REVIEW PAPER

Availability of Biomass for Energy Purposes in Nordic and Baltic Countries: Land Areas and Biomass Amounts

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Abstract

This review compiles information on the current state of the forests and analyses the potential of forest fuels for energy purposes in Denmark, Finland, Norway, Sweden, Estonia and Latvia. In these countries the forest area is 61 mill. ha, corresponding to 52% of the land areas, which is high in a European perspective where 38% of the land area is forest (EU-27). Although some forest areas are protected, 75–92% of the area can still be used for wood production. Further, substantial agriculture land areas may also be available for production of biomass for energy. Coniferous species dominate the forests in Finland, Norway and Sweden, while a more even distribution of conifers and deciduous species is found in Denmark, Estonia and Latvia. The total growing stock is around 7,400 mill. m^3 and the annual increment is estimated to about 275 mill. m^3 yr^{-1}

Annual growth currently exceeds annual harvest, leading to the conclusion that some of the difference may be used for energy purposes in the near future. The current potential for forest fuel resources was estimated to 230–410 TWh yr^{-1} (830–1,480 PJ yr^{-1}) for the countries included and forest fuels will thus be of utmost importance for the future energy supply in the area.

A changing climate with larger standing volumes may affect the future growth positively and increase the potential harvest levels. Estimates from Finland, Sweden and Norway show an average growth increase of over 30% by the end of the century and substantially higher for specific regions.

Wood is extensively used for energy purposes and the forests hold a large potential for increasing the production of renewable energy. The potential may be further increased in the future with increased fertilization, extended breeding for enhanced biomass production, larger cultivation areas and changes of tree species and management systems.

Key words: annual forest growth, available land areas for forest, biomass availability, forest fuels, climate change effects, energy use, forestry regulations, growing stock, harvest potential of forest fuels, Nordic and Baltic countries

Introduction

The forests of the Nordic and Baltic countries contain large amounts of wood that support the wood processing industries and energy sectors as well as private forest owners. This resource is extensively utilized and contributes to a high degree to the economy of the countries.

The goals for the share of renewable energy set for 2020 by the Directive 2009/28/EC in EU (European Commission 2009) are for Denmark 30%, Finland 38%, Sweden 49%, Estonia 25%, and for Latvia 40%. The goals are high compared to most other EU countries, but Sweden and Estonia are already at the target levels (Eurostat 2012). The Nordic countries have thereafter adopted the ambitious strategy of reaching an independence of fossil energy sources in the energy sector by 2050 (IEA 2013). Renewable sources of energy within the Nordic and Baltic countries currently make up 46% of the total energy production (Denmark 22%, Finland 32%, Norway 61%, Sweden 48%, Estonia 24% and Latvia 33%) (Eurostat 2012). The forests within the Nordic and Baltic countries provide a large share of the biomass currently used for energy.

Biomass and waste provide a substantial share of the renewable energy in Denmark (78%), Finland (87%), Sweden (65%), Estonia (97%) and Latvia (86%), but are of less importance in Norway (12%) (Eurostat 2012). Other significant renewable energy sources are hydropower in Norway and Sweden (87% and 33% of renewable energy, respectively), and wind energy in Denmark (21%).

However, a likely increase in the future demand for renewable sources of energy instigated by national and international initiatives to reduce carbon dioxide emissions (e.g. European Commission 2009), may not be met by the current forest area using current forest management practices.

This review aims to compile information on the current state of the forests in the Nordic and Baltic countries and to describe and discuss the current and future potentials for renewable energy from forests. We rely on official statistics and investigations, from which we do our analysis. A main objective is to create a baseline to which future measures to increase growth can be compared.

Methods

Countries included in the analyses are Denmark, Finland, Norway, Sweden, Estonia and Latvia. Data are presented for forest land areas, growing stock, increment rates and the use of wood. We allocate figures to countries and also to site and age classes, forest types and tree species. We believe these are the most relevant data as a base for discussions about potential improvements on forest production

The majority of data and information are collected from recent official statistics and scientific reports from individual countries. We have also used other compilations like Forest Europe (2011). To handle forecasts about climate change we have used analyses made for the different countries. When collecting data from the different countries it was obvious that they didn't immediately correspond to each other. Therefore efforts were made to translate them to similar units and areas.

The most common way of expressing forest data is in volume of stem wood, i.e. cubic metres (m^3). To facilitate translation to weight and energy units we need conversion factors for wood from fresh volume to dry weight, i.e. basic density. Wood density is different for different species and varies with growth rate, age and tree component (stem, branches, roots etc.). We have used stem wood densities reported in the literature (Nagoda 1968, 1981, Hakkila 1971, 1979, Elfving 1986, Moltesen 1988, Sveriges Skogsvårdsförbund 1994, Chauret and Zhang 2002, Lundgren and Persson 2002, Pâcques 2004, Johansson 2005, Södra 2009) to transform volume to weight.

Branches and tops and needles of conifers, named forest residues, are a main part of the forest fuels, which have little competition from other interests. Normally, figures of growing stock and annual increments do not include this fraction. It has been shown that this residue fraction is relatively higher in conifers than in hardwoods (e.g. Marklund 1988, Repola 2008, 2009). The best overall estimate on branches and needles fraction of the growing stock is probably given by the Swedish National Forest Inventory (SLU 2014). They report a residue-to-stemwood ratio of 0.35 of dry weight for all land use classes in Sweden. Since this figure is dominated by conifers it is probably an adequate figure to use for conifer-dominated countries, but less so, when hardwoods constitute a major share. However, we have used this ratio when adding forest residues to figures on growing stocks and annual increments.

Because heating values for different species are fairly similar expressed on a weight basis (e.g. Nurmi 1991) we have used the same conversion factors for all species when converting dry weight to energy content. Since moisture reduces the energy values in relation to weight, we found it most relevant to base the calculations on dry weight of wood even if this high heating value can seldom be used in practice. For translation of dry weight of wood to energy we use 1 ton DM = 5.3 MWh = 19.2 GJ.

The methodology has been to strucure and compile official statistics on forestry of included countries to show areas, amounts and growth of wood, and to what extent these resources are used today. Restrictions involved in using the wood resources are also included. Country-wise calculations of potential harvest levels of forest fuels are compiled in a separate section.

Forest resources

Forest land areas

The land areas of Nordic and Baltic countries are generally dominated by forest land (Table 1). The total productive forest area is almost 61 mill. ha in the countries included in this study, which is more than 52% of total land area. However, the share is larger in the forest-dominated countries, Sweden and Finland, with 57–67%. These countries also dominate in absolute terms with more than 43 mill. ha forest land, making up 71% of the productive forest land area in the region. Denmark has a comparably small forest cover (14%), while the corresponding figures for Estonia and Latvia are 52% and 46%, respectively. Large areas in Norway are classified as mountains and plateaus without forest and forest land therefore constitutes 38% of total land area. The share of forest land is high in a European perspective, where 38% is defined as forest land in EU-27 (Forest Europe 2011).

Table 1. Land areas distributed on land use classes in Nordic and Baltic countries.

Country	Productive forest land	Other wooded land (EST, S, DK) poorly productive forest land (FIN), mountains, plateaus etc. (N), naturally afforested and bushes (LV)	Barren land (S), unproductive land (FIN), marsh/wetlands (N), wetlands, dunes etc. (DK), other land (EST, LV)	Other land (S, FIN), agriculture, build-up areas (N), artificial, agricultural areas etc. (DK), agriculture land (EST, LV)	Total land area	Forest land of total land area
	1,000 ha	1,000 ha	1,000 ha	1,000 ha	1,000 ha	%
Denmark	608	45	295	3,361	4,310	14.1
Finland	20,259	2,518	3,196	4,442	30,414	66.6
Norway	11,622	15,638	1,765	1,400	30,425	38.2
Sweden	23,099	7,387	4,941	5,370	40,797	56,6
Estonia	2,212	79	604	1,374	4,269	51.8
Latvia	2,986[1]/2,962[2]	113[2]	946[2]	2,403[2]	6,448[2]	46.3
TOTAL	**60,762**	**25,780**	**11,747**	**18,350**	**116,663**	**52.1**

Sources: Danmarks Statistik (2012), Johannsen et al. (2013), Estonian Environment Information Centre (2012), Finnish Forest Research Institute (2012), Latvian State Forest Service[1] (2012), Latvian State Land Service[2] (2012), Statistics Norway (2011) and Swedish Forest Agency (2013)

Data on forest land is presented in different ways in the country wise statistics, which may make comparisons somewhat difficult. They are here presented according to forest type, tree species and age class.

Forest types

The forest types and tree species distributions are presented differently in the national surveys among the countries. We have used the forest types defined in Forest Europe (2011), which provide good insight in the distribution of forest types for the north-south gradient and of tree species included (Table 2). Since the definitions in Forest Europe (2011) and the national statistics are not quite comparable some discrepancies may occur among the area figures, but these do not affect general conclusions about forest areas. The boreal forests are dominating and mainly found in Finland, Norway and Sweden. In those forests Norway spruce and Scots pine are the most common. Other frequent forest types are hemiboreal/nemoral forests, with conifers or with mixed conifers and deciduous species, mires and swamps, and non-riverine forests. In the latter, alder, birch and aspen are common. Non-native tree species are mainly found in Denmark, Norway and Sweden.

Age class distribution

The classification of forest areas into age classes provide information on the future potential for wood harvesting, although actual potentials may be affected by changes in forest area, growing conditions, silvicultural practices and damage such as wind throw or pests. In the countries included in this review, the majority of the forest area (30 mill. ha or 51%) is stocked with young to middle aged stands, i.e. 20–80 years old (Table 3, Figure 1). Also the youngest age classes, 0–20 years, are common and constitute 11 mill. ha (19%) of the forest area. Finland, Norway and Sweden have large shares with old forest compared to the other countries. Assuming conventional forest management, large areas of mature forest will thus be available for harvesting within the 2050 timeframe used in the analyses by the International Energy Agency (IEA 2013).

Table 2. Area distribution of forest types in the different countries

Forest type	Area (1,000 ha)					
	Denmark	Finland	Norway	Sweden	Estonia	Latvia
Boreal	0	15,462	5,415	15,211	950	411
Hemiboreal/nemoral, coniferous/mixed	28	451	1,147	6,380	39	1,229
Alpine	0	316	1,038	1,095	0	0
Acidophilous oak/oak-birch	28	0	21	125	0	0
Mesophytic deciduous	95	0	5	38	0	0
Beech	83	0	8	79	0	0
Mire and swamp	2	4,360	653	2,860	304	267
Floodplain	34	0	5	25	0	0
Non-riverine, alder/birch/aspen	0	1,462	1,719	2,253	909	1192
Introduced tree species	286	34	239	539	1	1
Unclassified	30	0	0	0	0	253
TOTAL	**586**	**22,085**	**10,250**	**28,605**	**2,203**	**3,353**

Reference year is 2010. Data taken from Forest Europe (2011)

Table 3. Age distribution of Nordic and Baltic forests expressed in 1,000 ha

Age class	Country						TOTAL
	Denmark	Finland	Norway	Sweden	Estonia	Latvia	
Unknown	90						90
0–20	123	3,565	1,387	4,891	279	537	10,782
21–40	158	3,723	1,284	4,822	400	383	10,770
41–60	136	4,048	1,779	3,891	619	567	11,040
61–80	46	3,268	1,615	2,334	445	644	8,352
81–100	24	2,339	1,520	1,964	199	414	6,460
101–120	12	1,156	1,170	1,588	72	188	4,186
121–140	8	622	1,043	1,321	49	68	3,111
>140	10	1,538	717	1,568	<1	55	3,889
Total	**608**	**20,259**	**10,518**	**22,379**	**2,063**	**2,854**	**58,681**

Sources: Johannsen et al. (2013), Finnish Forest Research Institute (2012), Granhus et al. (2012), Swedish Forest Agency (2013), SLU (2013), Estonian Environmental Information Centre (2012) and Latvian State Forest Service (2012)

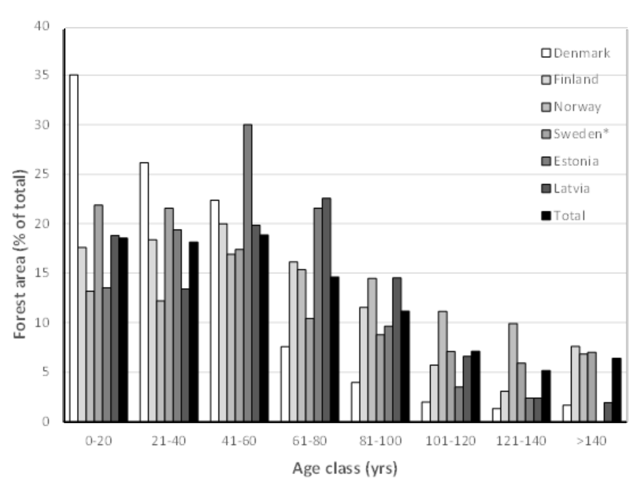

Figure 1. Age class distribution in Nordic and Baltic forests expressed in percentage of total forest area.* productive forest land

Growing stocks

Estimates of growing stock and growing stock per hectare are related to potential amounts of biomass available for harvest (Table 4). Scots pine and Norway spruce constitute together almost 77% of the growing stock within the Nordic and Baltic countries. The third most common species is birch (15%). In terms of growing stock, the Danish forests are different from the other Nordic countries by having a larger share of other broadleaves such as beech and oak (Figure 2). Denmark, Estonia and Latvia have the highest tree volumes when expressed per unit of area (Table 4).

If a residue-to-stemwood ratio of 0.35 (SLU 2014) is used for all six countries, residues will constitute 2,400 mill. m^3 in total. However, the ratio is not applicable, where hardwoods are more frequent than in Sweden, and the conversion from volume to weight is a rough estimate.

According to the extent of forest types defined in Forest Europe (2011), boreal forests have the largest growing stock (Table 5). The distribution is very much the same as for forest type areas (cf. Table 2). Beech forests have the highest volume per unit of area among the forest types (313 m^3 ha^{-1}) and, as expected, mire and swamp forests (72 m^3 ha^{-1}) and alpine forests (18 m^3 ha^{-1}) have the lowest.

Current growth and harvest

The productivity of the forests in the Nordic and Baltic countries is crucial for future availability of wood. Current growth acts as a benchmark for comparison of silvicultural initiatives such as fertilization, introduction of new tree species and implementation of breeding progresses.

The total annual increment on Nordic and Baltic forest land is over 275 mill. m^3 yr^{-1} (Table 6). Over 75% of the stem growth occurs in Finland and Sweden. Scots pine and Norway spruce are responsible for more than 70% of the increment. The highest productivity per hectare is found in Denmark and the lowest in Norway.

By applying the same residue-to-stemwood ratio as used under “Growing stocks” above, an additional 97 mill. m^3 yr^{-1} of branches and needles could be added to the annual increment of stem wood.

Availability of the growing stock for wood supply is generally high according to Forest Europe (2011).

Table 4. Growing stock in the Nordic and Baltic forests distributed on main tree species and expressed in mill. m^3 on bark

Tree species	Country						Total
	Denmark	Finland	Norway	Sweden	Estonia	Latvia	
Scots pine	8.4[1]	1,145	266	1,174	174		2,767[2]
Norway spruce	22.0	698	395	1,247	81		2,443[2]
Birch	4.8	384	140	363	121		1,012[2]
Other broadleaves	64.5	78	68	182	83		476[2]
Other conifers	25.4	<1	10	37	.		72[2]
Total	**125.1**	**2,305**	**879**	**3,002**	**458**	**631**	**7,400 (6,769[2])**
Total (m^3 ha^{-1})	206	111	111	134	207	221	

Sources: the same as in Table 3. [1] including all pine species; [2] Latvia not included

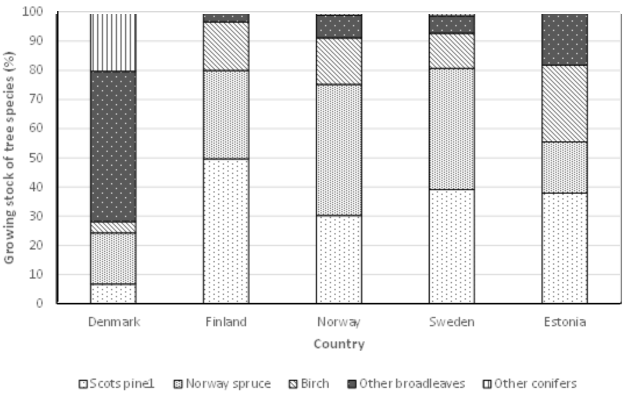

Figure 2. Growing stock in the Nordic and Baltic forests distributed on main tree species and expressed as percentages. All existing pine species are included in the Scots pine part in Denmark. No data on the volume-based species distribution was available for Latvia

The Finnish Forest Research Institute (2012) estimated that 97% of annual growth is available for wood supply. Overall, 89% of the growing stock is available, i.e. 6.6 of 7.4 billion m^3 of stem wood.

Annual harvests in the Nordic and Baltic States are consistently below the annual growth, giving possibilities to some increase of the future harvest level (Table 7). The current use of annual increment for wood harvest differs among the countries. Norway only uses 35% of the annual growth while Estonia uses 84%.

Available forest areas

The entire forest area is not available for forest production. Some areas are excluded for environmental reasons or due to legislation, or are technically unavailable. Here we assume that forest on unprotected, productive forest land can be used to sustain future forest fuel supply.

Table 5. Distribution of growing stock on forest types in the different countries

Forest type	Growing stock (1,000 m^3 o.b.)						
	Denmark	Finland	Norway	Sweden	Estonia	Latvia	TOTAL
Boreal	0	1,625,023	595,118	1,706,161	225,376	84,070	**4,235,748**
Hemiboreal/nemoral, coniferous/mixed	4,149	64,254	169,120	1,071,655	5,922	295,770	**1,610,870**
Alpine	0	6,609	37,285	n.a.	0	0	**43,894**
Acidophilous oak/oak-birch	3,443	0	3,121	25,338	0	0	**31,902**
Mesophytic deciduous	15,619	0	1,318	8,001	0	0	**24,938**
Beech	30,674	0	1,348	2,1268	0	0	**53,290**
Mire and swamp	368	358,052	27,707	144,105	42,738	33,810	**606,780**
Floodplain	7,658	0	873	3,392	0	0	**11,923**
Non-riverine, alder/birch/aspen	0	149,858	108,403	22,8473	166,783	210,200	**863,717**
Introduced tree species	51,445	3,436	53,458	34,203	609	258	**143,409**
Unclassified	0	0	0	0	0	8,722	**8,722**
TOTAL	**113,356**	**2,207,232**	**997,751**	**3,242,596**	**441,428**	**632,830**	**7,635,193**

Reference year is 2010. Data taken from Forest Europe (2011)

Table 6. Annual increment of stem volumes in Nordic and Baltic countries distributed on main tree species and expressed in mill. m^3 yr^{-1}

Tree species	Country						Total
	Denmark	Finland	Norway	Sweden	Estonia	Latvia	
Scots pine	3.3[1]	47.4	5.2	41.5	3.7	n.a.	101,1[3]
Norway spruce	n.a.	32.5	12.6	50.0	2.6	n.a.	97.7[3]
Birch	n.a.	19.6	3.2	15.3	3.3	n.a.	41.4[3]
Other broadleaves	3.2[2]	4.5	2.0	6.7	2.8	n.a.	19.2[3]
Total	**6.7**	**104.0**	**23.0**	**113.5**	**12.4**	**16.5**	**276.1**
Total (m^3 ha^{-1} yr^{-1})	8.8	5.1	2.9	5.1	5.8	5.8	

Sources: the same as in Table 3. [1] the figure is for all conifers; [2] the figure is for all broadleaves; [3] data from Latvia are not included. n.a. = not available

Table 7. Stem wood volumes in Nordic and Baltic States on forest land and the share available for wood biomass supply

Country	Growing stock			Increment	Fellings	Used share
	Total	Available for wood supply	Availability	Annual	Annual	Fellings of increment
	mill. m^3	mill. m^3	%	mill. m^3	mill. m^3	%
Denmark	125	112	90	6.71	3.39	51
Finland	2,305	2,024	88	104.05	58.12	56
Norway	879	797	91	22.98	8.07	35
Sweden	3,002	2,651	88	113.52	87.40	77
Estonia	458	398	87	12.40	10.47	84
Latvia	631	584	93	16.50	12.50	76
Total	**7,400**	**6,566**	**89**	**276.16**	**179.95**	**65**

Data taken from Johannsen et al. (2013), Finnish Forest Research Institute (2012), Statistics Norway (2011), Swedish Forest Agency (2013), Estonian Environment Information Centre (2012), Bekeris (2011) and Table 4 above. The estimates of available growing stock for wood supply were presented in Forest Europe (2011)

About 40 000 hectares (6.6%) is set aside in Denmark as non-intervention forests and for protection of specific forest types (old oak scrubs) in reference to the Strategy for Natural Forests, or is part of protected forest nature types according to the Habitat directive in the Natura 2000.

A large share of the forest land area in Finland can be utilized for wood production (18.6 mill. ha, 92%), while possibilities are lower on poorly productive forest land (cf. Table 1; Finnish Forest Research Institute 2012).

In Norway 2.7 mill. ha of the forest area (23%) is classified as protection forest (Nordic Family Forestry 2014) and 0.2 mill. ha (1.7%) is protected under The Nature Conservation Act. In addition, about 12 000 ha is also voluntary protected by the forest owners themselves, leaving about 8.7 mill. ha (75%) available for forest production.

The total forest area set aside for environmental protection in Sweden is 4.9 mill. ha (17.5%) (Swedish Forest Agency 2013). The formally protected forest land amounts to 1.0 mill. ha (3.6%), with the highest share in the northern part of the country. The area exempted from forestry is 2.8 mill. ha (10.0%) and more equally distributed over the country. Areas voluntarily set aside are substantial, with over 1.1 mill. ha (3.9%).

In Estonia forest land is classified either as areas under protection or as commercial forests. The forest land area available for wood production constitutes 1.7 mill. ha (75%).

In Latvia 190,000 ha (5.7%) are protective forest zones and 66,000 ha (2.0%) are natural forest biotopes (Bekeris 2011), thus leaving 92% for commercial use (Latvian State Forest Service 2012).

In total, across the Nordic and Baltic countries, 55.4 mill. ha (85%) is available for wood production. As the set aside areas are commonly less productive, the majority of the current growing stock (89%) is available (Table 7).

Other available land

In forest-rich countries like Sweden and Finland biomass from forest land make up the bulk production of biomass for energy, but afforestation of arable land can also produce substantial amounts of biomass in all Nordic and Baltic countries. During the last century arable land has been used for afforestation despite a policy framework that has promoted an expansion of croplands by subsidising agriculture on marginal lands (European Commission 2012). The decline in crop lands is, among others, related to an increase in efficiency in per area production of agricultural crops. Scenarios have shown that if technology continues to progress at current rates, the area of agriculture land would need to decline substantially (Rounsevell et al. 2005). For Finland, Norway and Sweden the estimated decline in cropland over 80 years was 33–67% and for Denmark 8–47%, depending on scenario. The reduction of agricultural land will, however, be lower if the rate of technology development decreases (Eckersten et al. 2008).

Afforestation of agriculture land involves a risk that ecologically valuable grasslands (EVGs) might be changed to forest land (Elbersen et al. 2014). However, it is not a topic of this review to evaluate figures on abandoned farmland available for afforestation given in the literature, but include the areas as a possible source for future biomass production.

In 1994 it became a political goal in Denmark to reach a share of 20–25% forest land within a tree generation, which is usually interpreted as 100 years. Based on this goal 250,000–470,000 ha of farm land should be available for afforestation.

Land areas for afforestation are limited in Finland due to the already large share of forested land. During the years 1969–1998 afforestation of abandoned agricultural areas varied between 2,000 and 18,000 ha yr^{-1} (Tilli and Toivanen 2000), and during the period 2004–2011 it has annually been varying between 2,000 and 3,600 ha yr^{-1}. The total area of fallows and uncultivated arable land available for afforestation was estimated to around 276,000 ha in 2011 (Ministry of Agriculture and Forestry in Finland 2012).

Areas available for afforestation are also limited in Norway due to low productivity and restrictions on converting open land to forest. According to Granhus et al. (2012), 175,000 ha of coastal heathland may potentially be afforested. Areas presently not used for farming are about 20,000 ha (SSB 2012).

Recent estimates on areas not actively used and available for afforestation show that Sweden has approximately 300,000–500,000 ha (Anon. 2006, Larsson et al. 2009). It should also be noticed that use of *Salix* and *Populus* in Sweden does not change land use class to forest land if cultivated as short rotation forestry for energy purposes, i.e. with rotations <10 and <20 years, respectively.

A rapid decline in agricultural land use occurred in Estonia after the independence in 1991. Today afforestation on abandoned agricultural areas is considered as one potential way of increasing bioenergy supply. In 2007 there were about 123,000 ha without any applications for Common Agriculture Policy area payments, and thus considered as abandoned land. Additionally, about 163,000 ha were only partially in use for agriculture (Landresource 2007).

According to Rural Support Service of Latvia (2012) the total area of agricultural land potentially available for forest fuel production is around 260,000 ha. Of this, 86% is unmanaged agricultural land and 14% is overgrown agricultural land.

In total, 1.6–2.0 mill. ha are potentially available for afforestation in the Nordic and Baltic countries, corresponding to an increase in the current productive forest area of 2–3%.

Effects of climate change and standing volume on future productivity

When considering future growth in our forests we can use measures like breeding, fertilization, introduction of new tree species and intensive silviculture methods. These measures can be directed in various ways in the future and are not part of this review. However, we cannot ignore the effects on growth of changes in climate and growing stock, which itself will affect forthcoming growth.

Increases in annual mean temperature and changes in precipitation patterns are expected in the future, along with increased CO_2 concentration in the atmosphere (Jylhä et al. 2004, Carter et al. 2005, Ruosteenoja et al. 2005, Kjellström et al. 2011, Poudel et al. 2011). A changing climate is likely to increase forest growth directly through intensified physiological processes such as extension of growing season (Berg et al. 2010), earlier budburst (Heide 1993, Bergh et al. 2003, Slaney et al. 2007), and elevated CO_2 concentration (Norby et al. 2005, Koca et al. 2006, Bergh et al. 2010). An increase in nitrogen mineralization may also positively affect future growth of Nordic forests (e.g. Melillo et al. 1993).

The growth of forests under climate change (a 4 °C increase in the summer mean temperature and an increase of atmospheric concentration of CO_2 from 352 ppm to 841 ppm by the end of the century) with current forest management practices over the whole Finland has been estimated to be 29% by 2050 and 44% by 2100 (Kellomäki et al. 2008). The mean stem wood growth was estimated to increase from 4.1 to 5.3 m^3 ha^{-1} yr^{-1}. Under the projected climate change, the growth has been estimated to increase with the largest relative changes in northern Finland and the highest absolute figures in the southern part (Kellomäki et al. 2008, Alam et al. 2010). However, the growth increase of Norway spruce was estimated in many sites to be small or even negative in southern Finland, mainly due to drought periods occurring with increases in temperature by the end of the century. The effect of a changed climate was estimated also to increase total standing volumes in Finland with 31% by 2050 (Kellomäki et al. 2008). The share of Scots pine was estimated to increase, whereas the share of Norway spruce was projected to decrease. However, most of the reduction may occur by the end of the 21st century when birch seemed to replace Norway spruce in many places if current forest management was obeyed (Kellomäki et al. 2008).

A temperature rise of 2 °C will increase forest production and uptake of CO_2 with about 75% in Norway, from 4 to 7 mill. tons annually within 100 years (Astrup et al. 2010). These estimates assume an unchanged forest management. If the annual harvest level is increased with 50%, the forest production increase will be only 30%, but this can be counteracted by an enhanced investment in planting and management.

The climate effect has been forecasted for Sweden in the SKA-08 report (Swedish Forest Agency 2008). According to this report the growth of Norway spruce will increase by 16–46% in different regions to the period 2071–2100. The corresponding figures for Scots pine and birch are 8–36% and 11–33%, respectively. The harvest in Sweden has historically been below the forest growth level and if this trend continues it will lead to a continued increase of growing stock. The growth effects of a changed climate and increased standing volume together were estimated to over 30% for Sweden in the year 2100 (Swedish Forest Agency 2008). According to a study by Poudel et al. (2011), a temperature rise of 4 °C over the next 100 years may increase forest production in north-central Sweden by 33% compared to a reference alternative without climate change. This temperature rise will allow an increase of the potential annual harvest by 32% in the region.

The possible impact of recent and predicted future climate change on forestry in Estonia was studied in the end of 1990s (Nilson et al. 1999, Kiviste 1998). It was verified by statistical analysis that forest growth had accelerated by 15% during the period 1950–1990, where climate change is probably one factor together with others like changes in forest management, changes in species composition and breeding improvements. In Latvia climatic factors, like temperature the previous growing season, have shown significant effects on height increment of Scots pine (Jansons et al. 2015). Elferts (2008) reported that the impact of chronological climate conditions on pine growth in Latvia could be explained with 35%, mainly due to temperature changes during February and March leading to earlier start of the vegetation period.

Regulations – legislations, directives and certifications

Suggested improvements for increasing biomass production, i.e. breeding, fertilization, introduction of clone material and exotic tree species etc., cannot be implemented without considering different kinds of regulation. Legislation, directives and certification demands must be followed in each country, although they are probably subjected to change over time. Some of the more important regulations are given as examples below.

In Denmark, the Forest Law (Naturstyrelsen 2015) provides the framework for forest management on the 72% of the forest area declared as forest reserve. On forest reserves the land must be wooded with trees that potentially can develop into high forest within reasonable time, i.e. within 10 years from clear felling. Within forest reserves, up to 30% may be managed with other management forms than high forest, including growing of Christmas trees, short rotation coppice, open areas for aesthetics or game management and forest grazing. Only few restrictions exist in the Danish Forest Law regarding the choice of forest tree species and management practises, except for the restrictions on land use within forest reserves. An exception is the management of forests classified as forest nature types according to the Habitat directive within Natura 2000 areas (20,000 ha). Forest on these areas must be managed without loss of the nature type.

Forest management practices are certified in Denmark according to FSC or PEFC standards on 253,000 ha of forest land. On certified forest land, which includes the state forests (17% of the forest land), the certification agreements impose specific restrictions on forest management practises. Implementation of close to nature principles for forest management has been a strategy within the state forests (17% of the forest land) since the Rio Conference in 1992 (Ministry of Environment 1994, 2005).

In Finland, introduction of clone material and foreign tree species are regulated by the Forest Act (1093/1996) and the Act on Trade in Forest Reproductive Material (241/2002). In the production of forest reproductive material only parent material which meets the requirements laid down in Annex II-V to Directive 1999/105/EC and classified accordingly, may be used. A national strategy for non-native species was adopted by a Government Resolution in March 2012. The purpose is, for example, to prevent damage and risks to the Finnish nature caused by non-indigenous species.

PEFC certification does not set up further restrictions for exotic tree species in Finland, while FSC requires that during a 5-year period, the forest owner may use exotic tree species at a maximum of 3% of the planting or regeneration area and maximum of 5% of the total forest land. A forest owner with less than 50 ha forest land may use exotic tree species to a maximum area of 2.5 ha.

Introduction of non-native tree species are restricted in Norway due to possible negative effects on the biodiversity and legislations are stated by the Ministry of Environment (2012a). As a main rule, planting of non-native tree species is accepted in areas if the natural reproduction can be controlled and negative effects on biodiversity and other local species are negligible. In addition, stronger restrictions are applied for species on the “black list” stated by the Norwegian Biodiversity Information Centre (Artsdatabanken 2012). For example, Sitka spruce (*Picea sitchensis*) is regarded as a high risk reproductive species and is seldom allowed for new planting.

FSC and PEFC standards in Norway represent an agreement between several environmental organisations, labour unions, outdoor life organisations, forest industry organisations and forest owner associations (Levende Skog 2009). The Norwegian government wants an active forest policy and stimulates, for example, fertilization of forest to increase carbon uptake, afforestation of new areas, breeding programs, increased plant density and a prohibition of young forest harvesting (Ministry of Environment 2012b).

In Sweden, several of the tree species of interest in a biomass production perspective are non-native species. Current legislation state that non-native tree species should be used cautiously and on a limited scale (Skogsstyrelsen 2009). This is interpreted as a maximum of 25% of the forest area of a forestry unit, although 50 ha are always allowed. The use of non-native species must be notified to the Forest Agency if the area is 0.5 ha or more and is not accepted in mountain forests. There are further rules if vegetative produced material is used, as exemplified by hybrid aspen and poplars. The maximum area on a forestry unit is then 5%, where 20 ha are always allowed.

FSC standards for certification include a further set of restrictions for the use of non-native tree species in Sweden (FSC 2010, Södra 2011), while the PEFC certification keeps to the directives of the Swedish Forest Agency. According to the certification by FSC, non-native species should be used very restrictively with a maximum of 5% of the productive forest area for an estate. If the estate area is less than 50 ha the maximum area is 2.5 ha. If forest owners use non-native species they must also prevent natural spread of them.

On agricultural land the rules for using trees from the genera *Populus* and *Salix* are different from the use on forest land. It is allowed to use *Salix* and *Populus* as agricultural crops, if they are used for energy purposes and the rotation cycles are shorter than 10 and 20 years, respectively. In addition, in principle there are no limitations of species choice when afforesting agriculture land.

According to the Forest Act in Estonia the following non-native tree species are allowed to be introduced (Riigikantselei 2010a): *Picea mariana*, *P. omorika*, *Pinus contorta*, *Larix decidua*, *L. sibirica*, *L.* × *sibirica*, *L.* × *kaempferi*, *L. gmelinii*, *L.* × *eurolepis*, *Pseudotsuga menziesii*, *Abies sibirica*, *Quercus rubra*, and *Populus* × *wettsteini*.

The Latvian Forest Law divides forest in ordinary forests and plantation forests. In ordinary forests specific species restrictions apply to forest management practices, including harvest minimum threshold diameter and stand age. For plantation forests, there are no limitations for harvesting and dimensions. Non-native tree species are accepted if they are suitable for cultivation in Latvia, but permission is needed from the state forest service and the research institute SILAVA.

Potential harvest levels for energy purposes

Biomass and biodegradable waste constitute a large proportion of the renewable energy supply, except in Norway. The percentage was 65–97% in 2010, Norway excluded. Other energy sources of significance for the countries are hydropower in Norway and Sweden (88 and 33%, respectively), and wind energy in Denmark (21%).

The situation and possibilities of harvesting forest fuels are presented country-wise below. Four main assortments for primary forest fuel can be identified: 1) roundwood (debranched stem wood); 2) slash (logging residues from above stump; 3) stumps and coarse roots; and 4) small sized trees (commonly from early thinnings, in which entire trees are chipped *in situ* and transported to conversion facilities).

Table 8. Primary supply of renewable energy in 2010 in the studied countries

Country	Total primary supply	Solar energy	Biomass and waste	Geothermic energy	Hydropower energy	Wind energy
	TWh	TWh	TWh	TWh	TWh	TWh
Denmark	36.3	0.8	28.2	0.1	0	7.8
Finland	105.0	0	91.8	0	12.9	0.3
Norway	134.4	0	16.0	0.4	117.6	0.9
Sweden	202.5	0.2	132.4	0	66.4	3.4
Estonia	11.5	0	11.2	0	0	0.3
Latvia	24.4	0	20.9	0	3.5	0
Total	**514.1**	**1.0**	**300.4**	**0.5**	**200.5**	**12.8**

Source: Eurostat (2012)

Denmark. In a study on potential Danish forest fuel resources (Table 9) a number of different scenarios depicting increasing intensity in production and use of forest fuels were developed and analysed (Graudal et al. 2013). The four scenarios were: 1) BAU – Unchanged forest management with an annual afforestation of 1,900 ha; 2) BIO – Focus on production with the current level of afforestation with increased use of conifers and breeding towards fast growing varieties. Increased thinning and increased production of bioenergy assortments; 3) ENV – Focus on environment with an increased afforestation and conversion to more broadleaves with longer rotation ages and reduced thinnings. Reduced harvesting of forest fuel assortments in broadleaves and reduced breeding of varieties for increased growth; 4) Kombi – Increased afforestation with use of nurse trees for forest fuels combined with set aside of unmanaged forest areas for biodiversity. Increased harvesting of forest fuel assortments and breeding of varieties for increased growth.

In the BAU scenario 1.0 mill. tons of biomass (18.3 PJ/5.1 TWh) was available, corresponding to 2.3% of the current energy use or 23% of the objective stated by the Ministry of Energy. In this scenario forest fuels are estimated to provide 2.8% of the energy use in 2050, corresponding to 18% of the objective. The three other scenarios resulted in increased production of forest fuels, ranging between 1.4 and 2.3 mill. tons of biomass and corresponding to 3.1–5.1% of current energy use. Depending on scenario, forest fuels are predicted to make up 4.4–7.0% of total energy use in 2050, corresponding to 29–46% of the wood for energy objectives stated by the Ministry of Energy (Graudal et al. 2013).

Finland. The Finnish potential recoveries of industrial wood and raw material for forest fuel (roots,

Table 9. Scenarios for future availability of forest fuels in Denmark

Scenario		Year			
		2012	2020	2050	2100
Energy consumption (PJ/TWh)		814/225	750/207	650/179	550/152
Wood for energy objective		81/22	90/25	100/28	100/28
BAU	Biomass (mill. tons)	1.0	0.9	1.0	1.2
	Energy (PJ/TWh)	18.3/5.1	17.0/4.7	18.0/5.0	21.2/5.9
% of energy		2.3	2.3	2.8	3.9
% of wood for energy objective		22.6	18.9	18.0	21.2
BIO	Biomass (mill. tons)	2.3	2.0	2.5	3.7
	Energy (PJ/TWh)	41.5/11.5	35.8/9.9	45.7/12.6	66.0/18.2
% of energy		5.1	4.8	7.0	12.0
% of wood for energy objective		51.2	39.7	45.7	66.0
ENV	Biomass (mill. tons)	1.4	1.2	1.6	2.0
	Energy (PJ/TWh)	25.2/7.0	21.6/6.0	28.8/8.0	36.0/9.9
% of energy		3.1	2.9	4.4	6.5
% of wood for energy objective		31.1	24.0	28.8	36.0
Kombi	Biomass (mill. tons)	1.7	1.6	2.5	4.0
	Energy (PJ/TWh)	30.4/8.4	28.1/7.8	45.7/12.6	72.6/20.0
% of energy		3.7	3.7	7.0	13.2
% of wood for energy objective		37.5	31.2	45.7	72.6

Source: Graudal et al. (2013), Figures were translated from PJ to TWh with the constant given in the Methods section

stumps, branches, foliage and stem + bark of waste wood) were analysed in three scenarios (current, sustainable and maximum) by Kärkkäinen et al. (2008) over a 50-year period (2003–2052). The impact of climate change was included and forest management regimes were optimized for timber production. The potential amount of the forest fuel assortments was estimated to 35 mill. tons yr^{-1} (186 TWh/670 PJ) in the maximum cutting scenario during the period 2003–2013. In the sustainable cutting scenario, the corresponding figure was around 25 mill. tons yr^{-1} (132 TWh/480 PJ). During the period 2043–2053 the potential recovery of forest fuel was calculated to 22, 26 and 29 mill. tons yr^{-1} (117, 138 and 154 TWh or 410, 500 and 560 PJ) for the current, sustainable and maximum cutting scenarios, respectively.

The proportion of forest fuel assortments changed during the time due to a change in age structure of forest stands and forest management. As the biomass of branches and foliage in relation to the stem is generally greater in young trees than in mature trees, the proportion of logging residues will be greater compared to that of industrial stem wood in Finland in the future. The amount of spruce-dominated mature forest will also decrease during the coming decades. Consequently, the total amount of residues from the final cuttings of spruce-dominated forests may decrease in Finland (Kärkkäinen et al. 2008). The forest fuel potential of early thinning of small trees for biomass has been found to increase over time both for current and changing climate in the whole of Finland by the end of the 21st century (Alam et al. 2010, Kellomäki et al. 2010). The amount of harvestable small trees is also highly dependent on logging method. Räisänen and Nurmi (2011), for example, found that a top diameter increase for logging residues (6 to 10 cm) will result in an increase of total residue from 6.9 to 12.2 tons DM ha^{-1} for Scots pine and from 10.2 to 14.5 tons DM ha^{-1} for Norway spruce.

Estimated total forest fuel potentials may be affected by practical limitations and the results should mainly be considered as theoretical potentials. However, Helynen et al. (2007) estimated that the current technically harvestable amount of forest fuels (wood chips) in the Finnish forests is around 16 mill. m^3 (85 TWh/310 PJ). Of this, 45% comes from harvests in young forests and first thinnings. The remaining 55% represent logging residues from final fellings.

Norway. Prognoses of the available resources of forest fuels have been made for Norway based on three different scenarios (Gjølsjø and Hobbelstad 2009). Level 1 includes the potential of all forest areas without economical, technical or biological restrictions, assuming that all possible residues from thinning and final felling are used. Level 2 is reduced for off road extraction distances exceeding 1.5 km, for terrain steeper than 90% (~38°) and for environmental restrictions. Level 3 includes level 2 restrictions, but include additional areas with an intensive forest road building program. According to these scenarios, the overall potential for extraction of wood for biomass (Level 1) is 5.11 mill. tons (27.1 TWh/98 PJ) (Table 10). When technical and environmental restrictions are added, the potential is 3.84 mill. tons (20.4 TWh/74 PJ).

There is presently a large unused resource of stumps and large roots in Norway, but current extraction is negligible due to economical, technical and environmental reasons. The utilization of slash has increased the last years; however, in 2014 economical subsidies were removed by the new government. In 2012 about 110,000 m^3 loose volume of chips from forest residues were extracted (Lileng 2012). Nevertheless, other sources of forest fuels are larger, including trees from roadsides, cultivated landscapes and deciduous forests. Lileng (2012) reports a total potential of about 900,000 m^3 loose volume of forest chips. The potential of small sized trees is also considerable (Løken et al. 2012).

Sweden. The dominant forest fuel assortment in Sweden is slash from final harvest. Slash harvest amounted to 2.3 mill. tons of dry matter (c. 12 TWh/ c. 44 PJ) during 2011 (Swedish Forest Agency 2013), corresponding to 57% of the forest fuels used in Sweden (Brunberg 2012). According to estimates presented in the SKA-08 report it should be possible to double this amount without serious impact on the environment (Table 11). Egnell and Björheden (2013) evaluated a changed minimum top diameter for pulpwood,

Table 10. Annual harvest potential of slash, stumps and large roots (sum of thinning and final felling) in Norway

Restriction level	Thinning and final felling						TOTAL		
	Slash			Stumps and large roots					
	Mton DM	TWh	PJ	Mton DM	TWh	PJ	Mton DM	TWh	PJ
Level 1	3.39	18.0	65	1.73	9.2	33	5.11	27.1	98
Level 2	2.54	13.5	49	1.29	6.8	25	3.84	20.4	74
Level 3	3.05	16.2	59	1.55	8.2	30	4.60	24.4	88

Sources: Gjølsjø and Hobbelstad (2009) and Løken et al. (2012). Details about restriction levels are given in the text. The relation 1 ton DM = 5.3 MWh = 19.2 GJ has been used when transferring dry weight to energy units

from 5 to 10 cm, and found that available logging residues from final felling and thinning would annually increase by 2.3–2.6 mill. tons of dry matter (12–14 TWh/ 44–50 PJ).

Round wood for energy accounted for 29% (6.1 TWh/ 22 PJ) of the harvest of forest fuels. The annual harvest of small-sized trees was 2.3 TWh (8.3 PJ) in 2011, which was about 11% of forest fuel harvest (Brunberg 2012). This assortment has a large potential for increase, and Nordfjell et al. (2008) estimated that harvests of small-sized trees in Sweden could be raised to at least 5 mill. tons of dry matter (> 25 TWh/ ~100 PJ) annually. However, this biomass resource is mainly of interest for the bioenergy industry and can only be efficiently utilized if new harvest and logging techniques are developed.

Stumps have also a high potential for increasing the amount of forest fuels (Thorsén et al. 2011). Its potential was shown by the SKA-08 report, which stipulates that 17.5 mill. tons (85.6 TWh/ 311 PJ) of biomass is available without restrictions (Swedish Forest Agency 2008). FSC has recently raised concerns around stump harvests and at the moment no increase from the actual harvest level of 0.6 TWh, 3% of primary forest fuels (Brunberg 2012), can be expected.

Estimates by Nordfjell et al. (2010) show that less than 20% of the total annual forest fuel potential is currently utilized in Sweden. The annual potential of forest fuel harvest was estimated to 7.4–19.2 mill. tons (39–102 TWh/ 142–369 PJ) from final felling and 3.5–9.7 mill. tons (19–51 TWh/ 67–186 PJ) from thinning operations. It was also stated that the forest fuel potential is 2.8 to 4.4 times higher on forest land than on agricultural land.

Estonia. The potential level of utilization of forest resources in Estonia is estimated by the Forestry Development Programmes (Riigikantselei 2010b). Three scenarios of potential wood supply were presented for the period 2011–2020: 1) active wood supply – the area of strictly protected forests will not change; 2) moderate wood supply – the share of strictly protected forests will increase to 10%; and 3) shrinking supply of wood – the share of strictly protected forests will be increased to 12%. These scenarios showed that the active wood supply alternative resulted in an availability of 15.3 mill. m^3 (34 TWh/ 123 PJ), moderate supply 12.0 mill. m^3 (27 TWh/ 98 PJ) and shrinking supply 8.3 mill. m^3 (19 TWh/ 69 PJ).

In the new "Long-term Development Programme for the Estonian Energy Sector up to year 2030+" the potential volumes of forest fuels were estimated. The calculation was based on the moderate scenario of the Forestry Development Programme for the period 2011–2020 (see above). The results (Table 12) show a total

Table 11. Annual harvest potential of slash and stumps in thinning and final felling and small-sized trees in Sweden according to three restriction levels

Operation	Restriction level								
	Level 1			Level 2			Level 3		
	Mton DM	TWh	PJ	Mton DM	TWh	PJ	Mton DM	TWh	PJ
Final felling									
Slash	7.43	36.4	132	5.11	25.0	91	3.17	15.4	56
Stumps	11.74	57.5	209	6.87	33.8	122	4.24	20.8	75
Thinning									
Slash	3.93	19.2	70	2.67	13.1	48	1.73	8.4	31
Stumps	5.73	28.1	102	2.70	13.2	48	1.75	8.5	31
Small-sized trees	0.5	2.2	9	-	-	-	-	-	-
TOTAL	**29.33**	**143.4**	**522**	**17.35**	**85.1**	**309**	**10.89**	**53.1**	**194**

Estimates come from the SKA-08 report for the period 2010-2019 (Swedish Forest Agency 2008). Potentials are expressed in weight (mill. tons of dry matter) and energy (TWh/PJ). In the scenarios the potential for bio fuel harvest was estimated for three different restrictions in a reference alternative. Level 1 implied that no restrictions were used and all possible forest fuels were used. Level 2 had ecological restrictions where no forest fuels were removed within 25 m from other land use classes, from peat soils or from wet and moist areas on fine-grained soils. Level 3 had both ecological and technical/economic restrictions. The transfer from weight to energy units was done with lower constants in the SKA-08 report (1 ton DM = 4.9 MWh = 17.8 GJ) than elsewhere in this review energy potential of 6.15 mill. m^3 yr^{-1} (~13.5 TWh/ ~50 PJ) and also that fuel wood and biomass from industry residues dominate.

Latvia. Estimates in Latvia reveal that annual technologically available forest fuel is 23.9 TWh yr^{-1} (87 PJ yr^{-1}) (Gruduls et al. 2013). About 40% of this amount is firewood and around 60% small-sized trees and residues. It should be observed that 31% of the forest fuel amount is only available during winter time. More forest fuels will be available from pre-commercial thinnings in the future from about 20% of the forest stands. Lazdiņš et al. (2013) estimated total extractable aboveground biomass to 2.96 mill. tons annually (15.4 TWh of primary energy) from an area of 161,000 ha. Another potential forest fuel resource is firewood from naturally afforested lands, which have a total area of 260,000 ha and a total growing stock of around 2.8 mill. m^3 (Lazdiņš et al. 2010)

to 92% in the different countries. In addition, some forest land is not available for harvest operations due to technical difficulties. In Norway, for example, 11% of the productive forest area is classified only for cable yarding (Granhus et al. 2012). However, there are still large areas available for wood production, where harvest operations are allowed and can be carried out.

Increasing land areas may be available for afforestation and biomass production in the future. There is a general trend in Europe of reducing agriculture land (Rounsevell et al. 2005). A political goal in Denmark is to obtain 20–25% forest land, which means 250,000–470,000 ha will be afforested. The total area of fallows and uncultivated arable land was estimated to almost 280,000 ha in Finland in 2011 (Ministry of Agriculture and Forestry in Finland 2012). There are nearly 200,000 ha of coastal heathland and unused agriculture land in Norway (Granhus et al. 2012, SSB 2012), and in Sweden estimates (e.g. Larsson et al. 2009) show that 300,000–500,000 ha are available for afforestation. In Estonia almost 300,000 ha (Landresource 2007) and in Latvia about 260,000 ha are potentially available for forest fuel production (Rural Support Service of Latvia 2012). Thus, there is 1.6–2.0 mill. ha currently not in use. Some of this may be comparably unfertile land but large areas are available for wood production.

Since there is a general trend that more fertile soils are less protected than less fertile ones on forest land, a reduction of forest land area will be of less importance for available biomass than the figures suggest. A look into the availability of volumes and growth show, for example, that 97% of total tree growth is available in Finland. The total potentially available forest fuel of the region amounts to between 230 and

Table 12. Results from the "Long-term Development Programme for the Estonian Energy Sector up to year 2030+".

	Volume of biomass (1 000 m^3)										
	From fellings									From wood industry	Total
	Stemwood from fellings						Felling residues	Stumps	Non-forest land		
	Logs	Small logs	Pulp-wood	Fuel-wood	Residues	Total					
Total	2,870	1,429	2,692	2,856	2,128	11,975	1,435	150	200	3,402	
Usable for energy purposes	0	0	0	2,856	0	2,856	718	150	200	2,232	6,156
Energy potential											
(TWh)				6.28			1.58	0.33	0.44	4.91	13.5
(PJ)				23.24			5.84	1.22	1.63	18.86	50.8

Source: Arengufond (2013)

Summation and Discussion

This review for the Nordic and Baltic countries shows that forest land constitutes in average 52% of the total land area (Table 1). Both the total forest areas and the share of forest land are largest in Sweden and Finland (57 and 67%, respectively). Agricultural lands are dominating only in Denmark, where forest land constitutes 14% of the total area. The comparably small share of forest land in Norway (38%) is mainly due to large areas of mountains and plateaus. If these areas are excluded the forest land share will be almost 80%.

Some of the productive forest areas are not available for wood supply due to different kinds of legislation and protection. Overall, 85% of the forest land area is available for wood production, ranging from 75

410 TWh yr^{-1} (830–1480 PJ) depending on restriction levels (Table 13). A closer look at the national level shows that the Danish potential of forest fuel supply is 5–12 TWh (18–42 PJ) (Graudal et al. 2013). Calculations on technical potential for Finland resulted in 16 mill. m^3 (36 TWh/ 130 PJ) available annually today (Helynen et al. 2007). Prognoses by Kärkkäinen et al. (2008) of the theoretical potential indicate 22–25 mill. tons yr^{-1} (117–132 TWh yr^{-1}/ 420–480 PJ yr^{-1}) in a sustainable cutting scenario with the current climate during the forthcoming 40 years. Norwegian estimates of the current forest fuel potential include three levels, from all possible wood to technical and biological restrictions. The annual harvesting potential was found to be 3.8–5.1 mill. tons DM yr^{-1} and represents 20–27 TWh yr^{-1} (73–98 PJ yr^{-1}) for energy purposes. Swedish calculations for the period 2010–2019 showed a potential of 11–29 mill. tons DM yr^{-1}, which was calculated as roughly 55–145 TWh yr^{-1} (200–525 PJ yr^{-1}), with three levels involved (Swedish Forest Agency 2008). In Estonia 6.15 mill. m^3 yr^{-1} (c. 13.5 TWh yr^{-1}/ c. 50 PJ yr^{-1}) has been considered available according to the moderate wood supply scenario, and in Latvia the technologically available forest fuel amount has been estimated to almost 24 TWh yr^{-1} (87 PJ yr^{-1}) (Gruduls et al. 2013).

The primary supply of biomass and waste in 2010 was 28 TWh (101 PJ) in Denmark, 92 TWh (333 PJ) in Finland, 16 TWh (58 PJ) in Norway, 132 TWh (478 PJ) in Sweden, 11 TWh (40 PJ) in Estonia and 21 TWh (76 PJ) in Latvia (Table 8). Although the values are not completely comparable between scenarios and real supply, which includes waste, the figures indicate that substantially more forest fuels can be utilized than is used today. Growth promoting measures like increased fertilization, increased use of improved plant material, extended cultivation areas, change of tree species and management systems etc. have not been included but will increase the wood amounts available for energy purposes.

Table 13. Annual current harvest potential of forest fuels in the Nordic and Baltic countries

Country	Potential with lowest level of restrictions			Potential with highest level of restrictions		
	Mton DM	TWh	PJ	Mton DM	TWh	PJ
Denmark	2.3	11.5	41.5	1,0	5.1	18.3
Finland	35	186	670	22	117	420
Norway	5.11	27.1	98	3,84	20.4	74
Sweden	29.33	143.4	522	10,89	53.1	194
Estonia[1]	3.2	16.8	62.2	1.7	9.1	33.4
Latvia	4.52[2]	23.9	87	n.a.[3]	n.a.[3]	n.a.[3]
Summary	**79.5**	**409**	**1,481**	**44.0**	**229**	**827**

For details, see the sections for respective country. [1] = estimation according to scenarios of the Forestry Development Programme for the period 2011–2020. [2] = calculated backwards, [3] = the same value was used for lowest and highest restriction levels in the Summary row, n.a. = not available.

The figures above are estimates without considering a changing climate with warmer weather and more precipitation, which will most probably increase the future availability of wood in the northern latitudes of the Nordic and Baltic countries (IPCC 2014). Finnish estimates for 2050 indicate a total growth increase of 29% (Kellomäki et al. 2008). In Sweden, the effects of a changed climate and increased standing volume were estimated to increase the growth by more than 30% for the whole country until the year 2100 (Swedish Forest Agency 2008). Estimates from Estonia show that forest growth has accelerated with 15% during the period 1950–1990 (Nilson et al. 1999). This means that figures based on the current situation of availability and climate most probably will increase in the future.

As the use of renewable energy is already high in the region (e.g. Eurostat 2012), the vision of independence of fossil energy by 2050 in the Nordic countries can be approached with confidence and energy from forest fuels will most likely be of great importance in the future in all Nordic and Baltic countries.

Conclusions

Renewable energy use is large in the Nordic and Baltic countries and dominated by biomass and waste. The geographical region displays differences due to different growing conditions but also because of varying forest policies and practices. This review shows that the potential to further increase the use of forest fuels is high and is an important tool in the vision of independence of fossil energy sources. Availability of growing stock for wood supply is 89% in the region and 65% of annual increment is used today, indicating that harvest levels may increase without sacrificing the well-stocked forests and biodiversity. The current potential for forest fuel resources has been estimated to over 400 TW yr^{-1} (1,450 PJ yr^{-1}). The climate effect will most probably increase forest growth on high latitudes. In the future it is also possible to further increase productivity by fertilization, breeding, changes of tree species, intensive management systems and by afforestation of new land areas.

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References

Alam, A., Kilpeläinen, A. and Kellomäki, S. 2010. Potential energy wood production with implications to timber recovery and carbon stocks under varying thinning and climate scenarios in Finland. *BioEnergy Research* 3: 362–372.

Anonymous 2006. På väg mot ett oljefritt Sverige [Towards an oil-free Sweden]. Kommissionen mot oljeberoende, 45 pp. (In Swedish)

Arengufond 2013. ENMAK:Eesti pikaajaline energiamajanduse arengukava 2030+ [ENMAK: Estonia's long-term energy development plan 2030+]. http://www.energiatalgud.ee/index.php?title=ENMAK:Eesti_pikaajaline_energiamajanduse_arengukava_2030%2B. (In Estonian)

Artsdatabanken 2012. Exotic species in Norway including Norwegian black list. Norwegian Biodiversity information centre, 210 pp. (In Norwegian)

http://www.metla.fi/julkaisut/workingpapers/2008/mwp069.pdf.

Astrup, R., Dalsgaard, L., Eriksen, R. and Hylen, G. 2010. Utviklingsscenarioer for karbonbinding i Norges skoger [Development scenarios for carbon sequestration in the Norwegian forests]. Norwegian Forest and Landscape Institute, Oppdragsrapport 16/2010, 31 pp. (In Norwegian)

Bekeris, P. 2011. *Latvia's Forest During 20 years of Independence*. BALTI Group, Riga, 46 pp.

Bergh, J., Freeman, M., Sigurdsson, B., Kellomäki, S., Laitinen, K., Niinistö, S., Peltola, H. and Linder, S. 2003. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries, *Forest Ecology and Management* 183: 327–340.

Bergh, J., Nilsson, U., Kjartansson, B. and Karlsson, M. 2010. Impact pf climate change on the productivity of silver birch, Norway spruce and Scots pine stands in Sweden with economic implications for timber production. *Ecological Bulletins* 53(15): 185–195.

Brunberg, T. 2012. Forest fuel: methods, products and costs 2011. Skogforsk, Resultat no 10, Uppsala, 2 pp. (In Swedish with English Summary)

Carter, T.R., Jylhä, K., Perrels, A., Fronzek, S. and Kankaanpää, S. 2005. FINADAPT scenarios for the 21st century: alternative futures for considering adaptation to climate change in Finland. FINADAPT Working Paper 2, *Finnish Environment Institute Mimeographs* 332. Helsinki, 42 pp.

Chauret, G. and Zhang, T. 2002. Wood characteristics and end-use potential of two fast-growing exotic larch species (*Larix gmelinii* and *Larix siberica*) grown in Ontario. Forintek Canada Corp., Project No. 3563, Report. Sainte-Foy, QC, 37 pp.

Danmarks Statistik 2012. *Statistisk Årbog 2012 [Statistical Yearbook 2012]*. Danmarks Statistik, Copenhagen, 523 pp. (In Danish)

Eckersten, H., Karlsson, S. and Torssell, B. 2008. *Climate change and agricultural land use in Sweden. A literature review*. Swedish University of Agricultural Sciences, Report from the Department of Crop Production Ecology No. 7, Uppsala, 135 pp.

Egnell, G. and Björheden, R. 2013. Options for increasing biomass output from long-rotation forestry. *Wiley Interdisciplinary Reviews: Energy and Environment* 2: 465–472.

Elbersen, B., Beaufoy, G., Jones, G., Noij, G.-J., Doorn, A., Breman, B. and Hazeu, G. 2014. Aspects of data on diverse relationships between agriculture and the environment. Report for DG-Environment. Contract no. 07-0307/2012/633993/ETU/B1. Alterra. Wageningen, April 2014, 224pp.

Elferts, D. 2008. Influence of climatic factors on the radial growths of Scots pine *Pinus sylvestris* L. in western Latvia on dry Soils. Doctoral Thesis, University of Latvia, Riga.

Elfving, B. 1986. Odlingsvärdet av björk, asp och al på nedlagd jordbruksmark i Sydsverige [The value of growing birch, aspen and alder on abandoned fields in southern Sweden]. *Sveriges Skogsvårdsförbunds Tidskrift* 5/86: 31–41. (In Swedish with English Summary)

Estonian Environmental Information Centre 2012. *Yearbook Forest 2010*. Keskkonnateabe Keskus, Tartu, 226 pp. (In Estonian with English translations)

European Commission 2009. Directive 2009/28/EC if the European Parliament and of the Council of 23 April 2009. *Official Journal of the European Union* 52 (L140): 16–62.

European Commission 2012. The Common Agricultural Policy – A story to be continued. European Union, Luxembourg, 20 pp.

Eurostat 2012. The contribution of renewable energy up to 12.4% of energy comsumption in the EU27 in 2010. Eurostat Newsrelease 94/2012, 2 pp.

Finnish Forest Research Institute 2012. *Finnish Statistical Yearbook of Forestry*. Finnish Forest Research Institute, Vanda, 452 pp.

Forest Europe 2011. *State of Europe's Forests 2011 – status and trends in Sustainable Forest Management in Europe*. Forest Europe Liaison Unit, Oslo, Norway, 337 pp.

FSC 2010. Svensk skogsbruksstandard enligt FSC med SLIMF-indikatorer [Swedish forestry standards under FSC with SLIMF indicators]. Svenska FSC, v-2-1 050510, Uppsala, 81 pp. (In Swedish]

Gjølsjø, S. and Hobbelstad, K. 2009. Energy potential in Norwegian forest. Norwegian Forest and Landscape Institute, Report 09/2009, 11 pp. (In Norwegian)

Granhus, A., Hylen, G. and Nilsen, J.-E. Ø. 2012. Skogen i Norge. Statistikk over skogforhold og skogressurser i Norge registrert i perioden 2005–2009 [Statistics of Forest Conditions and Resources in Norway]. Ressursoversikt fra Skog og landskap 03/12, 85 pp. (In Norwegian with English Introduction)

Graudal, L., Nielsen, U. B., Schou, E., Thorsen, B. J., Hansen, J. K., Bentzen, N. S. and Johannsen, V. K. 2013. Muligheder for bæredygtig udvidelse af dansk produceret vedmasse 2010–2100 [Options for sustainable expansion of Danish-produced wood biomass 2010-2100]. University of Copenhagen, Skov og Landskab, 87 pp. (In Danish)

Gruduls, K., Bārdulis, A., Lazdiņš, A. and Makovskis, K. 2013. *Forest biomass resource assessment on the base of National Forest Inventory in Latvia*. Central Baltic Interreg IV A Programme 2007-2013, The Development of the Bioenergy and Industrial Charcoal (Biocoal) Production, Report of BalBiC – project cb46, 63 pp.

Hakkila, P. 1971. Basic density, bark percentage and dry matter content of grey alder (*Alnus incana*). *Communicationes Instituti Forestalis Fenniae* 71.5, 32 pp.

Hakkila, P. 1979. Wood density survey and dry weight tables for pine. spruce and birch stems in Finland. *Communicationes Instituti Forestalis Fenniae* 96.3, 59 pp.

Heide, O.M. 1993. Daylength and thermal time responses of budburst during dormancy release in some northern deciduous trees. *Physiologia Plantarum* 88: 531–540.

Helynen, S., Flyktman, M., Asikainen, A. and Laitila, J. 2007. Metsätalouteen ja metsäteollisuuteen perustuvan energialiiketoiminnan mahdollisuudet [Forestry and forest industries based on energy business opportunities]. *VTT Tiedotteita – Research Notes* 2397, 66 pp. (In Finnish)

IEA 2013. *Nordic Energy Technology Perspectives*. OECD/IEA and Nordic Energy Research, IEA Publications, Paris, 211 pp.

IPCC 2014. *Climate Change 2014 – Synthesis Report.* IPCC, Geneva, Switzerland, 151 p.

Jansons, Ā., Matisons, R., Zadiņa, M., Sisenis, L. and Jansons, J. 2015. The effect of climatic factors on height increment of Scots pine in sites differing by continentality in Latvia. *Silva Fennica* 49(3) article id 1262, 14 pp.

Johannsen, V. K., Nord-Larsen, T., Riis-Nielsen, T., Suadicani, K. and Jørgensen, B. B. 2013. *Skove og plantager 2012 [Forests and forest plantations in 2012].* University of Copenhagen, Skov og Landskab, Frederiksberg, 189 pp. (In Danish)

Johansson, T. 2005. Stem volume equations and basic density for grey alder and common alder in Sweden. *Forestry* 78: 249–262.

Jylhä, K., Tuomenvirta, H. and Ruosteenoja, K. 2004. Climate change projections for Finland during the 21st century. *Boreal Environmental Research* 9: 127–152.

Kärkkäinen, L., Matala, J., Harkonen, K., Kellomäki, S. and Nuutinen, T. 2008. Potential recovery of industrial wood and energy wood raw material in different cutting and climate scenarios for Finland. *Biomass and Bioenergy* 32: 934–943.

Kellomäki, S., Peltola, H., Nuutinen, T., Korhonen, K. T. and Strandman, H. 2008. Sensitivity of managed boreal forests in Finland to climate change, with implications for adaptive management. *Philosophical Transactions of the Royal Society* 363: 2341–2351.

Kellomäki, S., Alam, A. and Kilpeläinen, A. 2010. Forest biomass for fuel production – potentials, management and risks under warmer climate In: Thorsteinsson, T. and Björnsson, H. (eds.) *Climate Change and EnergySystems: Impacts, Risks and Adaptation in the Nordic and Baltic Countries.* Nordic Council of Ministers 2011, p. 161–178.

Kiviste, A. 1998. Estimation of Estonian forest growth change in 1951–1994 on the basis of forest inventory data. Climate change studies in Estonia, Stockholm Environment Institute Tallinn Centre, Tallinn, p. 191–196.

Kjellström, E., Räisänen, J., Engen–Skaugen, T., Rögnvaldsson, Ó., Įgśstsson, H., Ólafsson, H., Nawri, N., Björnsson, H., Ylhäisi, J., Tietäväinen, H., Gregow, H., Jylhä, K., Ruosteenoja, K., Shkolnik, I., Efimov, S., Jokinen, P. and Benestad, R. 2011. Climate Scenarios. In: Thorsteinsson, T. and Björnsson, H. (eds.) *Climate Change and EnergySystems: Impacts, Risks and Adaptation in the Nordic and Baltic Countries.* Nordic Council of Ministers 2011, p. 35–64.

Koca, D., Smith, B. and Sykes, M.T. 2006. Modelling regional climate change effects on potential natural ecosystems in Sweden. *Climate Change* 78: 381–406.

Landresource 2007. Final report of the study financed by the Estonian Rural Development Foundation. 88 pp. (In Estonian with English Summary) (http://www.bioenergybaltic.ee/bw_client_files/bioenergybaltic/public/img/File/MRlopparuanne2007.pdf)

Larsson, S., Lundmark, T. and Ståhl, G. 2009. Möjligheter till intensivodling av skog [Opportunities for intensive cultivation of forests]. Slutrapport från regeringsuppdrag Jo 2008/1885, SLU, 136 pp. (In Swedish)

Latvian State Forest Service 2012. State Register of Forests (SRF) Latvia, CD Forest Statistics, www.vmd.gov.lv.

Latvian State Land Service 2012. *Land Report of the Republic of Latvia*. The State Land Service, Riga, 20 pp.

Lazdiņš, A., Lazdiņa, D. and Liepa, I. 2010. Characterization on naturally afforested farmlands in Latvia. *Research for Rural development* 2010: 176–181.

Lazdiņš, A., Kalēja, S., Gruduls, K. and Bārdulis, A. 2013. Theoritical evaluation of wood for bioenergy resources in pre-commercial thinning in Latvia. *Research for Rural development* 2013: 42–48.

Levende Skog 2009. Standards for a sustainable Norwegian forestry, 27 pp. (In Norwegian)

Lileng, J. 2012. Subsidies of chips for bioenergy is popular. Norwegian Agricultural Authority, 2 pp. (In Norwegian)

Løken, Ø., Eriksen, R., Astrup, R. and Eid, T. 2012. The total biomass of trees in Norway. Table collection, Norwegian Forest and Landscape Institute, Resource survey 01/2012, 37 pp.

Lundgren, C. and Persson, B. 2002. Provenance variation in stem wood basic density and dry matter for *Picea abies* grown on farmland in southern Sweden. *Forest Genetics* 9: 103–110.

Melillo, J. M., McGuire, A. D., Kicklighter, D. W., Moore, B. III, Vorosmarty, C. J. and Schloss, A. L. 1993. Global climate change and terrestrial net primary production. *Nature* 363: 234–239.

Marklund, L. G. 1988. Biomass functions for pine, spruce and birch. Swedish University of Agricultural Sciences, Dept. Forest Survey, Report 45, Umeå, 73 pp. (In Swedish with English Summary)

Ministry of Agriculture and Forestry in Finland 2012. *Yearbook of Farm Statistics.* Information Centre of the Ministry of Agriculture and Forestry, 269 pp.

Ministry of Environment 1994. *Strategi for bæredygtig skovdrift [Strategy for sustainable forest management].* Betænkning nr. 1267, Miljøministeriet, Skov- og Naturstyrelsen, 217 pp. (In Danish)

Ministry of Environment. 2005. *Handlingsplan for naturnær skovdrift i statsskovene [Action plan for natural forest management in state forests]*. Miljøministeriet, Skov- og Naturstyrelsen, 61 pp. (In Danish)

Ministry of Environment 2012a. Legislations for planting non-native tree species for forestry use, Ministry of environment, Oslo, 12 pp. (In Norwegian)

Ministry of Environment 2012b. *Norwegian climate politics.* Ministry of environment, Oslo, Communications to the Parliament No. 21, 200 pp. (In Norwegian)

Moltesen, P. 1988. *Skovtræernes ved og anvendelse [Wood of forest trees and its use]*. Skovteknisk Institut, Frederiksberg, 132 pp. (In Danish)

Nagoda, L. 1968. Volumvekt og vanninnhold hos gråor (*Alnus incana*) [Density and water content of grey alder (*Alnus incana*)]. *Meldinger fra Norges Landbrukshøgskole* 47.13: 1–9. (In Norwegian with English Summary)

Nagoda, L. 1981. Fysiske egenskaper hos osp (*Populus tremula* L.) [Physical properties of aspen (*Populus tremula*)]. *Meldinger fra Norges Landbrukshögskole* 60(7), Ås, 192 p. (In Norwegian with English Summary).

Naturstyrelsen 2015. Skovbrug [Forestry]. Miljøministeriet, Naturstyrelsen, København. http://naturstyrelsen.dk/naturbeskyttelse/skovbrug/

Nilson, A., Kiviste, A., Korjus, H., Mihkelson, S., Etverk, I. and Oja, T. 1999. Impact of recent and future climate change on Estonian forestry and adaptation tools. *Climate Research* 12(2–3): 205–214.

Norby, R.J., DeLucia, E.H., Gielen, B., Calfapietra, C., Giardina, C.P., King, J.S., Ledford, J., McCarthy, H.R., Moore, D.J.P., Ceulemans, R., De Angelis, P., Finzi, A.C., Karnosky, D.F.., Kubiske, M.E., Lukac,

M., Pregitzer, K.S., Scarascia-Mugnozza, G.E., Schlesinger, W.H. and Oren, R. 2005. Forest response to elevated CO2 is conserved across a broad range of productivity. *Proceedings of the National Academy of Sciences of the United States of America* 102: 18052–18056.

Nordfjell, T., Nilsson, P., Henningsson, M., Wästerlund, I. and Vinterbäck, J. 2008. Unutilized biomass resources in Swedish young dense forests. In *Proceedings of the World Bioenergy Conference and Exhibition on Biomass for Energy*: 323–325. Jönköping, Sweden, 27-29 May 2008. Swedish Bioenergy Association, Stockholm.

Nordfjell, T., Athanassiadis, D. and Lundström, A. 2010. Harvesting potential of forest fuels in Sweden. In *OSCAR Proceedings from the 2010 Nordic-Baltic conference on forest operations*, Honne, Norway, October 20–22, 2010. Report from Norwegian Forest and Landscape Institute 12/2010, Ås, pp. 19–20.

Nordic Family Forestry 2014. The Nordic Forest Owner's Associations. www.nordicforestry.org/facts/Norway.asp

Nurmi, J. 1991. Heating values of whole-tree components. Danish Forest and Landscape Res. Inst., Research Report No. 10, p. 78–92.

Pācques, L. E. 2004. Roles of European and Japanese larch in the genetic control of growth. architecture and wood quality traits in interspecific hybrids (*Larix × eurolepis* Henry). *Annals of Forest Science* 61: 25–33.

Poudel, B. C., Sathre, R., Gustavsson, L., Bergh, J., Lundström, A. and Hyvönen, R. 2011. Effects of climate change on biomass production and substitution in north-central Sweden. *Biomass and Bioenergy* 35: 4340–4355.

Räisänen, T. and Nurmi, J. 2011. Impacts of changing the minimum diameter of roundwood on the accumulation of logging residue in first thinnings of Scots pine and Norway spruce. *Biomass and Bioenergy* 35: 2674–2682.

Repola, J. 2008. Biomass equations for birch in Finland. *Silva Fennica* 42: 605–624.

Repola, J. 2009. Biomass equations for Scots pine and Norway spruce in Finland. *Silva Fennica* 43: 625–647.

Riigikantselei 2010a. Riigi Teataja. https://www.riigiteataja.ee/akt/12759372.

Riigikantselei 2010b. *Eesti Metsanduse Arengukava Aastani 2020 [Estonian Forestry Development Plan 2020]*. Riigi Teataja, 39 pp. (In Estonian) https://www.riigiteataja.ee/aktilisa/3180/2201/1003/Eesti_%20metsanduse_arengukava.pdf.

Rounsevell, M. D. A., Ewert, F., Reginster, I., Leemans, R. and Carter, T. R. 2005. Future scenarios of European agricultural land use. II. Projecting changes in cropland and grassland. *Agriculture, Ecosystems and Environment* 107: 117–135.

Ruosteenoja, K., Jylhä, K. and Tuomenvirta, H. 2005. Climate scenarios for FINADAPT studies of climate change adaptation. FINADAPT Working Paper 15, *Finnish Environment Institute Mimeographs* 345, Helsinki, 32 pp.

Rural Support Service of Latvia 2012. http://www.lad.gov.lv.

Skogsstyrelsen 2009. *Regler om användning av främmande trädslag [Rules on the use of exotic tree species]*. Skogsstyrelsen, Meddelande 7, Jönköping, 138 pp. (In Swedish)

Slaney, M., Wallin, G., Medhurst, J. and Linder, S. 2007. Impact of elevated carbon dioxide concentration and temperature on bud burst and shoot growth of boreal Norway spruce. *Tree Physiology* 27: 301–312.

SLU 2013. *Forest statistics 2013 – Official Statistics of Sweden*. Swedish University of Agricultural Sciences, Umeå, 155 pp. (In Swedish with English Summary)

SLU 2014. *Forest statistics 2014 – Official Statistics of Sweden*. Swedish University of Agricultural Sciences, Umeå, 163 pp. (In Swedish with English Summary)

Södra 2009. *Lövskogsskötsel [Management of hardwood forests]*. Södra, Skogsavdelningen, Växjö, 20 pp. (In Swedish)

Södra 2011. *Certifierad skog enligt FSC och PEFC [Certified forests under FSC and PEFC]*. Södra, Växjö, 28 pp. (In Swedish)

SSB 2012. *Statistical yearbook*. 400 p. ISBN 978-82-537-8456-4. ISSN 0377-8908. In Norwegian.

Statistics Denmark 2013. http://www.statbank.dk/SKOV6.

Statistics Norway 2011. *The National Forest Inventory*. Statistics Norway, Oslo.

Sveriges Skogsvårdsförbund 1994. *Praktisk Skogshandbok [Practical Forestry Manual]*. 14:e uppl., Sveriges Skogsvårdsförbund, Djursholm, 510 pp. (In Swedish)

Swedish Forest Agency 2008. Skogliga konsekvensanalyser – SKA-VB 08 [Consequence analyses for forests – SKA-VB 08]. Skogsstyrelsen, Rapport 25, Jönköping, 146 pp. (In Swedish)

Swedish Forest Agency 2013. *Swedish Statistical Yearbook of Forestry*. Swedish Forest Agency, Jönköping, 373 pp.

Thorsén, Å., Björheden, R. and Eliasson, L. 2011. Efficient forest fuel supply systems – composite report from a four year R&D programme 2007–2010. Skogforsk, Uppsala, 116 pp.

Tilli, T. and Toivanen, R. 2000. Scenarios of the development of afforestation of arable land in Finland and the related CO_2 sinks during 2000 to 2012. *Pellervo Economic Recearch Institute Reports* no 170, 66 pp. (In Finnish with English Summary)