Baltic ForBio

Forest Energy Atlas

Project Report on Development, Training and Training assessment of a GIS platform

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Baltic ForBio Project Summary

Forest biomass is a very important source of renewable energy in the Baltic Sea Region. Over 80 % of the renewable energy consumed in Estonia, Finland, Latvia, Lithuania, and Poland is produced from forest biomass. The share ranges from 40 to 60 % for Denmark, Germany, and Sweden. Several studies have projected that the demand for forest biomass for energy use in the Baltic Sea Region would increase sharply in the future. At present, a major part of the forest biomass used for energy purposes is by-products of the wood-based industry, recycled wood, and firewood used by households. Forest harvesting produces a huge amount of residues, of which a large share could be used for heat and electricity production, but instead they are left in the forest due to economic and ecological reasons. There is thus large potentials to tackle the increasing demand for forest bioenergy by increasing the harvest of logging residues and small trees in pre-commercial thinning.

The Baltic ForBio Project aimed to increase the production of renewable energy in the Baltic Sea Region by improving the capacity of public authorities, forest and energy agencies, organizations of forest owners and entrepreneurs, and forest advisory organisations to promote the harvest and use of logging residues and small trees harvested in early thinnings. The project consist of five work packages solving particular aspects of promotion of biomass use in the Baltic Sea Region. Based on available technologies and research results, the project has developed cost-effective and sustainable harvest methods, decision support tools, guidelines and training programs for the harvesting of logging residues and small trees. **The project has also produced, in close cooperation with key stakeholders, a GIS platform and database enabling the user to make spatially explicit estimates of forest biomass potentials for five countries (Sweden, Finland, Estonia, Latvia and Lithuania) surrounding Baltic Sea.** The project also aims to develop innovative business models for developing small-scale bioenergy plants in a rural area in the Baltic Sea Region.

Aim of the Work Package 4

Work Package 4 developed an open-access internet-based tool for assessing spatially-explicit harvesting potentials of biomass for energy production and included the following sub-objectives:

1) Develop a GIS platform that enables users to explore spatially-explicit energy wood potentials
2) Compile the potentials from national sources into a database
3) Develop a training programme consisting of three training sessions and a user handbook containing instructions on how to use the GIS platform, hands on examples of using the GIS platform, information of how the data were collected and also an appreciation of data quality.

The knowledge provided in work package 4 fills in gaps of information on the amounts and location of available forestry feedstock, which can facilitate investments in forest energy production and policy decisions on the national and international level. Access to spatially-explicit and reliable estimates of forest biomass supply is enhancing the capability of key stakeholders (national, regional, and local authorities, organizations for renewable energy, and larger energy enterprises) to make reliable feasibility analysis of bioenergy development projects, especially large scale projects with significant demand for biomass and support of political will.

Communication strategy in Work Package 4

Communication of project results in work package 4 aimed in increasing knowledge among the national, regional, and local authorities, who can utilize the outputs in developing national strategies and policies as well as in setting regional targets and planning for wood energy project development together with energy enterprises and their associations who can use the quantitative data in planning of future investments. The key stakeholders have been reached through meetings and workshops between the project partners and stakeholder organisations, and by distributing information on the GIS platform and database in brief to all the main stakeholder organizations which have been identified by project partners and associated partners in different countries. The internet-based tool was made available to all stakeholders and other interested organizations already before the end of the project.

Training programme and Forest Energy Atlas user guide

Regional training sessions in Finland, Sweden, Estonia, Latvia and Lithuania have been carried out parallel with regional development activities. The communication strategy aimed to bridge the knowledge gaps between different key stakeholders.

The training programme for the use of the web-based Forest Energy Atlas developed in work package 4, is composed of three training sessions and a user guide. In practical training the possibility was given to merge all three training sessions in one longer session. The training concept has a didactic structure based on joint learning and adjusted for defined key stakeholders. The didactic structure consists of objectives, contents, learning outcomes, methodology and assessment of each training session. The training sessions were planned and executed by trained personnel that has compiled the countrywise forestry feedstock data in the Forest Energy Atlas.

The aim of the first training session was getting the key stakeholders familiar with the GIS platform and database, understanding system thinking and design. One of the main objectives of the first training session was that participants acquire and exchange knowledge on the existing situation on forest biomass spatial distribution and availability in their regions. The second training session aimed at getting deeper into the functionalities of the GIS platform and database. At the third training session, the key stakeholders have used their knowledge to start developing potential renewable energy strategies and investment plans (business planning and investment preparation) in their regions based on the knowledge acquired from the previous training sessions.

Assessments of the outcomes as well as the competence development were carried out to find out how far the knowledge skills and attitudes have changed before and after training occasions.

Country Reports on Communication and Training Activities

In total ca. 125 stakeholder staff, representing seven different sectors predominantly involved in forestry had at least a Forest Energy Atlas training occasion (Table 1). By far the biggest representation of participants in the training occasions has been from production (57%) mainly in Lithuania and Finland followed by representatives from the research and governance.

Table 1. A number of participants in training and their represented sector in partner countries.

Represented Sector	Country					Share of Sector
	Sweden	Finland	Estonia	Latvia	Lithuania	
Research		4	3		24	24%
Governance	1	5	7	3	3	15%
Consulting		2	9	5		13%
New Product Development					2	2%
Raw Material Procurement	4	11	4		24	34%
Production	6			1	66	57%
Processing & Refining	1					1%
Other	1	3		2		5%

Sweden

In Sweden, the focus has been on communicating the Forest Energy Atlas to the stakeholders. It was judged that the best way to make the Forest Energy Atlas known to the actors was to visit forest companies and organisations and teach their personnel to use the Forest Energy Atlas. The following stakeholders were visited in Sweden:

- Forest owners associations: Mellanskog and Norra;
- Forest Companies: Sveaskog, Holmen and Svenska Cellulosa Aktiebolaget (SCA)
- Interest organisations: SVEBIO; BioFuel Region; Association of Energy producing companies; Association of forest industry; Association of Forest Energy;
- Private companies; Storuman terminal, Bioendev, ELMEK.
- Research Institutes: Skogforsk

Also, a film was recorded on the Forest Energy Atlas and how to use it was explained. More visits to companies were planned but due to COVID19 restrictions could not be done. In the training, the area selection tools were judged to be of great use for the users. It became clear that the Forest Energy Atlas can help forest companies to plan how much biomass they will take out from the forest but cannot replace their own planning tools. Additionally, the Forest Energy Atlas has been used in educating forestry students at the Swedish University of Agricultural Sciences (SLU) and research at Universities and the Forest Research Institute Skogforsk. Students have familiarized themselves on strengths and limitations when using Forest Energy Atlas for biomass estimations. Forest Energy Atlas and Baltic ForBio project has been showcased as one of the usable tools for development of the East Baltic Sea region in Sweden.
SLU used the Forest Energy Atlas to project industrial pulpwood availability in Sweden for four major pulp mills as well as the availability of logging residues in their nearby surroundings for biofuel production in the biorefining processes (Appendix 1). The results and applied methods for creating Forest Energy Atlas are being prepared for publication in proceedings at the FORMEC (The forest engineering network) conference in Oregon, the USA in August 2021. Similarly, Skogforsk together with the Chalmers University of Technology used Forest Energy Atlas to estimate the availability of logging residues close to four main pulp mills for increased heat production to drive CO_2 capture processes at these facilities. BioFuel Region together with SLU and ELMEK company used the Forest Energy Atlas to calculate amount of biomass around the town of Storuman. In addition, the Forest Energy Atlas will be used in the project Market Uptake Support for Intermediate Bioenergy Carriers (https://www.music-h2020.eu/) for biomass availability calculations after that the Baltic Forbio project has ended.

Finland

One training occasion for the Finnish stakeholders was held as a physical meeting with a possibility to sing up for a webinar at the premises of Natural Resources Institute Finland (Luke) in Helsinki. Altogether six persons participated in the physical meeting and 37 persons had signed up for the webinar. The participants represented altogether 12 public authorities and 13 enterprises.
No further evaluation of the training has been carried out so far. In Finland, the situation of the COVID-19 pandemic has not affected training, because one training occasion had been planned.

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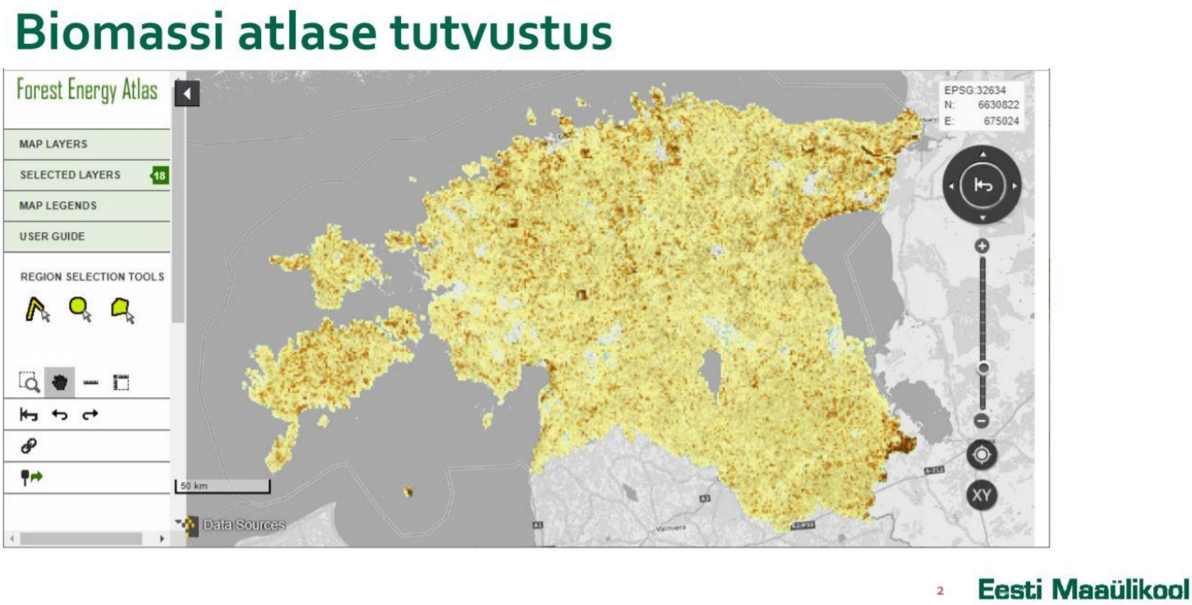

Figure 1. Material for training ocassion of Forest Energy Atlas in Nakatu, Estonia. Source: [*https://www.eramets.ee/wp-content/uploads/2020/08/Bioatlas-25.-26.08.2020.pdf*](https://www.eramets.ee/wp-content/uploads/2020/08/Bioatlas-25.-26.08.2020.pdf)

Estonia

In Estonia, there have been two training occasions on 25th and 26th of August with approximately 40 participants from different sectors. The training was conducted within the framework of a Forest Owners' Association's seminar and took place in a seminar room of Nakatu tourism farm. The trainer introduced the Forest Energy Atlas and showed different functions of it (Figure 1). The attendees also tried these functions and engaged themselves through different scenarios. The training went well and there was quite a strong discussion between the trainer and the attendees. On the second training occasion day, 20 participants out of 40 filled in Forest Energy Atlas training and evaluation forms (Appendix 2). There has not been any other training occasions in Estonia, except one in Tartu in October 2019, but there was only one participant who did not even fill the training and evaluation form.

Table 2. Participants evaluation of the training ocasion in Estonia.

Please mark your level of agreement with the statements listed below	Strongly Agree	Agree	Disagree	Strongly Disagree	Not relevant to this training event
1. The objectives of the training were met	60%	40%	0%	0%	0%
2. My training expectations were fulfilled	50%	50%	0%	0%	0%
3. The training materials (user guide) were relevant	55%	45%	0%	0%	0%
4. The content of the training was organised and easy to follow	65%	35%	0%	0%	0%
5. The trainers were well prepared and able to answer any questions	85%	15%	0%	0%	0%
6. The length of the training was appropriate	55%	40%	5%	0%	0%
7. The pace of the training was appropriate to the content and attendees	55%	45%	0%	0%	0%
8. The examples demonstrated were helpful and relevant	75%	25%	0%	0%	0%
9. The Forest Energy Atlas interface was intuitive	25%	75%	0%	0%	0%
10. Thematic maps of biomass were visually illustrative	50%	50%	0%	0%	0%
Average	**58%**	**42%**	**1%**	**0%**	**0%**

Overall participants found training occasion and Biomass Energy Atlas well (42%) or very well organized and illustrative (58%) (Table 2).

Latvia

In Latvia a training material in video format has been prepared and published on distance learning platform and Youtube channel of the Forest Advisory and Service Center. The video material allows to introduce the Forest Energy Atlas to a broader public and shows its functionality to anyone interested in learning how to use the Forest Energy Atlas on their own. Other upcoming training occasions are planned as face-to-face meetings and press releases. One press release has been published at the end of Summer 2020 on the Forest Advisory and Service Center webpage (Figure 2).

Figure 2. Forest Energy Atlas on Forest Advisory and Service Center webpage. Source: http://new.llkc.lv/lv/nozares/mezsaimnieciba/meza-biomasas-atlanta-viss-par-baltija-pieejamo-kurinamo-koksni

In the early October 2020 the Forest Energy Atlas was introduced to the participants of the meeting of the executive directors of Latvian local governments. In the meeting the goal of Forest Energy Atlas, its provided opportunities and a face-to-face training occasion were given in order to explain and promote the use of forest biomass for energy production.

Lithuania

In Lithuania in total four training occasions have been planned of which two have been arranged. The first training occasion was aimed at Forest Research Institute and Vytautas Magnus University. In total 19 attendees participated of whom all were related to forest research and teaching. After evaluation of training by attendees, the majority praised the system, yet found it little relevant to their daily work and interests. Three persons found it highly useful for their teaching programs in the University and expressed their plans for dissemination of Forest Energy Atlas knowledge among students. In the end, no constructive suggestions for improving Forest Energy Atlas were received.

The second training occasion was arranged with the State Forestry Enterprise. In total 48 attendees participated of whom all represented central and regional offices, and the forest management department of State Forestry Enterprise. In Lithuania, there is only one State Forestry Enterprise, which is managing roughly 50% of all forests in the country. Evaluation of teaching was not effective as only seven evaluation forms were filled and sent in. However, during the discussion occasion, it was pointed out that attendees liked Forest Energy Atlas and they found it interesting and useful in their daily work. While the majority of requests towards the improvement of the functionality of Forest Energy Atlas was out of the scope of WP4 it is worth mentioning that participants would like to see the availability of wood fuel potential data of individual forest sites instead of the grid. And also, the possibility to separate data layers at the same time and having compatibility with existing local systems.

The third training occasion was an eye-to-eye meeting with members of Lithuanian Biomass Energy Association (LITBIOMA). The association involves the producers and suppliers of solid biomass and other local renewable resources, such as wood, straw, energy crops such as willow and peat, as well as the heat suppliers, producers and engineers of solid biomass boiler rooms and other equipment, developers of plantations and academic institutions. In the training occasion, information of Forest Energy Atlas was provided to 32 persons. Feedback was of low activity, and interest was lesser than expected. While Forest Energy Atlas was regarded as an excellent tool, biomass suppliers are generally not interested in logging residues today due to specific biomass market conditions in Lithuania.

In addition, additional two online meetings for associations of private forest owners were held on May 29 and July 24 2020. The meetings were unsuccessful, regardless of good dissemination of information via contact persons of respected associations, only six owners participated in teachings in total. Besides, we provided basic information of Forest Energy Atlas to 14 private forest owners who expressed interest in this system via phone. However, there was no feedback provided.

Feedback on Forest Biomass Atlas

Overall, approximately some 40% of the workshop participants that replied to the feedback form (Appendix 2) have returned to the Forest Energy Atlas. Most of the participants who returned to the Forest Energy Atlas represent scientific or policy-making/lobbing fields. However, it has been pointed out that it is too soon for the participants to use Forest Energy Atlas in a meaningful setup.

Most of the workshop participants have mentioned about Forest Energy Atlas to third persons. The information has been passed on mainly to state forest and forest management enterprises and members of forest owner's associations as well as energy wood processing companies.

Overall participants of workshops found Forest Energy Atlas mostly as an informative tool. When it comes to practical decision-making participants overwhelmingly missed forest ownership structure (state or private etc.). Due to the historic development of forests on abundant agricultural lands, participants in Latvia and Lithuania would like to see biomass distributions on these lands as well as biomass plantations such as willows. Additionally in Sweden and Finland, there is a growing interest to see the possibility of calculating transportation distances in the future.

Participants from Lithuania and Latvia gave the highest score (almost 90% gave a score of three and higher in the scale of 5) for the usefulness of Forest Energy Atlas in their professional lives. Among the Baltic States, the lowest score of 2 was given by participants in Estonia. The main professional interest has been on biomass density in specific regions in order to plan business decisions as well as for obtaining confirmation on the current state of statistics from multiple sources. Forest Energy Atlas has raised significantly less interest for personal use and personally, participants mainly used Forest Energy Atlas to satisfy their curiosity on biomass distribution among countries or their own or smaller nearby forest areas.

Most of the participants were using Forest Energy Atlas to obtain information in their residing countries. Researchers were the ones showing the most interest in cross-border data acquisition using Forest Energy Atlas.

In its current form, the future use of Forest Energy Atlas is intended for mainly informative purposes to promote local projects on biomass use. However, project members also intend to some extend to use it in education and research projects. Moreover, particularly members in Lithuania see the potential to use Forest Energy Atlas as a tool to promote improvements in their existing inventory systems in the country.

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Appendix 1.

Projecting Future Procurement Potential of Forest Resources Using Swedish Forest Inventory Data

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Appendix 2.

Training Evaluation Form and Follow up Questionnaire

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Projecting Future Procurement Potential of Forest Resources Using Swedish Forest Inventory Data

Kalvis Kons, Dimitris Athanassiadis

Abstract

In the last 20 years the use of forest biomass for energy production and saw log and pulpwood production has increaed by 68%, 11% and 31% in Sweden. As Sweden is trying to achieve net zero greenhouse gas emissions by 2045 the high demand for biomass can be expected also in future. Therfore a method to project amount of spatialy available biomass assortments for industries were developed. Available amount of different forest assortments were estimated and visualized in webbased tool using forest inventory data and nationwide projection analyses of available biomass for 2035-2039. In the 2035 – 2039 the most biomass and roundwood will be available in the Northen Southern Sweden. Resuts also indicate that already existing harvesting intesity is very high compared to the availbale biomass in the future. The industry can expect noticable more available biomass due to improved regeneration material and climate changes closer to 100 year period. With incrased competion between large pulp mills and biorefinaries the supply areas can exeed 200+ km to satisfy raw material demand. The long distance and high volume supply chain requirments will demand further improvement in transportation solution nationaly and cross-border in the Baltic Sea Reagion.

Keywords: GIS, assortment, biomass, bioenergy, pulwood, sawlogs, bark, supply, estimations

1. Introduction

Sweden has a good starting position to meet the aims of the Paris Agreement. The share of renewable energy in gross final consumption surpassed the 2020 goal of 50 % already in 2012 (Forsum, Sahlin, and Olsson 2018). The share of supplied energy from biomass, which consists mainly of forest biomass, alone was 26% or 141 TWh in 2018 (Swedish Energy Agency 2019). Sweden's 2016 Energy Agreement's goals are to achieve 100% renewable power by 2040 and zero net greenhouse gas emissions by 2045 (IRENA 2020; Ministry of Enviroment 2016).

In 2018 the most used energy carrier in final energy use in industrial and residential sectors was electricity. The final renewable energy use from biomass in these sectors was 39% and 41% (Swedish Energy Agency 2019). Increased use of primary forest biomass for heating can substantialy reduce the electricity consumption in the residential sector allowing redirecting electricity use in transportation sector and other nonsubstitutional applications. In addition, other industrial players besides pulp and paper sector will seek renewable energy sources to reduce their carbon emission in order to achieve the goals of the 2016 Energy Agreement (Ministry of Enviroment 2016). Since 2000, biomass use for energy production in average has increased by 3% annually reaching 68% increase in total (Swedish Energy Agency 2019). Today most by-product streams of residual biomass (e.g. bark and sawdust) from forest industry are fully utilized, leaving any further increase of biomass use for energy production on primary forest resources, such as logging residues, stumps and bark. Simultaneously with the increase of biomass use for energy purposes also harvested volumes of saw logs and pulpwood have increased annually reaching an overall increment of 11% and 31% respectively compared to year 2000 (Skogsstyrelsen 2019).

With continuing growth of the demand for biomass and roundwood it becomes more important to have good understanding of future biomass and roundwood availability. Geographical information systems (GIS), national forest inventory data and growth models are widely used to estimate available biomass potentials across the globe at regional, national and local scale (Noon and Daly 1996; Nord-Larsen and Talbot 2004; Castellano, Volk, and Herrington 2009; Rørstad et al. 2010; Yoshioka et al. 2011; Bouchard, Landry, and Gagnon 2013; Muinonen et al. 2013; Lundmark, Athanassiadis, and Wetterlund 2015; Fernandez-Lacruz et al. 2015).

However, while the annual demand of biomass and roundwood has increased, the main focus in above mentioned studies has been particularly on biomass potentials. Lundmark, Athanassiadis, and Wetterlund (2015) besides estimating the potential harvesting quantities of different biomass assortments have also estimated the harvesting costs on roundwood assortments, such as saw logs and pulpwood. Growing demand, overlapping procurement areas and increased transportation distances are the main reasons for increased procurement costs due to (Viana et al. 2010). There have been several

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methods applied to address overlapping demand regions for biomass, like allocating harvesting potential by minimizing transportation costs (Nord-Larsen and Talbot 2004; Ranta 2005) or by estimating regional balances of supply and demand or by totalling overlapping regions (Goerndt, Aguilar, and Skog 2013; Sánchez-García et al. 2015; Nivala et al. 2016; Ranta et al. 2012; Emer et al. 2011; Masera et al. 2006). For cost-effective industrial facilities that process forest biomass it is necessary to have access to regional estimates of raw material supply potentials in order to identify hot spots in their supply areas (Masera et al. 2006).

Nivala et al. (2016) and Anttila et al. (2018) have done regional balance studies of supply and demand of forest chips of very high level of detail. And even though there are many other studies estimating future biomass potentials and procurement costs using GIS tools and different growth models there is a knowledge gap on how to interactively visualize this information and allow different stakeholders to do their own biomass estimations in the regions of interest.

The aim of the study was to develop a method for illustrating spatially explicitly, annual projected forest biomass potentials of branches, stumps, bark, pulpwood and saw logs in Sweden for the period 2035-2039 and apply the method on estimating potentials in different geographic areas within Sweden.

2. Materials and Methods

The annual projected forest biomass potentials from final fellings and thinnings in Sweden of five assortments (branches, stumps, bark, pulpwood and saw logs) was estimated for the period 2035-2039 and represented in a raster map. Potential projections for branches, pulpwood and bark include aggregated values of Scots pine (*Pinus sylvestris L.*), Norway spruce (*Picea abies*), Silver birch (*Betula pendula*) and Downy birch (*Betula pubescens*). Potential projections for stumps and saw log biomass included only Scots pine and Norway spruce due to environmental restrictions when it concerns extractions of birch stumps and the low availability of birch sawlogs.

Two readily available datasets were used for the production of the raster map:

1. A forest map that shows the total forest biomass in the Swedish productive forests in 2015 (https://www.skogsstyrelsen.se/sjalvservice/karttjanster/skogsdataportalen/). This map has been developed through the processing of data from the national laser scanning that is performed annually in Sweden and plot data from test-sites from the Swedish forest inventory. The forest biomass volume (m^3 above-ground biomass /ha) is reported at a pixel level of 12.5x12.5 meters and is a measure indicating the volume content of stemwood plus logging residues. Stumps are thus not included but are estimated in our analyses from the available data…. Trees that are under 3 m in height and also birch forest in the mountains are not included in the estimation. The development of the forestry map is described by Nilsson et al. (2017).
2. The annual county-level projected forest biomass potentials from the Swedish Nationwide Forestry Scenario Analysis 2015 ($NFSA_{15}$) (Claesson, Lundström, and Wikberg 2015; Eriksson et al. 2015). The potential projections were made for all National Forestry Inventory (NFI) plots and initialized from the state of the plots observed in 2008–2012, located across Sweden and representing 22.4 million ha of productive forest land. NFSAs are regularly performed in Sweden covering all productive forest land (managed as well as protected forests). The $NFSA_{15}$ simulates among others, a business as usual (BAU) scenario projecting forest development and harvest level, given that today's management practices are practiced also in the future. The BAU scenario assumes that Swedish silvicultural practices will not change and annual fellings will stay at a level that is regarded as sustainable (harvesting less than annual increment), that environmental legislation will not change and that climate change will be light. Other scenarios, e.g. alternative forest management practices, are typically also included in NFSAs (Claesson, Lundström, and Wikberg 2015; Eriksson et al. 2015). For the $NFSA_{15}$ projections of annual maximum sustainable removal countywide (procurement volume) from final fellings and thinnings in Sweden of five forest biomass assortments (branches, stumps, bark, pulpwood and saw logs) were available for each of a total of 29,892 NFI plots (located across Sweden) for five year period from 2010 to 2110.

For the creation of the raster maps the BAU scenario projections for the period of 2035-2039 were used. In each county, each of the 12.5 x 12.5 m grid cells of the forestry map was assigned forest projection data of countywide projected potentials ($P_{i2035-2039}$) according to the amount of forest biomass (B_{a2015}; m3 above-ground biomass) it currently contained related to the current total amount of biomass in the county ($\sum_{i=1}^{n} B_{a2015}$). The NFSA15 annual countywide projected procurement volumes were expressed in solid m^3 under bark (m^3 sub) for saw logs and pulpwood and oven dry tons (odt) for bark, branches and stumps.

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$$P_{ai2035-2039} = \frac{B_a2015}{\sum_{i=1}^{n} B_{a2015}} * P_{i2035-2039} \quad (1)$$

where: P_{ai} = biomass potential in grid cell a in county i

n: the amount of grid cells in county i;

For the final estimations, the 12.5 x 12.5 m grid cells were aggregated into 1 km x 1km grid cells and nature protection areas were removed (Fig. 1).

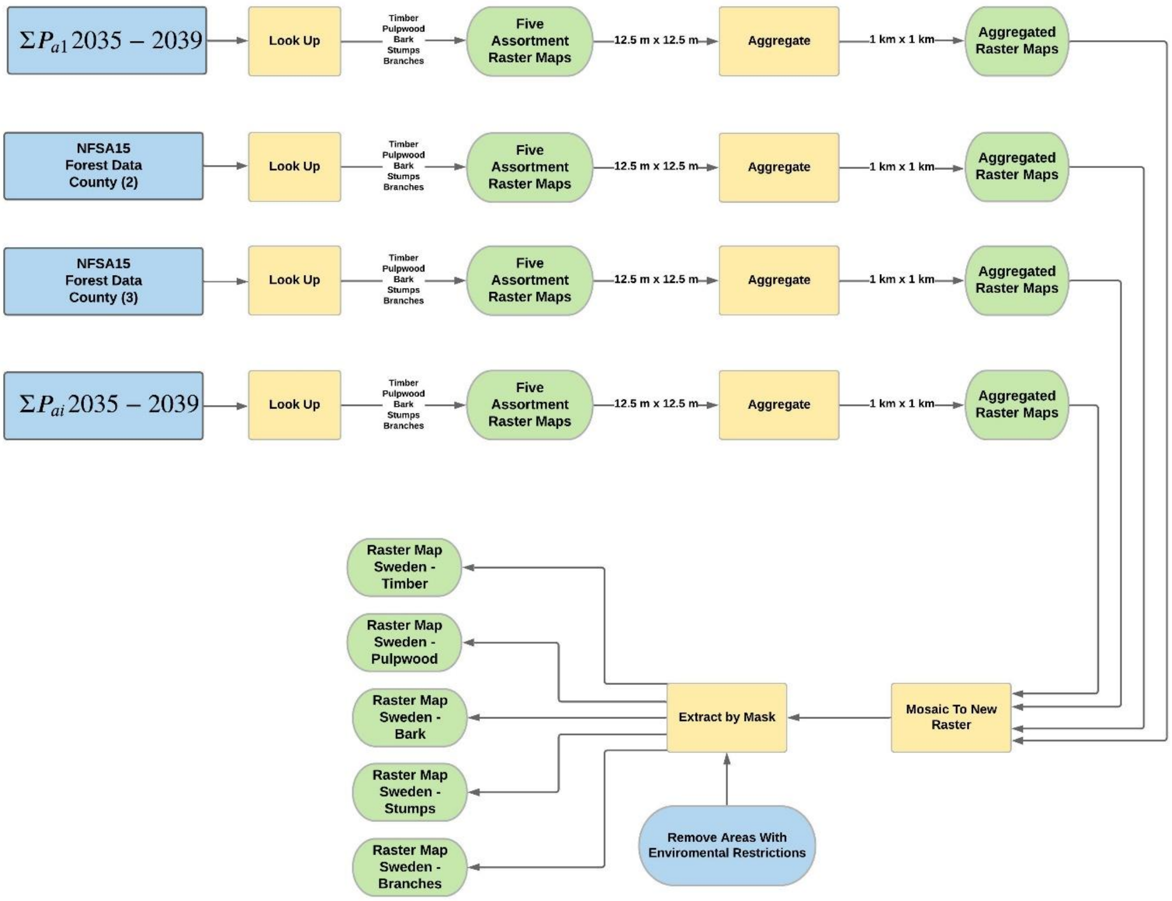

Fig. 1. The model workflow for producing raster maps that illustrate annual countywide projected procurement volumes for five forest biomass assortments (branches, stumps, bark, pulpwood and saw logs) in Sweden for the period 2035-2039. Look up, Aggregate, Mosaic to New raster and Extract by mask denote tools in the ArcGIS software.

The raster maps were then uploaded into the Forest Energy Atlas web application (https://forest-energy-atlas.luke.fi/). Three case studies of potential projections for different assortments and geographic areas were performed in order to exemplify the use of the raster maps. The case study areas were selected:

a) from the list of predefined regions (municipality, county, province or state) already existing in the Forest Energy Atlas web application; projected forest biomass of each assortment per ha of productive forestland was estimated for each county;

b) by drawing a circle with user-defined radius; circle-based procurement areas with 50 km, 100 km and 200 km radius were drawn to estimate projected pulpwood potential (m^3sub) around four major pulp mills (Metsä Board Husum, SCA Östrand, Södra Cell Mönsterås, Södra Cell Värö) with a minimum annual pulp production capacity of 700 ktons (Fig. 2). For conversion of pulp production capacity in tons to the pulpwood demand in cubic meters, a conversion factor of 4.76 m^3sub/ton pulp was used (Briggs 1994). The total pulp production capacity of the four selected pulp mills was 3080 ktons of pulp.

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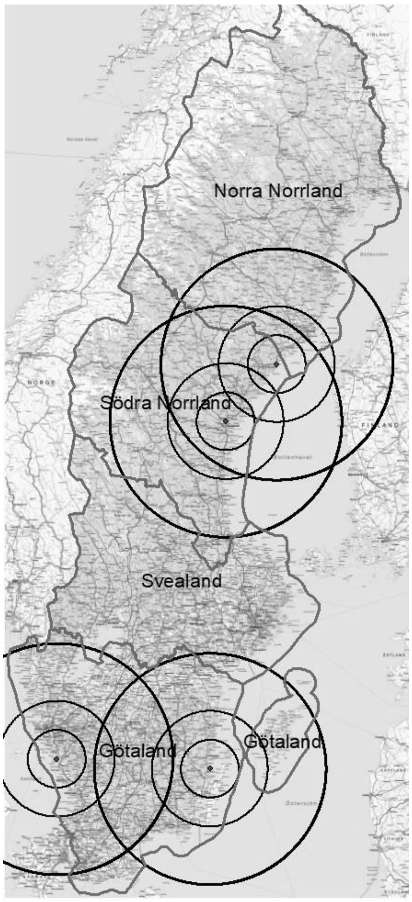

Fig. 2. Location of four major pulp mills and their assumed pulpwood sourcing areas in Sweden.

Additionally, a projection of available biomass of logging residues (branches and tops) was calculated for three potential lignin oil-producing biorefineries integrated into existing pulp/paper mills in Sweden. The branches raster (Raster Map Sweden Branches in Fig. 1.) was used for the calculations. The original raster with a pixel size of 1km x 1km was aggregated to a raster with a pixel size of 10km x 10km. The original raster was containing the branches without including any ecological restrictions and neither including the tree tops (upper stem part below 6 cm in diameter) in the estimates (. To correct that and provide an available amount of logging residues that is closer to reality the treetops were added to the branch biomass. It was assumed that approximately 8% of the logging residues are composed by tops. This quantity was then added to the quantity of the biomass of branches. Further, it was assumed that only 75% of the logging residue biomass (branches and tops) is harvested while the rest remains in the forest and decomposes. Furthermore, all pixels that had a logging residue density of less than 100 dry tonnes per 100 km^2 were removed from the data set to make the analysis easier to handle. Three locations for the pulp/paper mills producing lignin oil from logging residues originating from harvesting operations of pulpwood and sawlogs were selected; one in the north close to city Umeå (SWEREF 763017, 7074957), one in the middle close to city Gävle (SWEREF; 624067; 6729681) and one at the south part of Sweden close to city Göteborg (SWEREF: 329530;6346115). The assumption is that the production of the lignin oil would be integrated into the pulp mills located close to the shore of Baltic Sea or Kattegat Strait (North Sea) and will make transportation of products possible by sea transport.

Available logging residues were calculated within a buffer zone of 75 km around the facilities and all logging residues in the buffer was transported directly to the facilities by trucks. The central point of each 10km x 10km pixel was assumed to be the collection point of the logging residues that were produced within each pixel.

3. Results

The projected annual forest biomass (branches, stumps and bark) and roundwood potential in Sweden for the period 2035-2039 is 17’256’752 odt and 67’523’420 m^{3}sub respectively of which 30’669’863 m^3 sub is pulpwood and 36’853’557 m^3 sub is sawlogs.

Counties in the South of Sweden (Götaland) have the lowest amount of productive forest land (4’810’000 ha), but have the second-highest projected annual biomass and roundwood potential in period 2035 - 2039 (5’061’875 odt and 21’834’868 m^3 sub respectively) due to higher growth rate (m^3/ha) than the rest of the counties (Table 1). Counties in the North of Sweden (Norrland) have the highest amount of productive forestland (13’470’000 ha) and also the highest projected annual biomass and roundwood potential (7’632’987 odt and 26’752’819 m^3sub respectively) despite the lowest levels of growing stock. Counties in central Sweden (Svealand) have the least projected annual amount of biomass and roundwood potential counting at 4’561’890 odt for biomass and 18’935’733 m^3sub for roundwood. Jämtland in North Sweden is the county with the highest projected annual biomass potential equalling 1’796’232 odt. The highest projected annual potential of pulpwood at 3’014’604 m^3sub is in another county in the north, Västerbotten. However, the highest projected annual sawlog potential at 3’414’700 m^3sub is to be found in the southern county of Västra Götaland.

The four mills together consume 48% of the potential nationwide pulpwood availability for the period 2035 – 2039 (Table 2). According to our calculations based on the projected annual projected pulpwood potentials, in 2035 – 2039 only 11% – 16% of needed pulpwood demand can be procured within a 50 km radius from these pulp mills (Table 2). SCA Östrand pulp mill can procure the most pulpwood (16% of its demand) among all four pulp mills that were included in this analysis, however, in average pulp mills can procure 13% of their pulpwood demand within a 50 km radius. Within a procurement distance of 100 km radius, the pulp mills in the South of Sweden can procure 51% of their annual pulpwood demand while pulp mills in the North can procure 49%. The difference of available pulpwood volume becomes even wider between South and North with procurement areas of 200 km radius. Within 200 km procurement area, all pulp mills can cover their pulpwood demand by 157% - 178%. However, at such a long transport distance the procurement areas between all four pulp mills overlap making them partially compete for the same resource (Fig. 1). And also, due to the competition from other smaller market players within the procurement area technically available volumes will be even lower, especially with increasing transport distances.

Table 2. Present production capacity and pulpwood demand for the pulp mills with an annual pulp production of over 700 000 t and estimated pulpwood potential for harvesting 2035 – 2039.

Pulp mill	Production (t)	Pulpwood demand (m^3sub)	Max available pulpwood potential within 50 km, (m^3sub)	Available pulpwood vs demand, %	Max available pulpwood potential within 100 km, (m^3sub)	Available pulpwood vs demand, %	Max available pulpwood potential within 200 km (m^3sub)	Available pulpwood vs demand, %
Metsä Board Husum	730 000	3 474 800	377 245	11	1 502 650	43	5 454 987	157
SCA Östrand	900 000	4 284 000	681 434	16	2 322 452	54	7 113 623	166
Södra Cell Mönsterås	750 000	3 570 000	479 610	13	1 865 661	52	5 991 901	168
Södra Cell Värö	700 000	3 332 000	412 447	12	1 652 416	50	5 935 783	178
Total	3 080 000	14 660 800	1 950 736	13	7 343 179	50	24 496 294	167

Pulpwood demand can be satisfied only by 16% - 36% compared to the potential pulpwood availability within county borders where pulp mills are located. Södra Cell Värö has the least available pulpwood at 539’848 m^3/year in Halland’s county where it is located (Table 1). Interestingly Västernorrland’s county holds 30% of pulpwood demand from the two pulp mills in northern Sweden. According to table 2 a pulpwood potential from the county of Halland and two surrounding counties of Skåne and Västra Götaland would have been harvested to cover 100% pulpwood demand from Södra Cell Värö. To satisfy pulpwood demand from Södra Cell Mönsterås an additional pulpwood resource would be needed from counties of Östergötaland and Jönköping. In the North to guarantee uninterrupted pulpwood supply to the two pulp mills in Västernorrland an additional pulpwood volume should be taken from nearby counties of Jämtland and Västerbotten (Table 1).

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Table 1. Available biomass from five forest assortments in 21 counties of Sweden, year 2035 – 2039.

Administrative borders	Productive forest land, ha	Branches		Stumps		Bark		Pulpwood		Sawlogs		Total, odt/a	Total, m^3 (sub)/a
Götaland		odt/a	odt/a/ha	odt/a	odt/a/ha	odt/a	odt/a/ha	m^3 (sub)/a	m^3 (sub)/a/ha	m^3 (sub)/a	m^3 (sub)/a/ha		
Östergötlands	626000	184 066	0.29	321 340	0.51	130 933	0.21	1 082 131	1.73	1 835 026	2.93	636 339	2 917 157
Jönköpings	703000	222 062	0.32	377 545	0.54	151 960	0.22	1 379 479	1.96	2 011 841	2.86	751 567	3 391 320
Kronobergs	607000	194 243	0.32	327 673	0.54	131 037	0.22	1 172 935	1.93	1 657 599	2.73	652 953	2 830 534
Kalmar	733000	212 131	0.29	374 012	0.51	151 156	0.21	1 275 425	1.74	2 114 721	2.89	737 299	3 390 146
Gotlands	126000	21 536	0.17	41 563	0.33	14 792	0.12	108 805	0.86	126 484	1.00	77 891	235 289
Blekinge	185000	55 828	0.30	92 754	0.50	3 609	0.02	363 135	1.96	41 184	0.22	152 191	404 319
Skåne	357000	106 330	0.30	175 221	0.49	114 924	0.32	717 375	2.01	885 187	2.48	396 475	1 602 562
Hallands	275000	79 674	0.29	142 216	0.52	77 255	0.28	539 848	1.96	760 701	2.77	299 145	1 300 549
Västra Götalands	1198000	397 067	0.33	689 145	0.58	271 803	0.23	2 348 292	1.96	3 414 700	2.85	1 358 015	5 762 992
Subtotal	4 810 000	*1 472 937*	0.31	*2 541 469*	0.53	*1 047 469*	0.22	*8 987 425*	1.87	*12 847 443*	2.67	*5 061 875*	*21 834 868*
Svealand													
Stockholms	288000	69 299	0.24	118 072	0.41	47 630	0.17	382 840	1.33	507 557	1.76	235 001	890 397
Uppsala	489000	130 752	0.27	221 837	0.45	81 403	0.17	736 530	1.51	1 101 247	2.25	433 992	1 837 777
Södermanlands	339000	98 044	0.29	172 206	0.51	69 113	0.20	545 865	1.61	875 987	2.58	339 363	1 421 852
Västmanlands	304000	81 178	0.27	144 997	0.48	58 110	0.19	574 376	1.89	681 572	2.24	284 285	1 255 948
Örebro	573000	191 761	0.33	281 887	0.49	114 689	0.20	1 020 134	1.78	1 274 031	2.22	588 337	2 294 165
Värmlands	1334000	381 560	0.29	677 557	0.51	226 492	0.17	2 377 909	1.78	2 807 645	2.10	1 285 609	5 185 554
Dalarnas	2061000	394 611	0.19	754 451	0.37	246 241	0.12	2 728 018	1.32	3 322 022	1.61	1 395 303	6 050 040
Subtotal	5 388 000	*1 347 205*	0.25	*2 371 007*	0.44	*843 678*	0.16	*8 365 672*	1.55	*10 570 061*	1.96	*4 561 890*	*18 935 733*
Norrland													
Gävleborgs	1451000	345 500	0.24	656 523	0.45	224 028	0.15	2 390 380	1.65	2 958 839	2.04	1 226 051	5 349 219
Västernorrlands	1731000	413 311	0.24	788 155	0.46	237 554	0.16	2 341 997	1.35	2 373 245	1.37	1 439 020	4 715 242
Jämtlands	2823000	497 444	0.18	1 007 486	0.36	291 302	0.20	2 745 955	0.97	2 925 859	1.04	1 796 232	5 671 814
Västerbottens	3269000	478 109	0.15	984 533	0.30	280 978	0.19	3 014 604	0.92	3 017 347	0.92	1 743 620	6 031 951
Norrbottens	4196000	392 292	0.09	805 947	0.19	229 825	0.16	2 823 830	0.67	2 160 763	0.51	1 428 064	4 984 593
Subtotal	13 470 000	*2 126 656*	0.16	*4 242 644*	0.31	*1 263 687*	0.09	*13 316 766*	0.99	*13 436 053*	1.00	*7 632 987*	*26 752 819*
Total	23 668 000	4 946 798	0.21	9 155 120	0.39	3 154 834	0.13	30 669 863	1.30	36 853 557	1.56	17 256 752	67 523 420

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The total amount of logging residue biomass available within 75 km from the three lignin oil refineries is slightly over 300 kton odt (Table 3). The most logging residue biomass is available for the biorefinery in the central part of Sweden (176’769 kton odt) and the least amount is available in the northern part of Umeå (98’020 kton odt). The three biorefineries can source from 14 to 28% (14%, 28% and 19%) of logging residue biomass compared to total available biomass from only branches and bark in corresponding counties (Table 1) where all three facilities are located.

Table 3. The estimated amount of available biomass of logging residues for lignin oil production within 75 km from the facility, 2035 – 2039.

Location	Available biomass of logging residues (branches and tops), odt
Umeå (North Sweden)	98’020
Gävle (Central Sweden)	176’769
Göteborg (Southern Sweden)	124’069
Total	300’838

4. Discussion

Lundmark et al. (2015) presented the projected availability of roundwood, harvesting residues and stumps in raster maps in Sweden for the period 2010–2069 based on the $NFSA_{08}$ projections. In that paper the projected volumes in each county were aggregated to 27.75 x 27.75 km grid cells. The method gave a reasonable accuracy of estimated biomass within county borders but no consideration was taken on the current biomass load in each grid cell. That method is improved in this paper by assigning in each grid cell, forest projection data according to the amount of forest biomass each grid cell contains related to the current total amount of biomass in the county.

Issues with distribution of biomass estimates were noticed in Anttila et al. (2018) and Nivala et al. (2016). In these works, removing NFI plots with environmental restrictions possibly led to uneven distribution of available biomass. In the present paper only the theoretical maximum potential of the studied assortments is presented. The user of the raster maps is warned that it is not possible to procure the total of the theoretical potential of branches and stumps and that 40% of the projected potential should be left in the forest (Athanassiadis and Nordfjell 2017).

Anttila et al. (2018) have used similar to this study approach to distributing inventory data over a larger grid area. However, there are differences between Anttila et al. (2018) and the present study on how nature protected areas were removed. While the method used in this paper removes the areas with nature protected areas at the end of data processing using ArcGIS, Anttila et al. (2018) used a series of calculations and assumptions before projecting data on the raster grid.

Spatial analysis is scale-dependant as well as PC computing speed is dependent on amount of data it has to process. While we have not experienced computing speed problems when working with vector files, high resolution raster files (12.5 m x 12.5 m) take substantially longer to compute compared with 1 km x 1km raster grid. Similarly to Anttila et al. (2018) who increased their raster grid resolution to 1 km x 1 km from the 1 ha resolution in Nivala et al. (2016) study, also we found that 1 km x 1km resolutions were a good compromise between good regional results on biomass estimates and computing speed.

The fact that there is such a small discrepancy between projected potentials and current harvesting levels can be mainly explained by the very high present harvesting intensity and a short period of time that elapses between the present and the projection time. According to the $NFSA_{15}$ (Claesson, Lundström, and Wikberg 2015) in the business as usual scenario, the projected harvested potentials increase from 90.8 to 119.6 m^3 at the end of the 100 year period. Growth increases, due to genetically improved planting stock which will happen with every future rotation cycle of forest stands.

Currently one of the most expanding areas in the Swedish forest industry is investments in pulp mills and potential biorefinery integration in their surroundings. When comparing the maximum annual available pulpwood volumes (30.7 M m^3ub) for the years 2035 – 2039 and the harvested volumes of pulpwood for the years 2013 – 2017 (29.5 – 30.6 M m^3) (Skogsstyrelsen 2019) we can see that Swedish forest owners are already harvesting volumes close to those available in the future estimates. Just four big pulp mills in Sweden are already procuring ca. 49% of the available projected pulpwood potential for 2035 -2039 and 80% of this potential lies within 200 km radius from the pulp mills. As for pulpwood similar trend is observed for saw logs where harvested volumes for the years 2013 – 2017 have been 31.7 M m^3 – 36.6 M m^3 and our estimate for years 2035 – 2039 is 36.9 M m^3.

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The potential for lignin oil-producing biorefineries to source logging residues within 75km distance is quite limited (14% - 28%). The pulp mills and biorefineries also need a lot of energy in form of steam and heat which they are producing themselves by burning bark and other biomass residues and by-products from pulping. This means that biorefineries will directly compete with heat and power plans heating the nearby cities or with the heat and power plants within their own facilities therefore even further reducing the practically available amount of logging residues for lignin oil production.

Wetterlund et al. (2013) have summarized 14 studies where primary forest harvesting residue potential has been estimated for 2020 in Sweden. The results vary in the wide range from 16 TWh/year to 81 TWh/year. While this paper includes only branches in the primary harvesting residues, our estimate for years 2035 – 2039 is on the lower side at 28 TWh. There have been four studies estimating stump potential in 2010 with the highest estimate being 58 TWh/year and lowest 10 TWh/year. Our estimate for stumps in 2035 – 2039 is somewhat on the higher end at 42 TWh/year. The results obtained in this study are consistent with results found in the study by Lundmark, Athanassiadis and Wetterlund (2015) where their estimates were also on the lower end for harvesting residues and in mid-range for the stumps.

An important part of the development of the raster maps was to make them available to the stakeholders i.e. forest owners, forest owners associations, forest companies, authorities, researchers, and the general public. At the LUKE homepage (https://forest-energy-atlas.luke.fi/) the Forest Energy Atlas tool has been developed that allows to look at and work with, free of charge, raster maps developed in Sweden, Finland, Latvia, Estonia and Lithuania. The tool gives the possibility to the user to easily access and estimates the available amount of timber or biomass in the region of interest by using three regional selection tools.

5. Conclusions

In this study a method to project available biomass and roundwood potententials in the future were developed. Method is using high quality forest inventory data and countrywide future biomass projection analyses in combination with GIS analyses. The method was applied for the years 2035 – 2039 however it can aplied to any time period up to 100 years in the future. Obtained results are integrated in the ineractive webbased maps for use of different stakeholder groups to support policy making and investment decidions.

Results show that the most biomass and roundwood will be availbale for procurment in North and South Sweden. However this could bring disbalance in supply and demand, espicially for energy assortments, as traditionaly biomass for energy demand is higher in the central and Southern Sweden. Also with continuing investments in bio-refinaries, pulp mills and sawmills the forest and energy industry should not expect significnt increase of the available biomass raw materials in the next 20 years. Therfore any further procuremnt volumes has to come from efficiency improvements within exisiting supply chain.

Therfore the future development for the online tool is needed to include industrial demand on the country and cross-border regional level for supply and demand estimates in the Baltic Sea region as biomass and timber supply chains are highly interconnected in this region. Indicatative resutls show that further development will be needed in long distance and high volume supply chain and terminal, and log-yard designs and managament to tackle 200 km and longer transportation distances.

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Author Contributions

Dimitris Athanassiadis conceived, designed the experiments and performed the experiments; Dimitris Athanassiadis and Kalvis Kons analysed the data and wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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Training in Forest Energy Atlas Evaluation Form

Date of training event:

Location of training event:

Trainers:

Instructions: Please mark your level of agreement with the statements listed below	Strongly Agree	Agree	Disagree	Strongly Disagree	Not relevant to this training event
1. The objectives of the training were met					
2. My training expectations were fulfilled					
3. The training materials (user guide) were relevant					
4. The content of the training was organised and easy to follow					
5. The trainers were well prepared and able to answer any questions					
6. The length of the training was appropriate					
7. The pace of the training was appropriate to the content and attendees					
8. The examples demonstrated were helpful and relevant					
9. The Forest Energy Atlas interface was intuitive					

10. Thematic maps of biomass were visually illustrative					

11. What is your organisation doing? Encircle the correct alternative(s)
Research, Governance, Consulting, New Product Development, Raw material procurement
Production, Processing and Refining; Other, what?

12. Describe your tasks related to forest biomass in your everyday work

13. Which biomass are you especially interested in?
Saw logs; Pulp wood; Stumps; Bark; Logging residues; Firewood; Other, what?

14. Which region selection tools did you use? (e.g.

15. What was **most** useful in the training? How do you feel you can use Forest Energy Atlas when you are back in the office?

16. What was **least** useful?

17. What else would you like to see included in the training and also in Forest Energy Atlas? (e.g. other type of biomasses, other region selection tools etc.)

18. Do you have any suggestions that would make this training better?

19. Any other comments (any bugs, any last suggestions etc.)? Would you have liked further guidance in using the Forest Energy Atlas after this training event?

THANK YOU FOR COMPLETING THIS EVALUATION FORM. FEEDBACK RECEIVED WILL BE USED TO PROVIDE IMPROVEMENTS TO THE TRAINING MATERIAL AND THE FOREST ENERGY ATLAS INTERFACE.

EVALUATION FORMS SHOULD BE HANDED TO THE TRAINERS AT THE END OF THE EVENT. ALTERNATIVELY FORMS CAN BE SUBMITTED TO dimitris.athanassiadis@slu.se.

Follow Up Questioner on Forest Energy Atlas

Questions for feedback on Forest Energy Atlas:

1. Have trainees returned (yes/no) to the Forest Energy atlas after the training sessions?
2. Have they showed or mentioned atlas to someone else (yes/no)?
    i. If yes: to whom (in what field of business)?
3. What do they miss/would like to see added to the atlas (different time periods, demand estimations, facility location, forest ownership structure etc.)?
4. In the scale from 1 – 5, how useful they find Atlas to be for their professional life?
    i. What would they look for professionally in Atlas? (what interests them)?
5. In the scale from 1 – 5, how useful they find Atlas to be for their curiosity/free time?
    i. What would they look for personally in Atlas? (what interests them)?
6. Do you use it for your country or other countries in the atlas as well?
7. What is your indented use of Forest Energy Atlas as a project partner after the project has ended?