Research report no D 2.1.1
Helsinki 2014

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Synthesis report on bio-based raw material potential and availability

Sustainable Bioenergy
Solutions for Tomorrow

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ISBN 978-952-5947-62-5

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Preface

This report is a part of the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program, which is joint research program by FIBIC Ltd, and CLEEN Ltd. BEST program is funded by the Finnish Funding Agency for Technology and Innovation, Tekes.

The report belongs to BEST research program's Working Package 2 (WP2) "Radical improvement of bioenergy supply chains", and it's Task 2.1 "Raw materials" and Subtask 2.1.1 "Biomass resources – potential and availability". The aim of this report is to make synthesis review (state of art) of existing agri- and forest biomass resources and their availability. The outcomes and observations of this report can be utilised in biomass terminal concept modeling and planning.

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Jokioinen and Vantaa, May 2014

Name of the report: Synthesis report on bio-based raw material potential and availability

Key words: bioenergy, biomass, field, forest, Europe, India, China

Summary

This report summarizes the results of earlier reports on bioenergy potential for agri- and forest biomasses. Huge energy values are bound in different biomasses both in fields and forests. Usage of field biomasses is often criticized for creating competition with food products. However, crop residues and overproduction of grasslands that are available after taking care of their competitive usages and securing soil quality could provide 564 TWh of energy (energy content on the field) in Northern and Western Europe, and 1375 TWh in Eastern Europe. In China the crop residue potential could be 748 TWh and in India 578 TWh. If crop production would be efficient and all available land area after securing food availability would be taken into use to grow biomasses for bioenergy, the field bioenergy potential would be considerably higher than the residue potential in some countries. However, some countries like China and India have no available field area for bioenergy production per se, if they aim at self-sufficiency of food for the growing population. Eastern-European countries, and the former Soviet Union countries have large field bioenergy potential now and this potential could become much higher in the future, as in most of these countries population growth is low and yield gap compared to similar areas in Western Europe huge.

In Finland the consumption of wood fuels has increased rapidly since 1990s and is nowadays 24% of total energy consumption. The estimates of technical potential of forest bioenergy in the future vary from 24 to 118 TWh in Finland. The forest chips and especially the small-sized trees will be the most prominent components of the increase. The regional availability of forest bioenergy varies, because in some regions energy wood resources are already now fully utilized. For example, crown mass is well utilized in Western coastal area of Finland likewise stumps in some areas of Northern Finland. In Europe the forest resources have increased during the last 50 years. The increase in growing stock and positive annual net increment represents a potentially valuable source of forest bioenergy. In Europe the available forest fuels potential is approximately 187 million m^3 referring 411 TWh. The potential is especially high in Central and Northern Europe. For China the potential ranges from 140 to 200 TWh. Even though the agribiomasses show great potential in India, the potential of forest fuels is negligible.

Contents

1 Introduction

Bio-based raw materials for bioenergy can be collected from field and forest. Waste materials and side streams from different fields of industry, forestry and agriculture could and are used for bioenergy as well. E.g. black liquor is used for energy in pulp factories, sludge from animal husbandry is fermented to biogas, which is used for energy either at farm level or regionally, and different wastes of forestry are used in local or regional combined heat and power (CHP) plants either as wood chips or pellets. European Union (EU) is promoting cascading of all biomasses according to their value, and usage of biomasses for energy should according to EU be the last step in their use. Even wastes should rather be used for more valuable products, whenever possible and for energy only if no other usage is found.

Finland is committed as a part of EU climate policy to increase the proportion of renewable energy sources from current level of 28.5% (Pitkän aikavälin ilmasto- ja energiastrategia 2008). The EU set obligation to raise the share of renewable energy sources in energy consumption to 38% by year 2020. Therefore in the National Energy and Climate Strategy (2013) was stated that the use of forest chips should increase into level of 25 TWh, corresponding ca. 13 million m^3 of wood material by 2020. Thus the use of forest chips is encouraged through various government support measures. In the Finland's national forest programme 2015 was stated that the use of forest chips should increase into level of 10-12 million m^3 per year.

The availability and consumption of solid wood fuels are based on three main factors and their relations: 1) roundwood supply and demand, 2) production of forest industry and 3) structure of energy production (Kärhä et al. 2010). The roundwood supply and demand affect positively the amount of available felling residues in the forests, as well as by- and waste products of forest industry, all of which could be used for energy. The forest industry is in significant role in providing wood based fuels, and thus the roundwood consumption, wood trade market, and further, the vital forest industry should also be highlighted in the discussion of wood based energy sources. In the structure of energy production forest chips are in important role in achieving the desired level of renewable energy sources. The use of forest chips could be increased but already now the residues from the forest industry are fully utilized (Anttila et al. 2013). At the same time the importance of forest chips will further increase because the availability of by-products of forest industry have decreased during the last years due to the closures of pulp and paper mills and decreased production of saw and plywood mills (Ylitalo 2010, Kallio et al. 2011). Decreasing production of pulp mills results in decreasing consumption of black liquor and decreasing renewable energy sources. On the other hand decreasing saw mill production leads to lower level of final felling areas and thus lower level of stumps and logging residues, and further lower level of consumption of bark and sawdust.

Here we report three possible ways to collect bio-based materials for bioenergy: 1) collection of field plant residues and side streams of agricultural production 2) growing energy crops or woody biomasses for energy on surplus fields, marginal lands or on fields in vulnerable areas, where production of annual crops is not profitable, or should be avoided because of various environmental reasons and 3) collection of forest residues and side streams of wood based industry.

Both field and forest residues, as well as side streams from agriculture and wood industry could meet the EU biomass cascading principle and be used for bioenergy. However, there are some restrictions in their use, as described below.

2 Field biomasses for bioenergy

2.1 Crop residue and grassland surplus production potential

Food is produced in every country in the world, whether a country is self sufficient in food production or not. Every time food is produced, whether it is fruit, oil plants, or cereals, some residue is left over after the edible part is separated from the carrying biomass. The most obvious residue is straw of cereals. Usually only about 40-50% of total biomass of a cereal is collected from the field as seed yield (Hakala et al. 2009). This means that for a crop that produces 5000 kg of grain, another 5000 kg of straw is left on the field as crop residue (theoretical residue potential). From this biomass, about 30% stays on the field as stubble, but the rest (3500 kg/ha/year) could be collected for bioenergy (technical residue potential). When calculated like this, e.g. in Finland cereals alone produce 2.1 million tons of harvestable residue every year, which would contain 10.6 TWh energy (Pahkala and Lötjönen 2012). It is evaluated, however, that collection of cereal straw for energy would be possible in Finland only every second year, as some straw has to be cultivated into the soil to maintain soil organic matter. This would reduce the above figure to 1750 kg/ha/year. In addition, some straw is used every year for other purposes, and according to Pahkala and Lötjönen (2012), this usage could be 10-20% of the straw yield. The use of straw varies in different countries. In Denmark even 35% of the available straw residue is used for animal husbandry (Danish Technological Institute 2007).

In some countries, such as Finland, unsuitable weather conditions may prevent harvesting of straw in the autumn, and thus every second year 10% of straw yield has to be counted off the potential straw yield. In some countries, the weather factor is not as important, and there is no need to take autumn weather into account when calculating straw biomass potential. In some other countries, again, like India, where the temperatures favor microbial activity of soil throughout the year, maintaining soil organic matter may require cultivation of straw in the soil more often than just once in two years. The overall result for most European countries is that about 25% of the physiological residue potential of cereals could be used for bioenergy. How much could be safely and sustainably used in India remains to be studied. Estimates of technical residue potential for different Northern European countries, China and India are presented in Table 1. The estimate of the final residue potential that could be sustainably used for bioenergy, the above restrictions taken into account, could be 36% of the technical potential in the Nordic countries and 40% of the technical potential in the other European countries (Table 1).

Grasslands could be used more efficiently, if the collection of grass was economically feasible. At present in Finland grass is harvested for silage two times a year, and a third harvest is not favored, even when it would be possible. If grassland production is calculated according to a realistic yield estimate and usage by the head number of cattle, almost every country in Europe could produce some grass for bioenergy (Table 1) (Koljonen et al. 2012).

Estimates of realistic field residue and grassland surplus potential for energy from present-day fields are presented in Table 1. The last column in Table 1 gives an estimate of bioenergy that would be possible to produce sustainably from all residue and surplus biomasses. In the case of India and China the frequency with which crop residues can be collected without endangering the soil quality has to be specified. Here China and India have been treated as European countries (technical residue potential multiplied by 0.4).

At present the utilization of field biomass residues for bioenergy varies widely in different countries. In Finland, there are some farm scale boilers (scale <1 MWh), which produce heat by straw combustion, but there is nearly no commercial energy production based on straw. Surplus grass biomasses could be a potential source for biogas for energy, but they are not yet used in any mentionable degree. Denmark is probably the most efficient straw utilizer in Europe, with about 24 % of available straw resources used for energy production (Danish Technological Institute 2007). Share of 24 % corresponds with about 5.9 TWh.

Table 1. *Field crops residue potential and potential of surplus grassland harvests for bioenergy in some European countries, India and China. Average production values for 1998-2007 (Europe) and 1997-2006 (China and India). Cereals are the main field crops producing residue (straw), but in the presented figures also oil crops, potato, pulses and sugar beet are taken into account in Europe, and additionally sugar cane and other crops typical for India and China. Technical residue production = crop residue possible to harvest from the field. Technical residue gross energy = energy potential in the harvestable residue. Final residue potential = estimated usable bioenergy potential contained in the residue after reductions due to other usages and maintenance of soil quality. Grass potential = harvestable grassland overproduction for bioenergy. Data for European countries: Koljonen et al. 2012 (corrected values). Data for China and India: Hakala et al. 2009. DM=Dry matter.*

Country	Technical residue production, 1000 ton DM/year	Technical residue gross energy, TWh	Final residue potential, TWh	Grass potential TWh	Residue and grass bioenergy potential TWh
Nordic countries					**Sum: 39 TWh**
Finland	2 378	11.9	4.3	3.4	7.7
Denmark	6 588	32.9	11.8	0.0	11.8
Norway	806	4.0	1.4	1.7	3.1
Sweden	3 818	19.1	6.9	9.5	16.4
Baltic countries					**Sum: 23 TWh**
Estonia	486	2.4	1.0	3.8	4.8
Latvia	912	4.6	1.8	6.5	8.3
Lithuania	2 097	10.5	4.2	5.8	10.0
Western European countries					**Sum: 502 TWh**
The Netherlands	2 299	11.5	4.6	0.0	4.6
Belgium	2 435	12.2	4.9	0.0	4.9
Spain	13 354	66.8	26.7	55.3	82.0
Italy	14 518	72.6	29.0	21.8	50.8
Austria	3 437	17.2	6.9	5.8	12.7
Ireland	1 378	6.9	2.8	5.6	8.4
United Kingdom	17 982	89.9	36.0	41.1	77.1
Greece	3 162	15.8	6.3	0.0	6.3
Luxemburg	89	0.4	0.2	0.1	0.3
Portugal	857	4.3	1.7	16.2	17.9
France	50 305	251.5	100	42.0	142
Germany	38 079	190.4	76.2	12.2	88.4
Switzerland	865	4.3	1.7	4.7	6.4
Eastern European countries					**Sum:1375 TWh**
Albania	373	1.9	0.8	0.0	0.8
Bosnia-Herzegovina	761	3.8	1.5	8.7	10.2

Bulgaria	4 268	21.3	8.5	0.0	8.5
Croatia	2 089	10.4	4.2	0.3	4.5
Moldova	1 757	8.8	3.5	?	3.5?
Poland	22 443	112.2	44.9	9.1	54.0
Romania	11 321	56.6	22.6	23.7	46.3
Slovakia	2 478	12.4	5.0	6.4	11.4
Slovenia	347	1.7	0.7	1.2	1.9
Czech Republic	5 878	29.4	11.8	7.9	19.7
Ukraine	27 401	137.0	54.8	55.3	110.1
Hungary	8 992	45.0	18.0	4.2	22.2
Belarus	4 761	23.8	9.5	15.3	24.8
European Russia	48 981	244.9	98.0	959	1057
China	481 300	1869	748	?	**748**
India	351 100	1444	578	?	**578**

2.2 Growing energy crops or woody biomasses on surplus fields, marginal lands or on fields in vulnerable areas

Some countries, like Finland, are self-sufficient in food production when calculated only on energy basis, but depend on other countries for special products that are not possible to cultivate in a large scale. In Finland such products are e.g. grapes for wine, many fruits, and protein-rich feed for cattle. Some countries are not self-sufficient even in food energy production. Such countries may be solvent enough to buy food (e.g. South Korea, Japan, Luxemburg), while others have a problem to feed the population with a nutritious enough diet (many African countries). Some developing countries like India could provide a vegetarian diet for the whole population, but storage problems and uneven division of goods complicate the situation (Hakala et al. 2009). An example of another type of a developing country is China, who is more than self-sufficient in food production, and even able to export food.

In conditions where a country wants to avoid surplus production of agricultural products, or prefers to purchase food from other countries, some field may be set aside and could be used for cultivation of biomasses for bioenergy. Here, the cultivation methods and products should be carefully studied in order to avoid a situation, where energy balances of the products and greenhouse gas emissions of cultivation make biomass production for bioenergy a source rather than sink of greenhouse gases.

When calculating surplus area for bioenergy production, different scenarios could be taken into account. If no food was wasted in the path from production in the field to the end user, surplus areas for bioenergy could be found in most European countries even when using a moderate amount of meat in a diet (mixed diet). If vegetarian diet would be used, much less area would be needed for crops, and even more countries could set aside fields for bioenergy. Mitigation of climate change would also be possible by employing organic farming in larger areas (Hakala et al. 2012) or by practicing more extensive agriculture with lower yields but also lower inputs and greenhouse gas emissions. Organic farming and extensive agriculture could, however, lead to higher food prices, which might not be acceptable by the large public. Production of bioenergy in the fields would not be profitable for a farmer, but would require subsidies from the state to become a serious option. In Table 2 potential energy yields of fields dedicated for bioenergy are reported in a scenario, where meat is consumed moderately (a mixed diet, see Hakala et al. 2009), and food is not wasted in the path from field to end user. The possible changes in the available field area and their bioenergy production potential are estimated also for the near future with climate change (Koljonen et al. 2012). The future values are based on estimates of Paillard et al. (2011) for the technological development and estimates of Parry et al. (2004) for the climate change effects (under the scenario B1, where GHG emissions are gradually reduced, Nakicenovic et al. 2000). FAO database (www.fao.org) was used for estimations of population growth in different countries.

Table 2. *Potential surplus field area (share of present field area) and potential bioenergy production on this area at present in case of a mixed diet and efficient path of field products from field to end user, and estimation of the future potential in 2030, when development has been good (0.81% increase in yields per year in OECD countries and 2.22% increase in yields in former Soviet Union countries, including the Baltic countries). The data are based on Koljonen et al. 2012 and Hakala et al. 2009.*

Country	Field area (share of total field area) at present	Bioenergy potential at present (TWh)	Field area (share of total field area) in 2030	Bioenergy potential in 2030 (TWh)
Nordic countries				
Finland	0.4	33.4	0.5	50.4

Denmark	0.7	60.0	0.7	81.6
Norway	0.0	0.0	0.0	0.0
Sweden	0.4	43.7	0.4	54.4
Baltic countries				
Estonia	0.4	4.3	0.6	10.4
Latvia	0.6	13.1	0.8	27.0
Lithuania	0.6	19.9	0.8	41.5
Western European countries				
The Netherlands	0.0	0.0	0.0	0.0
Belgium	0.0	0.0	0.0	0.1
Spain	0.5	538.9	0.6	734.2
Italy	0.0	0.0	0.1	72.0
Austria	0.4	43.9	0.5	70.8
Ireland	0.7	109.2	0.7	134.9
United Kingdom	0.1	51.4	0.2	140.0
Portugal	0.0	0.0	0.1	9.4
France	0.6	618.2	0.6	849.2
Germany	0.2	94.3	0.4	266.4
Eastern European countries				
Moldova	0.3	9.5	0.6	32.3
Poland	0.4	172.7	0.5	258.6
Romania	0.5	201.7	0.6	282.5
Slovakia	0.2	11.4	0.3	20.9
Czech Republic	0.2	30.2	0.3	45.8
Ukraine	0.4	208.7	0.7	576.9
Hungary	0.5	94.1	0.6	122.9
Belarus	0.5	59.3	0.7	137.0
European Russia	0.5	747.1	0.7	1625.6
China	0.0	0.0	0.0	0.0
India	0.0	0.0	0.0	0.0

There have been a few large scale experiments to produce dedicated energy crops around Europe. The most successful has probably been biogas from maize silage in Germany and Austria. In 2008 Germany produced worth 28 TWh of biogas from maize and other crops, due to the favorable economical environment (Rechberger & Lötjönen 2009). This corresponds with 0.5 million ha of maize fields, and the area is growing.

In Sweden there is about 13 500 ha of willows growing on fields for bioenergy. This corresponds with about 0.6 TWh (Xiong & Finell 2009). The biggest experiment in Finland has been reed canary grass, which was cultivated nearly on 20 000 ha in 2008 (corresponding with 0.45 TWh) (Lötjönen et. al 2009). Thereafter, the economical environment has not been favorable for reed canary grass, and the cultivation area has decreased to 6 600 ha in 2013 (http://www.maataloustilastot.fi/kaytossa-oleva-maatalousmaa).

The biomass potential for bioenergy has been estimated by many researchers. In a recent research project Sahyog, funded by the EU and the Indian Ministry of Science and Technology, a database was formed, where estimates of residue and bioenergy potential of specific energy plantations (both forest, field and waste) in many European countries and India were collected. In Table 3 Finnish research results are compared with these estimates.

At present bioenergy is still not very largely used, with bioenergy forming about 13% of the global energy usage (REN21 2008). It has been more interesting to make estimates for a better future world with more bioenergy in use. Several estimates focus on year 2050, and depend on climate change assumptions and on assumptions on technology development by that year. Depending on the scenario, in 2050 the world could produce from 215 to 1272 EJ (60-353 PWh) energy on surplus fields only ($EJ=10^{18}$, $P=10^{15}$) (Hoogwijk et al. 2005, Smeets et al. 2007). Here even sub-Saharan Africa has been assigned bioenergy production numbers of 49-347 EJ (14-96 PWh). Western Europe could, according to Smeets et al. (2007), produce 13-30 EJ (3600-8000 TWh). Agricultural production can be intensive or extensive, and with intensification more biomass can be produced, as has been shown by the green revolution during the past 60 years. However, irrigation of abandoned fields and fertilization with N, P and K fertilizers are required for reaching good productivity. Already now the resources of P are decreasing, and world ecology has been disturbed by several irrigation programs. Therefore it looks unlikely that efficient bioenergy production could take place in a scale described by the Dutch researchers.

Table 3.*Total biomass potential from agriculture in Europe and India. The results are compared with a recent (December 2013) data base of the project Sahyog, co-funded by EU and Indian Ministry of Science and Technology. This database gives biomass availability estimates for bioenergy for most European countries and India. n.a. not assessed. The biomass figures reported for specific bioenergy crops in fields of India were suspiciously high, e.g. with sugar cane they were about one third of the actual harvested wet yield of the product. With oil crops the "used biomass potential" of specific oil bioenergy crops was the same as the entire harvested oil crops in India. Therefore only residue potential is reported here for India.*

Country	Crop residue and grass bioenergy potential (TWh)	Bioenergy potential of surplus fields (TWh)	Sahyog crop residue bioenergy potential (TWh)	Sahyog all farm side stream bio-energy potential (TWh)	Sahyog specific bioenergy crops (TWh)
Nordic countries					
Finland	7.7	33.4	4.9	8.9	0.4
Denmark	11.8	60.0	6.6	46.5	n.a.
Norway	3.1	0.0	n.a.	n.a.	n.a.
Sweden	16.4	43.7	3.6	13.8	1.8
Baltic countries					
Estonia	4.8	4.3	0.73	0.75	0.75
Latvia	8.3	13.1	0.79	60.3	0.55
Lithuania	10.0	19.9	2.1	2.4	n.a.
Western European countries					
The Netherlands	4.6	0.0	0.45	46.0	0.09
Belgium	4.9	0.0	2.0	36.8	0.32
Spain	82.0	538.9	19.3	255.9	3.2
Italy	50.8	0.0	23.5	149.6	1.0
Austria	12.7	43.9	6.9	7.7	0.7
Ireland	8.4	109.2	n.a.	1.1	0.18
United Kingdom	77.1	51.4	12.5	31.8	3.1
Greece	6.3	n.a.	5.2	22.8	44.6
Luxemburg	0.3	n.a.	n.a.	0.06	0.11

Portugal	17.9	0.0	1.3	21.7	3.9
France	142	618.2	40.3	157.9	0.09
Germany	88.4	94.3	59.3	189.4	48.1
Switzerland	6.4	n.a.	n.a.	n.a.	n.a.
Eastern European countries					
Albania	0.8	n.a.	n.a.	n.a.	n.a.
Bosnia-Herzegovina	10.2	n.a.	n.a.	n.a.	n.a.
Bulgaria	8.5	n.a.	15.0	15.9	0.06
Croatia	4.5	n.a.	n.a.	n.a.	n.a.
Moldova	3.5?	9.5	n.a.	n.a.	n.a.
Poland	54.0	172.7	21.8	109.5	5.3
Romania	46.3	201.7	0.01	3.7	n.a.
Slovakia	11.4	11.4	3.5	11.8	8.5
Slovenia	1.9	n.a.	0.44	1.2	n.a.
Czech Republic	19.7	30.2	14.3	34.2	n.a.
Ukraine	110.1	208.7	n.a.	n.a.	n.a.
Hungary	22.2	94.1	14.0	22.9	n.a.
Belarus	24.8	59.3	n.a.	n.a.	n.a.
European Russia	1057	747.1	n.a.	n.a.	n.a.
India	**578**	0.0	1076	?	?

3 Forest biomass for bioenergy

3.1 Finland

3.1.1 The current state of forests and the use of wood based bioenergy

The forestry land area in Finland is 26.2 million ha, corresponding 86% of land area. The growing stock volume on forest land area is 2 332 million m^3 and it has increased by almost 60% since the 1970s (Finnish statistical yearbook of forestry 2013). This is due to the fact that annual growing stock increment has been greater than the annual drain constantly during that time. In the year 2012 the annual increment of growing stock was 104.4 million m^3 of stemwood and the total drain 69.8 million m^3. The drain comprises of roundwood removals, logging residues and natural drain. Almost all of the roundwood removals from felling (57.2 million m^3) were in domestic use (56.1 million m^3) in 2012 (Finnish statistical yearbook of forestry 2013).

In Finland the annual consumption of wood fuels in the year 2012 was 92 TWh which is 24% of total energy consumption (Finnish statistical yearbook of forestry 2013).

The wood fuels can be separated into solid wood fuels (consumption in 2012 was 53 TWh), black liquor and other concentrated liquors (38 TWh), by-products and waste products from forest industry (2 TWh). The solid wood fuels consist of forest chips (15 TWh), bark (12 TWh), sawdust (4 TWh), industrial chips (2 TWh) and other solid wood fuels (1 TWh). The use of wood fuels increased to 23% of total energy consumption and therefore the wood fuels were the single most important energy source, being slightly ahead of oil products in year 2012. (Finnish statistical yearbook of forestry 2013).

The consumption of wood fuels has increased significantly since 1990s because of increased number of heating and power plants (Fig. 1). At the same time consumption of black liquor has increased and thus these factors have resulted to the current situation, where wood fuels have major role among energy sources (Fig 1).

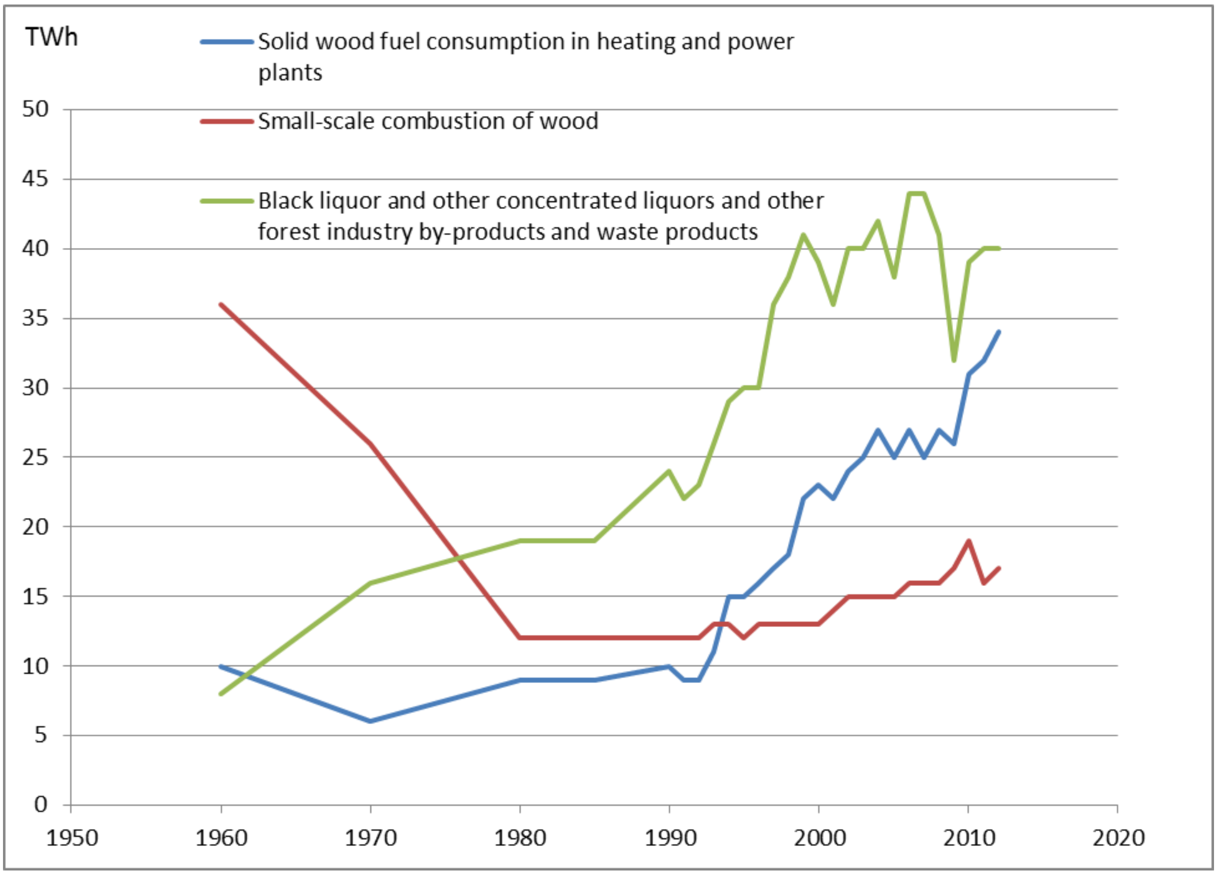

Figure 1. *Consumption of wood fuels during the years 1960-2012 in Finland (Finnish statistical yearbook of forestry 2013).*

In 2012, 8.3 million m^3 of forest chips were used in Finland, which is the highest recorded level of consumption so far. The use of forest chips increased 11% from the previous year. The consumption of forest chips started to increase rapidly since the year 2000, when the total use of forest chips was 0.9 million m^3. Since then, consumption has increased ca. 20% annually. In 2012, heating and power plants consumed 7.6 million m^3 of forest chips, and small-scale housing consumed 0.7 million m^3 (Finnish statistical yearbook of forestry 2013, Fig. 2).

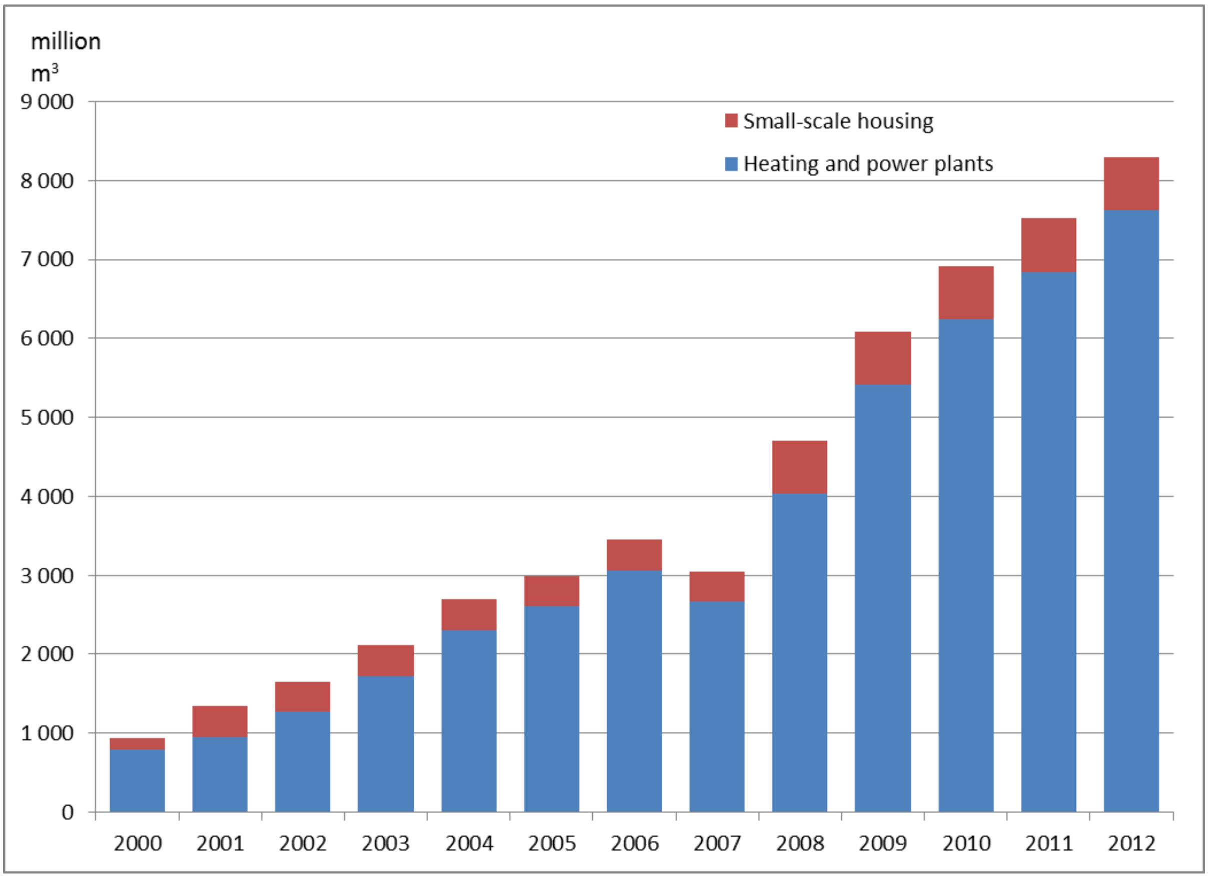

Figure 2. *Consumption of forest chips during the years 2000-2012 in Finland (Finnish statistical yearbook of forestry 2013).*

3.1.2 Forest bioenergy by components

In 2012, the Finnish heating and power plants consumed 17.8 million m^3 of solid wood fuels, of which 7.6 million m^3 were forest chips and 6.5 million m^3 bark (Fig 3). During the years from 2000 to 2012 the major trend has been increasing volume of forest chips consumption (Fig 3). At the same time the consumption of bark have slightly decreased and the consumption of sawdust, industrial chips and other have been more or less at the same level during the period (Fig 3) (Finnish statistical yearbook of forestry 2013).

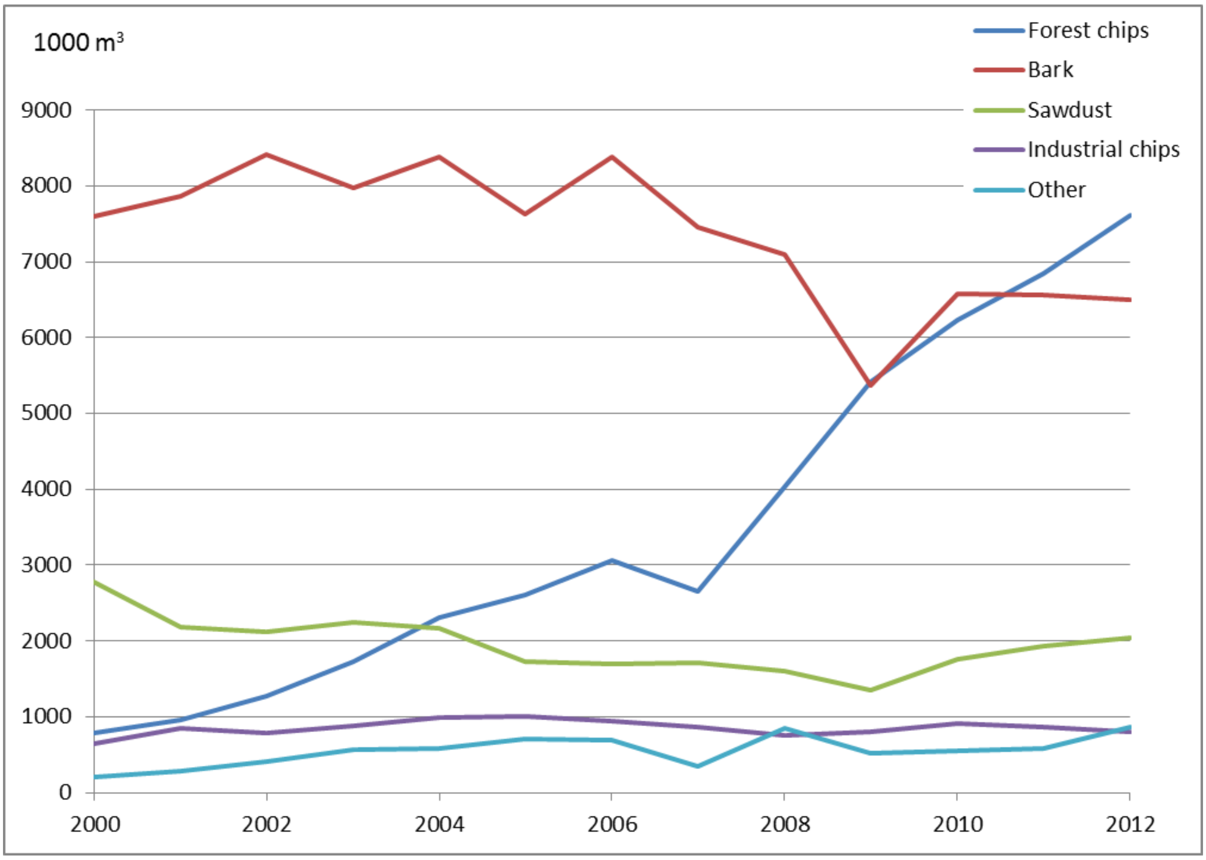

Figure 3. *Solid wood fuel consumption in heating and power plants during the years 2000-2012 in Finland (Finnish statistical yearbook of forestry 2013).*

The sources of raw material for heating and power plants from forests consist of small-sized trees, logging residues, stumps and large size timber. The sources of forest bioenergy can be separated into felled trees (whole trees, including crown or stems without branches) or components of trees that do not fulfil the requirements for industrial use (small size or poor quality) (Kärkkäinen et al. 2008). The tree components rejected for industrial use consist of tops of stems, branches, off-cuts of stems, stumps and roots (Kärkkäinen et al. 2008). The biomass harvested for energy use is usually converted into forest chips at the roadside in the forest or at the end-use site.

The consumption of different components of forest chips has been varied during years. The use of small-sized trees has increased rapidly after 2008 from 0.95 million m^3 into level of 3.6 million m^3 year 2012 (Fig. 4) (Finnish statistical yearbook of forestry 2013). At the same time the use of stumps achieved the current level 1 million m^3 already at year 2010 (Fig. 4).The use of logging residues increased steadily from 2000 to 2004 (from 0.4 to 1.5 million m^3, respectively) and after that more moderately up to current level of 2.6 million m^3 (Fig 4).

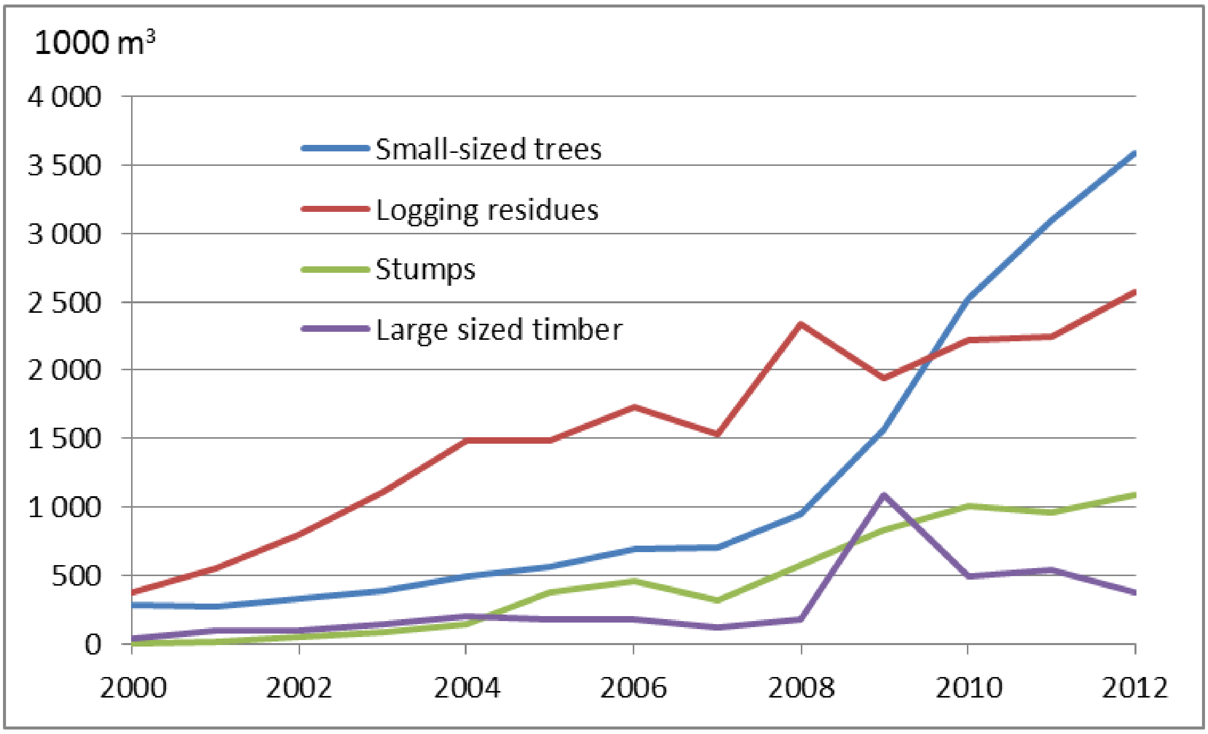

Figure 4. *Consumption of forest chips during the years 2000-2012 in Finland (Finnish statistical yearbook of forestry 2013).*

3.1.3 The regional variation of forest bioenergy

There is a large regional variation in the consumption of solid wood fuel. In 2012, the highest consumption for heating and power plants were in the region of South-Eastern Forestry centre (Ka-S, Fig 5). The consumption of bark and sawdust is highest in regions where forest industries producing side streams of bark and sawdust are located.

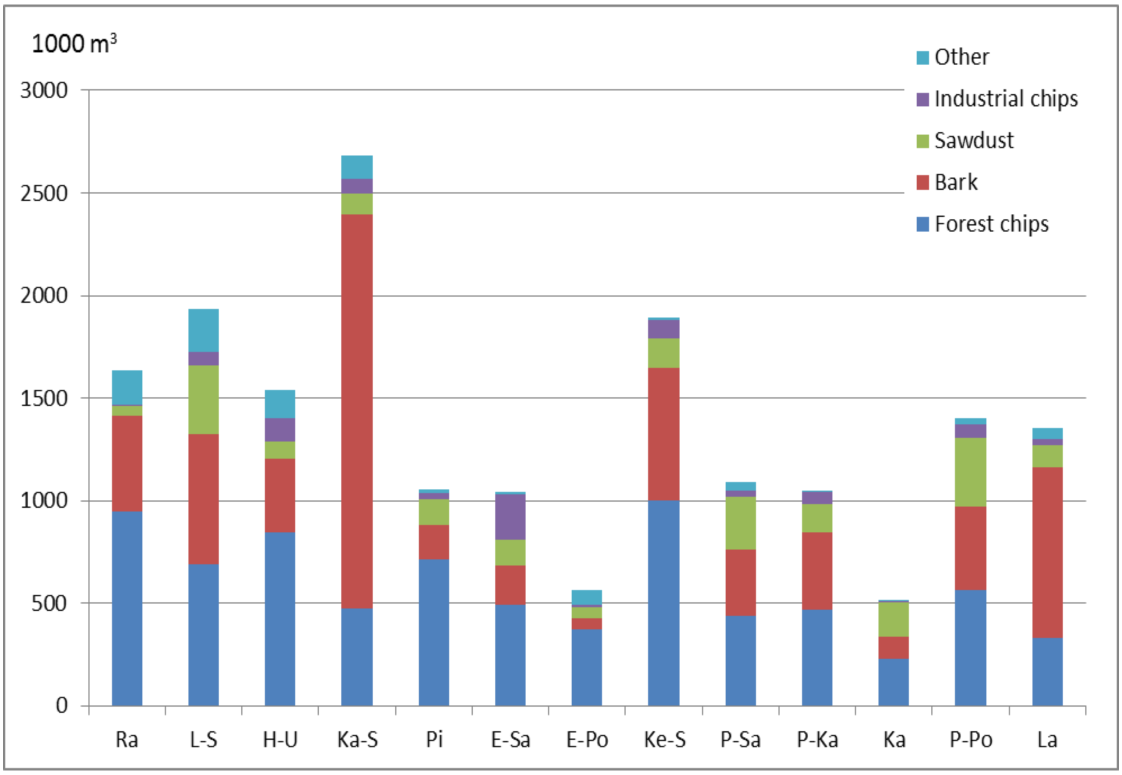

Figure 5. *Solid wood fuel consumption in heating and power plants by Forestry centre regions at year 2012 (Finnish statistical yearbook of forestry 2013).*

The highest consumption of forest chips is in Central Finland (Ke-S) Forestry centre and lowest at Kainuu region (Ka, Fig. 6). The proportion of small-sized trees of forest chips used by heat and power plants varies lot being highest at regions of the North-Western coast of Finland, Pohjois-Pohjanmaa (P-Po) and Lapland (La) and lowest at South-Eastern Finland (Ka-S) Forestry centres (Fig 6). The proportion of logging residues is regionally more evenly distributed, being highest at region of South-Eastern Finland (Ka-S) and Pirkanmaa (Pi) and lowest at Pohjois-Pohjanmaa (P-Po) Forestry centres.

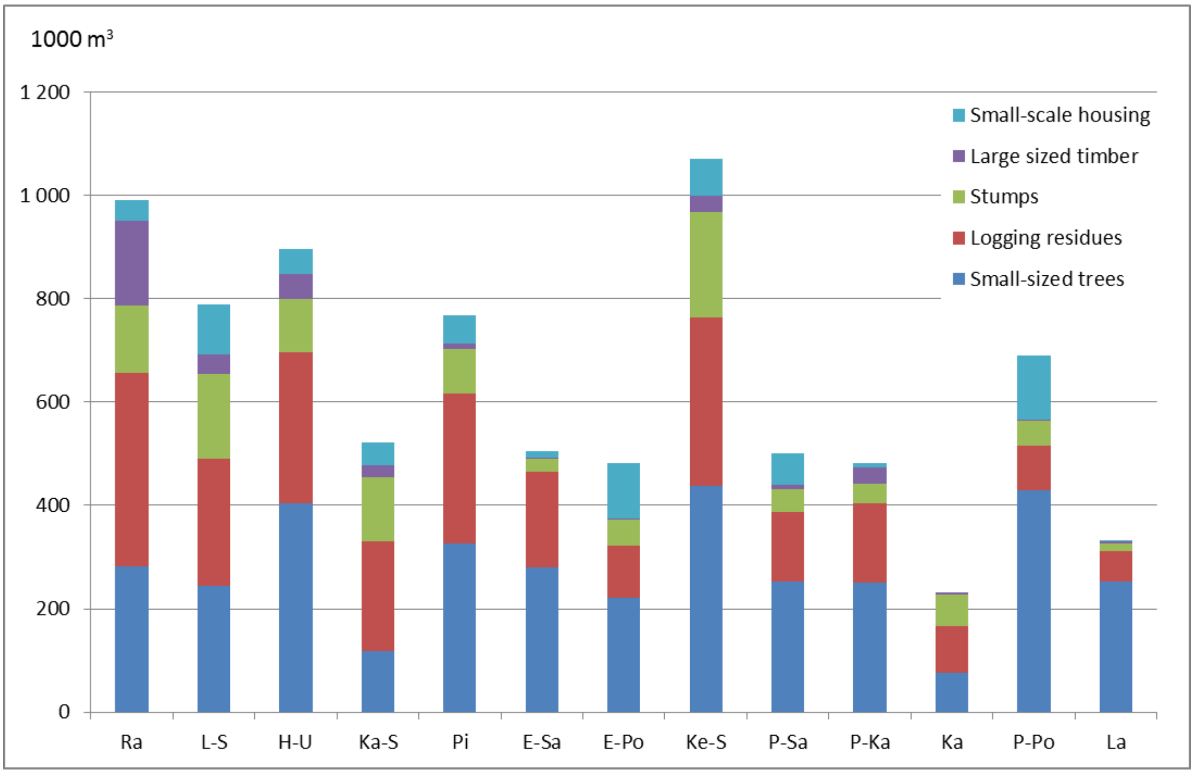

Figure 6. *Consumption of forest chips by Forestry Centres, 2012 (Finnish statistical yearbook of forestry 2013).*

3.1.4 The future potential of forest bioenergy

The potential of forest bioenergy estimates are based on forecasts on the development of forest resources and annual cuttings. The main source of forest chips are the forest residues. The amount of residues left in the forest after cutting is affected by tree species, size and branchiness of felled trees, as well as on the amount of decayed wood (Kärkkäinen et al. 2008). On the other hand, the production potential is dependent on cuttings, whether they are thinnings or final fellings. The potential of available reserve of bioenergy may not increase in thinnings as much as on final fellings (Kärkkäinen et al. 2008). Furthermore only a part of the total biomass potential is recoverable.

The future potential can be defined in different ways:

Theoretical potential describes the maximum biomass potential of bioenergy. It is net growth of woody biomass excluding current industry and firewood use (Asikainen et al. 2008).Theoretical potential of biomass is not totally available for bioenergy.

Technical potential describes more the level of available biomass potential. Many technological, economical, socioeconomic and environmental factors affect the availability of forest biomass (Hakkila 2004). In technical potential the availability reduction factors for harvestable forest fuels are taken into account (Asikainen et al. 2008). For example, based on silvicultural guide lines in Finland (eg. Äijälä et al. 2010), total energy wood recovery is not recommended for poor forest sites because of nutrient loss, and stumps are recovered only in spruce clear cut areas and in any case only part of stumps are recovered. Technical potential can also be defined as the total amount of surplus forest residues that can be collected without affecting commercial wood production (Haberl et al. 2010).

Several estimates have been calculated during the last years to determinate the potential of forest bioenergy raw material based on current forest resources and biomass functions and coefficients (e.g. Hakkila 2004, Ranta 2005, Ranta et al. 2007, Maidell et al. 2008, Kärkkäinen et al. 2008, Laitila et al.2008, Asikainen et al. 2008, Kärhä et al. 2010, Mantau et al. 2010, Verkerk et al. 2011, Anttila et al. 2013). The recent results of studies estimating forest bioenergy potential separated by theoretical and technical potential are presented in Table 4.

Based on the studies presented in Table 4, it can be stated that at national level the potential of energy wood will obviously fulfill the demand of estimated use of forest chips in the year 2020. The regional availability of forest bioenergy has also been studied recently. The results showed that in some regions energy wood resources are already now fully utilized (Anttila et al 2013, Asikainen & Anttila 2013) (Fig. 7). For example, crown mass is well utilized in Western coastal area of Finland likewise stumps in some areas of Northern Finland (Anttila et al 2013). In the areas of high utilization rates, it is likely that more expensive or valuable wood components will be used for energy, or transportation distances of energy wood will increase (Asikainen & Anttila 2013). The supply of energy wood depends on the consumption of roundwood by forest industry. If the consumption of industrial wood decreases, it will lead to decreased recovery of energy wood.

The small-sized trees will be the most prominent component on the increase (Asikainen & Anttila 2013). Especially using integrated energy and pulp wood harvesting in first commercial thinnings will result in moderately large energy wood potential. In addition, integrated energy and pulp wood harvesting method enables sorting of inferior wood quality into energy wood and pulp wood fractions in flexible way (Asikainen & Anttila 2013). The annual potential of small sized trees harvesting of stem trees (delimbed) is 6.2 million m^3, integrated energy and pulp wood ranges from 6.6 to 10.4 million m^3 (in addition pulpwood 1.8 – 2.5 million m^3) and whole trees (undelimbed) 8.3 million m^3, respectively (Asikainen & Anttila 2013).

Table 4. *Forest bioenergy potential in Finland presented in different studies. Theoretical potential refers the maximum biomass potential of bioenergy. Technical potential refers the level of available biomass potential and take into account the limitations of the biomass production practices.*

			TWh			
Study	Potential	Million m^3	Small-sized	Residues	Stumps	Total
Hakkila 2004	Theoretical	45	20	40	30	90
	Technical	15	10	16	4	30
Ranta et al. 2007	Theoretical	25.5	17	17	17	51
	Technical	12	7	11	6	24
Maidell et al. 2008	Theoretical	27.5	25.5	16.2	13.3	55
	Technical	11.75	12.4	6.5	4.6	23.5
Kärkkäinen et al. 2008*	Theoretical	79-49				158-98
(current climate scenarios)	Technical	57-59				114-118
Laitila et al. 2008	Technical	15.9	13.8	13	5	31.8
Kärhä et al. 2010,	Theoretical	52.25	53	26.3	25.2	104.5
(Basic scenario)	Technical	13.5	7.4	10.3	9.2	27
Anttila et al. 2013**	Technical	14.1 - 16.2	12.4-16.6	11.4	4.4	28.2-32.4
Hynynen et al. 2014	Technical	12.6	2.5	18.0	4.7	25.2
Metinfo/ Mela 2014						
years 2010-2019	Technical	21.1	14.4	15.6	12.2	42.2
years 2020-2029	Technical	22.1	20	15	9.2	44.2
years 2030-2039	Technical	22.1	19.2	15.6	9.4	44.2

* Two time spans: years 2003-2013 and 2043-2053
** Stem only or whole tree harvesting
*** small-sized stems, under dimensions of pulp wood

1 solid wood m^3= 2 MWh

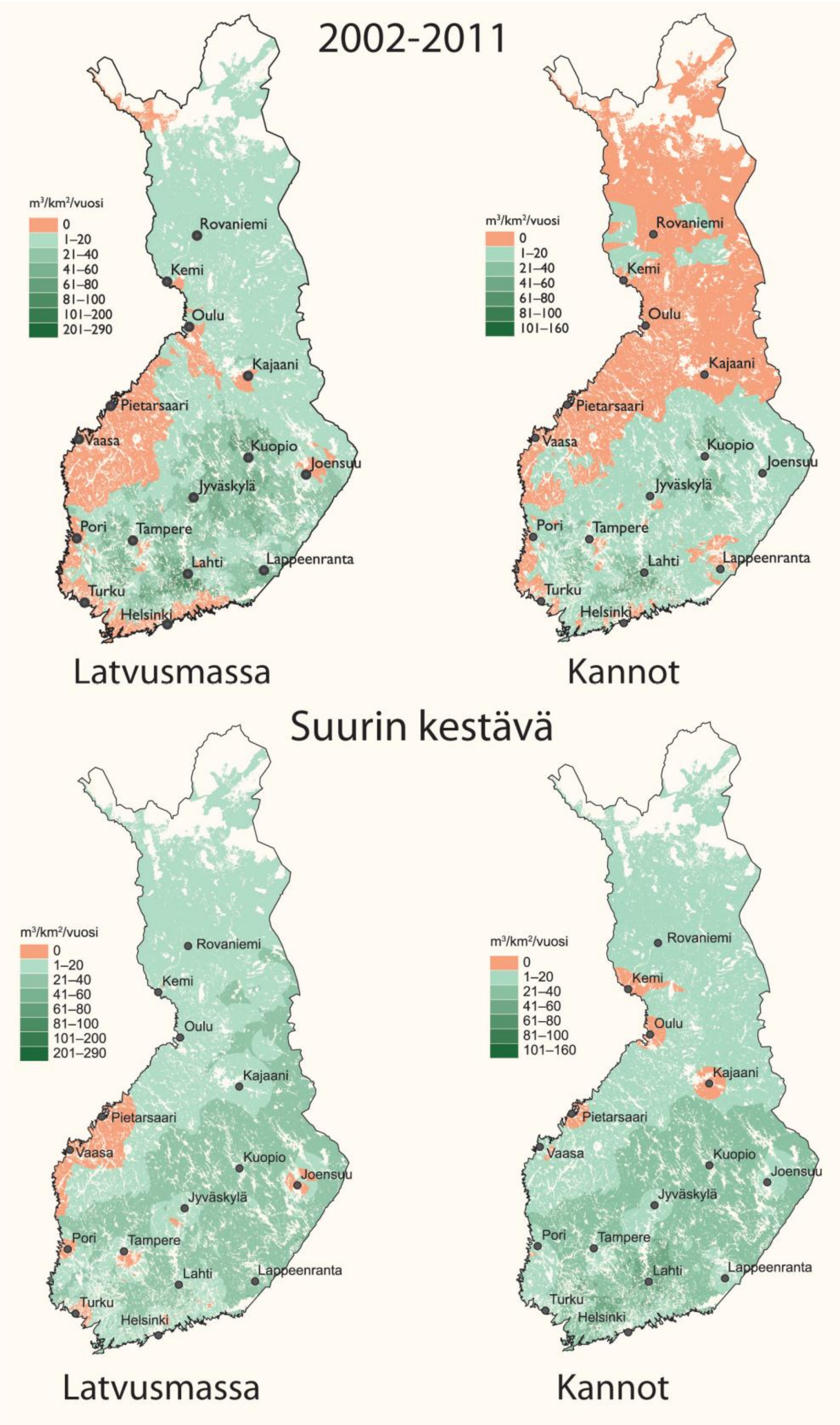

Figure 7. *The potential of crown mass and stumps in the years 2002-2011 based on realized cuttings and production potential in 2011 deduced by realized cuttings (suurin kestävä) Latvusmassa = crown biomass; Kannot = stumps. (Original source Anttila & Asikainen 2013).*

3.2 Wood biomass potential in Europe, India and China

The wood biomass potential has been studied recently in several studies with different time spans, scenarios and different fractions of solid wood fuels at European level (e.g. Asikainen et al. 2008, Mantau et al. 2010, Verkerk et al. 2011, Díaz-Yáñez et al. 2013) and globally (Anttila et al. 2009). There are lot of challenges in collecting and harmonizing data from different countries and different circumstances. Therefore, several projects focused on issues related to data collection. Biomass energy Europe (BEE) project (2008-2010) focused on initiation of harmonized methodologies for biomass resource assessments for energy purposes in Europe and its neighboring countries. Sahyorg project (started 2011) focused on linking EU and India projects, and the database of biomasses by countries was collected. Most recently, S2Biom project (started 2013) focuses on supporting the sustainable delivery of non-food biomass feedstock at local, regional and pan-European level through developing strategies, roadmaps and harmonized datasets.

Forest resources in Europe have increased during the last 50 years. The growing stock is approximately 19 700 million m^3 (Table 5) (Asikainen et al. 2008). Annual change rate (annual increment minus fellings) is about 237 million m^3 which is about 35% of annual increment (Asikainen et al. 2008). This means that increasing amount of wood is accumulating in forests, resulting in increased density of forests, and increased proportion of old age classes in European forests. This annual change rate could be described as reserve that nowadays will stay in forests, and at least part of this annual change rate could be utilized without risk of endangering sustainability of forestry.

The available annual amount of forest fuels in Europe was 187 million m^3 referring about 411 TWh of energy (Asikainen et al 2008). Theoretical potential of forest fuels has been estimated to be ca. 440 million m^3 per year (Asikainen et al 2008). According to Anttila et al. (2011), the global theoretical potential of modern fuelwood in EU27 countries from logging residues was 284 million m^3, while Asikainen et al. (2008) resulted in estimation value of 324 million m^3. Mantau et al. (2010) estimated that annual available forest energy potential in Europe is currently 722 TWh and in 2030 varies from 222 to 750 TWh. Torén et al. (2011) estimated that in EU27 countries forest resources allow in direct and indirect biomass supply of 156 and 204 million m^3 in year 2006, and 243 and 229 million m^3 in the year 2020, respectively. The potential is especially high in Central and Northern Europe (Table 5).

For China, the results of Anttila et al. (2009) gave a potential range of modern fuelwood supply being annually 70-104 million m^3 referring 140–208 TWh, respectively. The theoretical potential according to Cuiping et al. (2004) is 556 TWh annually. For India the potential of modern fuelwood has been estimated to be negligible, the range being 2-3 million m^3 referring 4-6 TWh (Anttila et al. 2009). The modern fuelwood is defined to be used at an industrial scale having relatively high efficiency compared to traditional use of fuelwood (Anttila et al. 2009). In the biomass database updated by Sahyog project, there were no results for biomass from forestry in India.

Table 5. *Growing stock, roundwood consumption, theoretical and available forest fuels in Europe by Asikainen et al. (2008) and Sahyog database. Forest fuels consisted of logging residues (stem wood loss, branches, tops, needles, stumps and roots) and 25% of annual change rate of growing stock and stumps and coarse roots of trees for change rate.*

	Asikainen et al. 2008					Sahyog biomass database, 2014	
	Growing stock, million m³	Industrial roundwood production, million m³	Theoretical forest fuel potential million m³	Available forest fuels, million m³	TWh	Available felling residues *, gross potential million m3	Total biomass of felling residues, gross potential, TWh
Austria	1 159	17.3	22	8.6	17.2	4.6	9.3
Belgium	172	5.2	4.5	2.1	4.3	0.8	1.6
Bulgaria	568	5.4	4.5	2.7	5.4	2.2	4.4
Cyprus	-	0.0	-	-	-	-	-
Czech Republic	736	17.0	19.7	8.1	16.2	5.1	10.1
Denmark	76	2.1	1.1	0.5	0.9	0.5	1.0
Estonia	447	11.6	6.3	1.6	3.2	1.2	2.3
Finland	2 158	61.4	63	23.9	47.7	15.3	30.5
France	2 465	43.4	42	21.3	42.6	14.5	28.9
Germany	-	55.5	73.7	30.9	61.8	20.1	40.3
Greece	177	2.2	-	-	-	0.5	1.1
Hungary	337	6.7	2.6	1.0	2.0	2.0	4.0
Ireland	65	3.1	3.5	1.5	3.0	0.4	0.7
Italy	1 447	9.6	12.9	9.8	19.6	16.3	36.9
Latvia	599	15.2	12	5.4	10.7	1.8	3.5
Lithuania	400	6.8	6.5	2.6	5.2	4.4	2.5
Luxembourg	26	0.3	0.3	0.2	0.5	0.0	0.0
Malta	-	-	-	-	-	-	-
The Netherlands	65	1.1	0.9	0.4	0.8	0.2	0.5
Poland	1 864	32.6	32.2	12.6	25.3	8.1	16.7
Portugal	350	11.4	8.7	3.9	7.8	1.9	3.8
Romania	1 347	16.5	8.5	2.1	4.1	5.2	10.4
Slovakia	494	7.2	7.4	3.2	6.3	2.4	4.8
Slovenia	357	2.9	3.9	1.8	3.6	0.9	1.7
Spain	888	17.9	16.8	8.3	16.6	5.5	11.0
Sweden	3 155	75.3	75.6	29.3	58.5	25.0	50.0
United Kingdom	340	9.2	11.1	5.2	10.3	2.8	5.7
EU 27 TOTAL	**19 692**	**437.1**	**439.3**	**186.7**	**373.4**	**141.6**	**281.6**

* Felling residues are tops, branches, bark, stumps

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