decline in wood use by the forest industry is the most important factor for decreasing utilisation of forest biomass. Keeping the utilisation rate of pulpwood, logging residues, and stumps at the same level in relation to sustainable harvesting potential as past years' average for logs and pulpwood (80%), an additional 14 million m^3 of wood (2 million m^3 logging residue and stumps and 12 million m^3 of pulpwood) could be allocated for energy purposes (for biofuel, heat, and power). Adding one million m^3 of forest chip that is allocated for biofuels in the government's strategy to the above figure, 15 million m^3 of wood in total would be used for synthetic-biofuel production, enabling approximately 80 PJ/yr (1.8 Mt/yr) of production.

Given the published plans of the companies, in the best case, two to three BTL plants producing approximately 600,000 t/yr (26 PJ/yr) of second-generation biofuels will be realised in Finland in the first phase (by 2015). Later, nearer 2020, greater, even million-plus-ton-per-year production of second-generation biofuels is theoretically possible from indigenous forest biomass. However, this requires that a significant amount of pulpwood be allocated for energy purposes. This will be realistic only if demand for wood in the forest industry decreases as estimated in the basic projection. In addition, in this case, energy production from black liquor and solid forest-industry by-products (bark and sawdust) remains far below the targets of the Energy and Climate Strategy, with the gap being about 50 PJ in 2020. Compensating for this gap by increasing wood use in heat and power production would require about seven million m^3/yr of wood. Then, only roughly that same amount of wood would remain available for biofuel production and the production potential of second-generation biofuels would be approximately 40 PJ/yr (0.9 million t). In this situation, taking a 25 PJ/yr national biofuel consumption target and the existing 20 PJ/yr biofuel production capacity into account, approximately 35 PJ/yr (0.8 million t) of biofuel would be available for export. Comparing the export potential and demand for biofuels in the EU (10% of road transport fuels' consumption, or approximately 1,500 PJ), one finds that Finland could cover approximately 2–3% of the demand for biofuels in the EU in 2020. However, it is not clear that the remarkable new production capacity of second-generation biofuels will have been created in Finland by 2020, as several factors constrain the realisation of the scenario. The schedule for commercialisation of BTL technologies in Finland and worldwide is still unclear. It remains unknown which of the BTL technologies currently under development will become commercially mature first. First-generation biofuels dominate the early biofuels market, but second-generation biofuels have good opportunities to gain a considerable market share as 2030 nears[6]. However, the market penetration of second-generation biofuels could easily be delayed. In addition, costs of raw materials affect decisions on the locations of BTL plants. Another important issue is whether raw material for BTL plants can be sourced at a competitive price in Finland in comparison to alternative locations for the plants in, for example, Latin America.

5.3 Evaluation of results and uncertainties

For this paper, the major sources of information were forestry statistics and recently published studies and papers on second-generation biofuels. Sufficient initial data were available concerning national energy policy targets and the actual energy and raw material use of wood. In particular, Finnish forestry statistics provide comprehensive information on forest resources and wood use. Recently published studies offered good information for composing an outlook on the options for integration of biofuel production with the forest industry. By contrast, detailed technological and economic information on various BTL technologies and their current status was available to only a limited extent, and the prospects of BTL plants had to be compassed on the basis of the information available from company releases and public presentations.

The main uncertainty in the results and conclusions is related to forest-industry wood use figures and the introduction of BTL plants toward 2020. In this paper, 2007 was selected as the first reference year. That was a peak year for the Finnish forest industry in the production of forest products and wood use, and since then, the industry's production and wood use have decreased. In the light of present cuts in pulp and paper capacity and predictions of the forest industry's future, it is unlikely that production will reach those peak-year levels by 2020. The figures for the wood use of the forest industry in the basic projection for 2020 were selected according to the gloomiest but also the most comprehensive recently published forecast. In the wood stream calculations, it was assumed that logging residues consists only of crown biomass and that firewood and energy wood consist only of stem wood. In actuality, logging residues include stem wood as a form of tops, and energy wood harvested as whole trees includes crown biomass. Furthermore, some firewood is made from sawmill by-products and logging residues. However, these assumptions have a negligible effect on the results of the wood stream calculations. Given the options for utilising forest biomass for large-scale production of biofuels, the following elements affect the results (wood streams).

First, the paying capacity in various pulpwood end-use sectors (the forest industry, biofuel production, heat and power plants, and pellet mills) in 2020 will determine the actual consumption volumes for pulpwood in various sectors. Furthermore, production subsidies for small-diameter energy wood, for example, and other energy policy measures – such as emission trading, energy taxes, and investment grants – will affect wood markets.

Second, approximately half (7 M m^3) of the volume of pulpwood, logging residues, and stumps that will become theoretically available by 2020 as a result of the decrease in the wood use of the forest industry and the increased growth of forests is needed to compensate for the decline in energy production from forest-industry by-products (black liquor and solid processing residues). Otherwise, the government's total target for wood energy cannot be met. On the other hand, the use of other renewable energy sources, such as agro-biomass or wind energy, could be increased from the current target levels. However, the development of the use of various renewable energy sources is highly dependent on energy policy measures.

6. Conclusions

In 2006–2010, the forest industry permanently closed nearly three million tons of pulp, paper, and paperboard capacity in Finland. According to the forecast by METLA that was utilised in the basic projection applied in this paper, production of paper and paperboard in Finland will decline by 2020 to almost the same level it had in the early 1990s. In parallel with this, volumes of forest-industry by-products and the energy derived from those by-products will fall. As part of the work toward the renewable energy targets set for 2020, the government is striving to increase the annual use of forest fuels by approximately 10 million solid cubic metres in comparison to the level that prevailed in 2007. As a result of improvements in forest management, the growth of forest biomass is increasing and the annual sustainable harvesting potential of stem wood will increase by 10 million m^3 in 2007–2020. Despite the increasing use of forest fuels, the declining wood use of the forest industry and increasing harvesting potential of stem wood will lead to a situation in which considerable oversupply of stem wood (especially for pulpwood) exists in Finland in 2020. With the rate of utilisation of pulpwood, logging residues, and stumps set at 80%, an additional 14 million cubic metres of wood (12 million m^3 of pulpwood and two million solid cubic metres of logging residues and stumps) could be allocated for energy purposes. Adding that to the government's target of utilising a million cubic metres of wood for biofuels in 2020 yields a total of 15 million m^3 of wood used for biofuel production, enabling approximately 80 PJ/yr (1.8 Mt/yr) of synthetic biofuel production. However, the opportunities to utilise forest biomass for biofuel production are ambiguous. Decreasing forest-industry production reduces the volumes of the forest industry's energy by-products (black liquor, bark, and sawdust), and much less energy will be derived from by-products in 2020 than was estimated in the government's strategy. Compensation for the latter gap, if implemented solely via increased use of forest biomass energy, requires that about half (7 milliom m^3/yr) of the under-utilised wood potential be allocated for heat and power production in 2020. Then approximately seven million cubic metres of wood would remain available for biofuels, enabling 40 PJ/yr (0.9 million t) in synthetic biofuels' production. Taking the existing biofuel production capacity (20 PJ/yr) and national biofuel consumption target (25 PJ) into account, one finds that the potential net export of biofuels from Finland in 2020 would be 35 PJ (0.8 million t), corresponding to approximately 2–3% of European demand for biofuels.

Liquid biofuel production from forest biomass offers opportunities to develop new bioenergy business within the forest industry. Finland's major forest-industry companies have invested in commercialising second-generation biofuel's production technologies that use forest biomass as raw material. From the standpoint of commercialisation of BTL technologies, the opportunities for efficient process integration that enables high, over 70% total conversion efficiency is a key advantage in the forest industry in comparison with separate BTL plants. Decisions on construction of the first industrial-scale BTL plants within the forest industry will be made after the processes are proved on the current pilot scale – at the earliest, in 2011. Nevertheless, economic factors will have the pivotal role in the decisions. Biofuel production has to be profitable business for the companies, and the risk associated with this costly investment should be at an acceptable level.

As a whole, Finnish forest biomass resources and their utilisation (for raw material and energy) and the technological issues related to second-generation biofuel production within the forest industry involve a great deal of complexity, uncertainty, and interdependence. The essential factors for realising the scenario of large-scale second-generation biofuel production and meeting the renewable energy targets in Finland are:

- commercialisation of second-generation biofuel production technologies
- a high utilisation rate for the sustainable harvesting potential for forest biomass, and
- use of some pulpwood harvesting potential for energy purposes.

The factors that would support the above scenario are:

- mobilising the resources of other renewable energy sources, such as wind energy and agro-biomass, and
- importing biomass for energy purposes.

Further research is needed for investigating techno-economic opportunities to increase the utilisation of other indigenous renewable energy sources, especially wind energy and agro-biomass, to above their current 2020 usage targets and consequently release forest biomass for biofuel production. Import of raw biomass for biofuel production would enable considerably greater biofuel production than that considered in this paper. BTL plants integrated with the forest industry have higher conversion efficiency than standalone BTL plants do; accordingly, their capacity to pay for raw material will be higher than that of separate BTL plants. Therefore, the options for import of biomass and integration of the BTL process with other heat loads, such as large district heating networks in coastal areas, are worthy of further investigation. The competitiveness and economics of second-generation biofuels are essential factors influencing the market penetration of biofuels. Optimal allocation of biomass resources among various end uses and optimisation of energy policy measures both are issues that deserve more research. It is recommended that similar wood stream studies be carried out in other countries, to confirm the applicability of the methodology followed in this paper in, for example, Russia, where the decrease in raw wood export to Finland has resulted in a large surplus of forest biomass for second-generation biofuels.

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THE COMPONENTS OF WOOD STREAM REVIEW, CALCULATION STEPS AND INITIAL DATA USED

Component 1. Wood streams in the forest industry

The forest industry procures wood primarily for use as raw material. In the manufacturing of primary products, a significant amount of the wood ends up in energy production or is converted into by-products that are utilised in energy production. An investigation of wood streams in the forest industry is needed for determining how much domestic and imported wood ends up in forest products and energy use. Investigation of the wood streams of the forest industry is done by means of a forest-industry wood stream model that was developed in an earlier study and is described in detail in source [1]. The model takes into account the differences between the branches of the forest industry in the efficiency of wood's conversion into products. Branch-specific consumption volumes for round wood, imported pulp chips, and indigenous woody by-products in the forest industry and production volumes for sawn timber and plywood are needed as the initial data for the model. Wood use in 2007 in different branches of the Finnish forest industry and assumptions concerning wood use in 2020 in different projections are presented in Table 1. Actual forest industry production and the projections are presented in Figure 1.

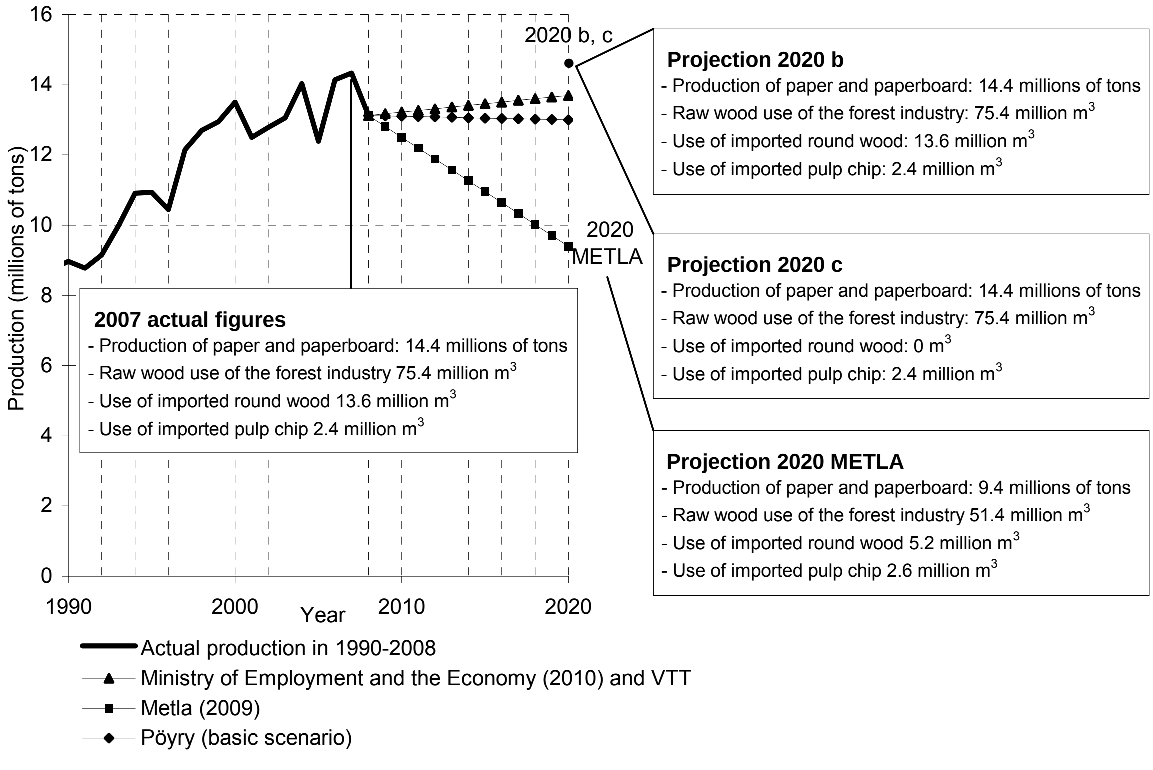

Figure 3. Production of paper and paperboard in Finland in 1990–2008, forecast to 2020, and the projections reviewed [2-4].

Table 1: The use and sourcing of wood for the forest industry in Finland in 2007 and projected to 2020 (figures include bark)

Year/projection	2007 actual[a] (million m^3)	2020 METLA[b] (million m^3)	2020 b (million m^3)	2020 c (million m^3)
Total raw wood use	75.4	51.4	75.4	75.4
Use of indigenous round wood	59.4	43.6	59.4	73.0
Use of imported round wood	13.6	5.2	13.6	0
Use of imported pulp chip	2.4	2.6	2.4	2.4
Wood use in different branches of the forest industry				
Sawmills				
- domestic round wood (logs)	26.5	20.7	26.5	28.0
- domestic pulp chip	0	0	0	0
- imported round wood (logs)	1.5	1.3	1.5	0
- imported pulp chip	0	0	0	0
Plywood mills				
- domestic round wood (logs)	3.2	3.7	3.2	4.0
- domestic pulp chip	0	0	0	0
- imported round wood (logs)	0.7	0.7	0.7	0
- imported pulp chip	0	0	0	0
Fibre and particle board mills				
- domestic round wood (pulpwood)	0	0	0	0
- domestic pulp chip	0.8	0.8	0.8	0.8
- imported round wood (pulpwood)	0	0	0	0
- imported pulp chip	0.1	0.1	0.1	0.1
Other mechanical wood processing				
- domestic round wood (logs)	0.4	0	0.4	0.4
- domestic pulp chip	0	0	0	0
- imported round wood (logs)	0	0	0	0
- imported pulp chip	0	0	0	0
Chemical pulp mills				
- domestic round wood (pulpwood)	20.2	14.4	20.2	30.0
- domestic pulp chip	7.5	4.0	7.5	7.5
- imported round wood (pulpwood)	9.8	2.4	9.8	0
- imported pulp chip	1.9	1.9	1.9	1.9
Mechanical and semi-mechanical pulp mills				
- domestic round wood (pulpwood)	9.1	4.8	9.1	10.6
- domestic pulp chip	3.1	1.3	3.2	3.2
- imported round wood (pulpwood)	1.5	0.8	1.5	0
- imported pulp chip	0.4	0.6	0.4	0.4

[a] Source [5].
[b] Source [2] expecting: 1) figures for other mechanical wood processing that are assumed to be zero for simplification of the calculations by the authors and 2) figures for chip use by fibre and particle board mills that are assumed by the authors.

Component 2. Forest growth and forest biomass harvesting potential

Despite the expansion of the forest industry and increased consumption of round wood over the past five decades, the total volume of growing stock of Finnish forests is on the rise. The annual growth of Finnish forests has been rising since the 1950s, because of improvements in forest management, and total growth has exceeded total removal since the 1970s. Draining of low-production forest areas on moist peatlands has been an important measure to boost the growth of Finland's forests. On the basis of extensive national forest inventories, METLA has estimated annual sustainable removal of logs[2] and pulpwood[3] from Finnish forests in 2007–2016 at 70 million m^3. Exceeding the sustainable level means a decrease in future harvesting possibilities. METLA estimated that the sustainable harvesting potential of logs and pulpwood will increase, to about 80 million m^3, from 2017 to 2026.[6]

Timber assortments that are harvested for energy use include energy wood, logging residues, and stumps. Energy wood has consisted of stem wood that is not suitable (i.e., has too small a diameter) for the forest industry and is mainly available from first and second thinnings. The term 'small-diameter energy wood' is used for wood that does not meet the size requirement for pulpwood (normally, the minimum top diameter for pulpwood is 6–9 cm) and is harvested for energy use (often as a whole tree). Logging residues and stumps are produced from crown biomass[4] and root wood. In Finland, the majority of firewood (approximately 80%) comes from stem wood: from small-diameter energy wood and wood that fulfils the requirements of pulpwood and logs. The remainder of the firewood is composed of logging residues and residues from sawmilling for household use.[7] In this paper, the assumption is that firewood is made solely from stem wood, to simplify the analysis.

Some forest area is protected, or other environmental restrictions limit harvesting potential. The biomass growth in these forests comprises non-exploitable forest biomass potential. A small amount of growing stock is lost through mortality. Also, some stem wood that is harvested for logs and pulpwood does not meet the quality and diameter requirements of the forest industry and is left in the forest. The primary source of stem wood loss is the undersized tops, especially in the first thinning.[8] The increment of stem wood that may be harvested without environmental restrictions but is not harvested comprises untapped stem wood potential. In this paper, sustainable stem wood harvesting potential furthermore includes small-diameter wood that does not meet the diameter requirement for pulpwood. The sustainable potential of small-diameter stem wood corresponds to the technical small-diameter stem wood potential defined by Hakkila[8] as five million cubic metres per year. Untapped stem wood potential is calculated by subtracting harvesting volumes of logs and pulpwood and small-diameter energy wood from the sustainable stem wood harvesting potential.

Similarly to stem wood, environmental restrictions and mortality reduce the available volume of crown biomass and root wood. For example, Finnish forest management practices restrict the harvesting of stumps and logging residues from mineral soils.[9] The above-mentioned limitations to harvesting compose the non-exploitable potential. The actual harvesting potential for logging residues and stumps is directly dependent on the volume of final felling (harvesting volume of logs), whereas the production potential of small-diameter energy wood is not dependent on markets for industrial round wood. The initial data and assumptions for review of forest growth and biomass harvesting potential are presented in Table 2.

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[2] Logs are used as raw material for sawn timber and plywood, and they are most valuable forest biomass.
[3] Pulpwood is smaller-diameter logs and is used as raw material for wood pulps.
[4] More precisely, logging residues include over 10% stem wood (tops); however, this fact is not relevant for the results of this study.

Table 2: Initial data and assumptions for increment and harvesting potential of forest biomass divided into stem wood and crown biomass and root wood (figures include bark)

Parameter / year and projection	2007 actual (million m^3)	2020 METLA (million m^3)	2020 b (million m^3)	2020 c (million m^3)
Stem wood:				
Stem wood growth	99	114[a]	114[a]	114[a]
Sustainable harvesting potential	75	85	85	85
▪ *Logs*[b]	*32*	*33*	*33*	*33*
▪ *Pulpwood*[b]	*38*	*47*	*47*	*47*
▪ *Small-diameter stem wood*[c]	*5*	*5*	*5*	*5*
Harvesting of stem wood for raw material (logs and pulpwood)	57.7	43.6	59.4	73.0
▪ *Logs*	*28.0*	*24.4*	*30.1*	*32.4*
▪ *Pulpwood*	*29.7*	*19.2*	*29.3*	*40.6*
Forest-industry use of domestic round wood (logs and pulpwood)	59.4	43.6	59.4	73.0
Crown biomass and root wood:				
Crown and root wood growth[d]	75	86	86	86
Technical harvesting potential for crown biomass and root wood (logging residues and stumps)	10[e]	14[f]	14[f]	14[f]

[a] The figure is an estimate by the authors. Between 1975 and 2007, annual stem wood growth has increased from 58 to 99 million m^3, and on the basis of this trend-line, annual stem wood growth in 2020 was forecast to come to 114 million m^3. The figure is in line with the estimated increase of sustainable harvesting potential of stem wood. [10, 11]

[b] Source [10].

[c] The figure corresponds to technical harvesting potential for stem wood that does not meet the size requirements for pulpwood – source [8].

[d] Assumed to be 75% of stem wood growth, from data available from source [10]. The figure corresponds to the ratio of the total mass of dry biomass in stem wood (955 million t) to the mass of other biomass in living trees (714 million t).

[e] Source [8]. According to the study, the theoretical harvesting potential for crown biomass and root wood is 36 million m^3/yr and the technical harvesting potential is 10 million m^3/yr, of which 8 million m^3/yr is logging residues (including foliage) and 2 million m^3/yr stumps (figures are in solid m^3). The theoretical harvesting potential includes all stem wood, crown biomass, and root wood left in the forest in conjunction with timber harvesting. Technical harvesting potential is defined according to the theoretical maximum potential by accounting for technological and environmental limitations, such as that not all crown biomass and root wood can be recovered and forest management guidance does not allow removal of stumps and logging residues on mineral soils.

[f] The latest studies (e.g., that of Kärhä et al.[12]) have indicated greater (14 million m^3/yr) technical harvesting potential for logging residues and stumps in 2020, on the basis of the looser restrictions for forest chip production that were included in previous forest management practices; e.g., harvesting of stumps is currently allowed also from pine- and birch-dominant forests. Earlier, logging residues were collected only from spruce-dominant final fellings. The harvesting potential for 2020 is assumed to be equivalent to the techno-ecological harvesting potential of logging residues and stumps presented in source [12]. The harvesting volume of logs in 2020 is assumed to be roughly at the level prevailing in 2007.

Component 3. Forest biomass harvested for energy

In this paper, forest biomass harvested for energy includes firewood, energy wood, stumps and logging residues. The calculations on wood streams are made based on the assumption that the two first of the above mentioned timber assortments are made from stem wood whereas the latter two are made from crown biomass and root wood. A summary of the volumes of forest biomass harvested for energy is presented in Table 3.

Table 3: Parameters used for forest biomass harvested for energy

Parameter / year and projection	2007[a] (million m^3)	2020[b] (2020 METLA, 2020 b, and 2020 c) (million m^3)
Stem wood:		
Firewood	6	5
Energy wood	1	5
Crown biomass and root wood:		
Logging residues and stumps	2	9
Total	9	19

[a] *The actual figures for forest biomass harvested for energy were available in forestry statistics. [10, 11] In 2007, the use of forest chips came to 2.7 million solid cubic metres, of which approximately two thirds came from logging residues and stumps.[13] Energy wood consisted almost solely of small-diameter trees that did not fulfil the size requirement for pulpwood. In the same year, firewood consumption was approximately six million cubic metres. The volume of firewood is defined with the calorific value of firewood assumed to be 8.1 GJ/m.[3] [7]*

[b] *The use of forest chips and firewood in 2020 is set according to governments targets, at 13.5 million solid cubic metres for forest chips and five million for firewood.[14] The assumption is that the shares of energy wood, logging residues, and stumps in forest fuel consumption will be one third each in 2020.[12]*

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