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Baltic ForBio

Baltic ForBio – A Decision Support Tool for Harvesting Logging Residues

Wenchao Zhou

Department of Forest Economics

Swedish University of Agricultural Sciences

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Contents

1. Introduction

The Baltic ForBio app is a decision support tool for analyzing the production costs and profitability of harvesting forest residues as energy. Residues are in the forms of logging residues from final felling, small trees from pre-commercial thinning, and logging residues from thinning. Logging residues consist of tops and branches of harvested trees, usually left in the site when carrying out final felling or commercial thinning. Small trees refer to the whole trees harvested at pre-commercial thinning. Costs of producing these biomass for energy use can vary along supply chain from the forest site to the end-use plant. For example, the main costs for utilizing logging residues from final felling can include the forwarding cost (cost of collecting the residues and transport them to roadside), the cost of chipping the residues at the roadside, and the cost of transporting the chips to a plant. Meanwhile, the forwarding cost can depend on various factors. For instance, the time that it needs to forward the residues per ha to roadside depends on the amount of residues per ha, load capacity of the forwarder used to do the job, transport distance to the roadside, and terrain conditions. For small tree biomass, the production costs include the cost of cutting small-sized trees as well. The cutting cost depends on which cutting method is used. There are two cutting methods in practice: the whole trees method and the delimbed wood method. The time that is consumed to cut the trees depends on the number of trees to cut, the average tree size, and so on.

Steps of cost analysis

Generally, the App estimates forest residues production costs in two steps.

In the first step, the total amount of residues is estimated for the forest stand that is planned for final felling, pre-commercial thinning, or commercial thinning by using stand-level or individual tree biomass functions. As inputs, the user needs to provide data describing the stand, for example, standing volume, and composition of tree species. *In the second step*, various costs along the residue production chain are calculated, including costs for harvesting, forwarding, chipping, and transporting. In this step, the user needs to provide relevant technical data, e.g., forwarder's load capacity, economic data, e.g., forwarder cost per working hour, and spatial data, e.g., single-way distance to roadside, transportation distance to a plant. Revenues from producing residues is calculated by multiplying the price and the quantity of the biomass. Finally, the App can generate a report, which can be saved as pdf file or printed.

1.1 Logging residues from final felling

Logging residues include tree tops and branches of harvested trees. Alternative residues supply chains are:

a. Logging residues - Forwarding to roadside
b. Logging residues - Forwarding to roadside - Chipping at roadside - Transporting chips to plant
c. Logging residues - Forwarding to roadside – Transporting loose residues to plant

The amount of tree tops and branches is estimated using the stand-level biomass functions developed by Lehonen (2004) for pine, spruce, and broadleaved three species, respectively. The functions that provide the biomass of components living branches and stems from the stem volume, or standing volume, are used. It is assumed that the biomass of the tops accounts for 5 % of the stem biomass. The time consumed by forwarding the residues to roadside is estimated using time consume functions for forwarding logging residues (see Appendix). The time consumed by transporting logging residue chips or loose residues is estimated using time functions (see Appendix 1.5).

Example 1.1

A 4 ha spruce stand at 90 years old is located in middle Sweden and is planned for final felling. The standing volume is measured to be 375 m^3/ha, consisting of pine 0%, spruce 100 %, and broadleaf 0%. The associated logging residues is estimated (by the App) to be 12.3 ton DM/ha or 27.7 m^3 solid volume/ha. Suppose that 75% of these residues are extracted for energy use and the average forwarding distance to roadside is 400 meters. When a forwarder with load capacity 16 m^3 solid is used, the forwarding time consumption is estimated (by the App) to be 2.1 G15-h per ha. Given a cost of 950 kr/G15-h for the forwarder, it is estimated that the cost for forwarding is 1949 kr/ha, and that the cost for forwarding for the whole 4 ha stand is 7797 kr.

1.2 Small trees from pre-commercial thinning

The entire biomass of the small trees removed is used as energy. Basic biomass supply chains are:

a. Harvesting small trees - Forwarding to roadside
b. Harvesting small trees - Forwarding to roadside - Chipping at roadside - Transporting chips to plant
c. Harvesting small tress - Forwarding to roadside - Transporting loose residues to plant

The biomass of the trees is estimated using individual tree biomass functions of Marklund (1988). The functions provide the biomass of components living branches, dead branches and stems, for pine, spruce, and broadleaf. The biomass is a function of the diameter at breast height of the tree. The production costs can include the cost of cutting trees, the cost of forwarding the harvested trees to roadside, or chipping and

transporting costs. Standard machine, or small machine can be used to perform the cutting operations. When small machine is selected, the user needs to provide the harvester's productivity. When standard machine is used, there are two cutting methods to choose: the whole trees method and the delimbed wood method. The time consumption of harvesting the small trees are estimated using time consumption function (Appendix); the time consumption of forwarding the biomass to road side is estimated using function (Appendix); the time consumption of transporting the biomass to plant is estimated using function (Appendix).

Example 1.2

There is a 2 ha of forest stand at the age of 25 years, within which pre-commercial thinning is to be carry out. The small trees to be removed are used as energy feedstock. The stand has 5000 trees per ha, consisting of spruce 40%, and 60 % broadleaf trees. The mean diameter (i.e., quadratic mean diameter) is 6.8 cm. 35% of the stems will be removed, resulting in 3250 tree per ha being left. It is required that the mean diameter of the remaining stand is 6.8 cm. The stand after thinning consists of 40 % spruce and 60% broadleaf. It can be derived that 1750 stems per ha are cut, with a mean diameter of 6.8 cm. The biomass of the small trees removed is estimated (by the App) to be 16.1 ton DM/ha, or 35.3 m3 solid volume/ha. Thinning is carried out using standard machine, together with the whole trees cutting method. Accordingly, the harvesting time is estimated (by the App) to be 21.9 G15-h per ha. Assume that the harvester cost is 1050 kr/G15-h, the harvesting cost is estimated to be 23001 kr per ha and 46002 kr for the whole stand. The average distance to the road side is 400 meters, the forwarding time is estimated (by the App) to 4.0 G15-h per ha. Given a forwarder cost of 800 kr/G15-h, the forwarding cost is estimated to be 3239 kr/ha, and 6478 kr for the whole stand.

1.3 Logging residues from thinning

Logging residues from commercial thinning include tops and branches of the harvested trees, which usually is left on the site. Basic supply chains are:

a. Logging residues - Forwarding to roadside
b. Logging residues - Forwarding to roadside - Chipping at roadside - Transporting chips to plant
c. Logging residues - Forwarding to roadside - Transporting loose residues to plant

Different to the estimation of logging residues from final thinning, the biomass of residues from thinning is estimated using the individual tree biomass functions of Marklund (1988). Using the diameter at breast height of a tree as independent variable, the functions of Marklund (1988) provide the biomass

components branches and stems. In calculating the total amount of logging residues (including tops and branches), it is assumed that the biomass of top part is 5% of the tree's stem biomass.

Example 1.3

There is a 4 ha forest stand at 35 years old in Southern Sweden. The stand has 2000 trees per ha, with pine 0%, spruce 80% and broadleaf 20%. The mean diameter (quadratic) of the stand is 12.2 cm. A thinning operation is to be carried out for the stand, and the logging residues (tops and braches) will be extracted for energy use. Thinning intensity is 35%. After thinning, 1300 trees per ha are left, with spruce 80% and 20% broadleaf. The mean diameter (quadratic) after thinning is 13.2 cm. Accordingly, the number of stems removed is 700 stem/ha. The associated biomass of logging residues is estimated (by the App) to be 4.9 ton DM, or 10.7 m^3 solid volume per ha. Residues are forwarded to road side, with average distance 400 meters. Then, the forwarding time is estimated (by the APP) to be 1.6 G15-h per ha. Given a forwarder cost of 800 kr/G15-h per ha, the forwarding cost is estimated (by the App) to be 1286 kr per ha, or 5144 kr for the entire stand.

2. Installing and Applying the Decision Support Tool

System requirements

The Baltic ForBio app requires Microsoft windows 10, and .Net framework 4.6 or higher. The app installer will if the framework exists, and if not, will start to download the framework from internet and install it.

The app starts with a welcome page (Figure 1), allowing the user to choose the country in which the forest stand is located. After the country is selected, press button **Start**, the main page shows up. Note: if the user does not make a selection, the country saved in the previous run is chosen automatically.

Figure 1

In the main page, the user is waited for selecting which type of biomass (forest residues) to extract for energy use and for cost analysis. There are three options: 1) Logging residues from final felling, 2) Small trees from pre-commercial thinning, and 3) Logging residues from thinning.

2.1 Logging residues from final felling

To perform cost analysis for harvesting logging residues generated at final felling, select **logging residues from final felling** in box **Biomass Type** in the top of the page (Figure 2). Then, in Tab page **Stand and Biomass**, provide stand-level data describing the stand. This includes the following information. ***Property name*** - name for the stand (optional); ***Area*** - size of the stand to harvest; ***Age*** - the age at which the stand is for final felling; ***Standing volume*** - the growing stock measured in cubic meter standing volume per ha; ***Species share*** - percent volume distribution by tree species. While selecting or typing, the App calculates the amount of biomass residues (tops and branches) generated at final felling; the estimated biomass is provided in the table on the right-hand side of the page. The available biomass is expressed in three different units. In box **Extraction Rate** the user needs to specify what percent of the residues is going to extract for energy use (note: Swedish forestry agency recommends 20% of available logging residuals shall be left at site for biodiversity protection and nutrition purpose). As all the necessary information are

filled, the user can either select the tab **Production Method and Costs** or press the button **Next (**located at the bottom of page), switch to *page* **Production Method and Costs**.

In the page (Figure 3), the user needs provide technical and economic data necessary for calculating various costs of extracting logging residues.

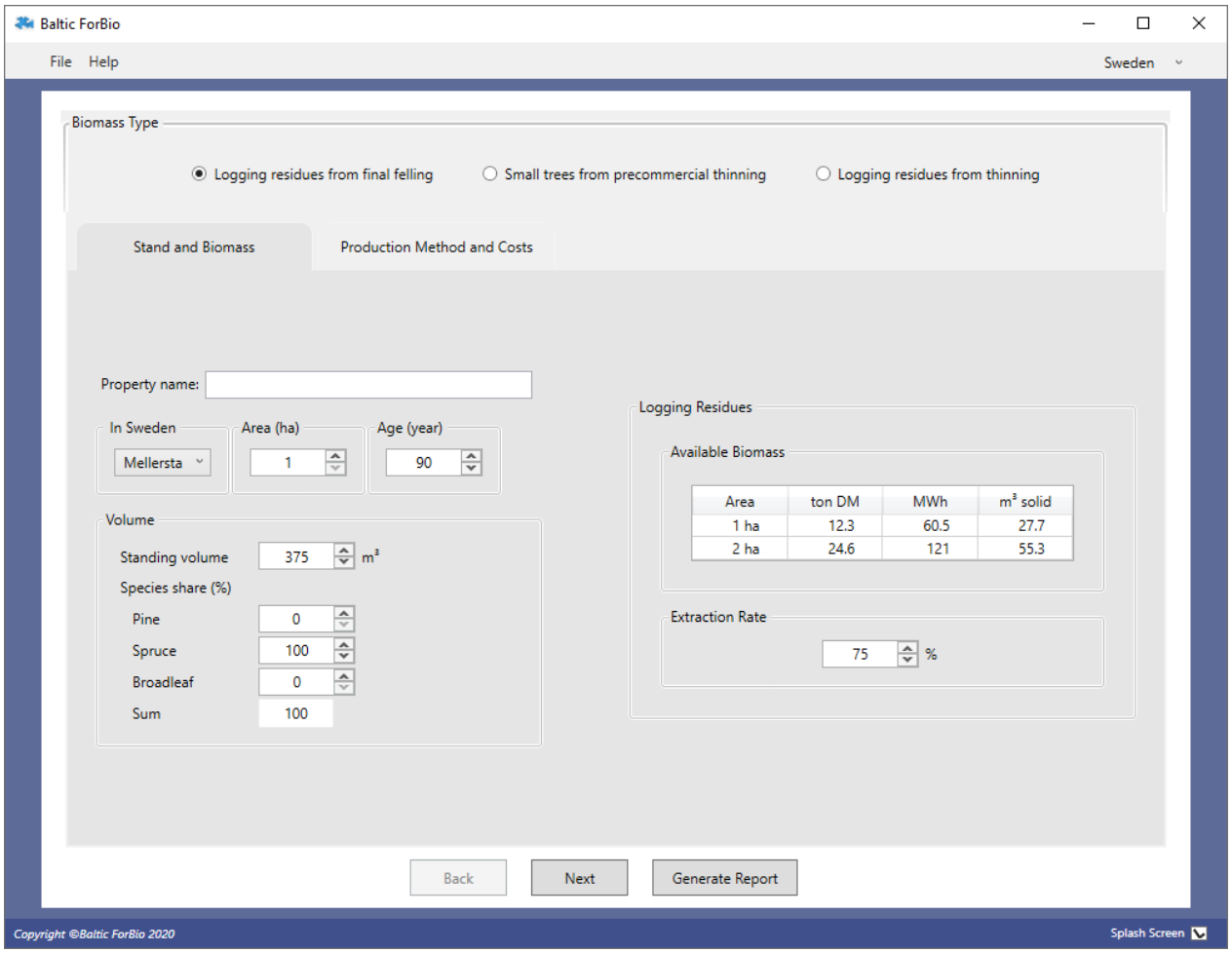


Figure 2

In box **Transportation Options**, choose where the biomass residues are sold and transportation method. ***at roadside***, the residues are paid at the roadside and no further transportation to carry out. This option accounts for only forwarding cost; ***at plant gate***, the residues are chipped at the roadside, then chips are further transported by chip truck to plant, at which the biomass is paid. This option accounts for

forwarding cost, chipping cost and transportation cost. Additionally, data on **Distance to plant gate**, **Transporter cost,** and **Chipping cost** are required to specify; ***at plant gate with loose***, the biomass is further transported in the form of loose residues to plant and is paid at the gate. This option accounts for forwarding cost and transportation cost. When selected, data on **Distance to plant gate and transporter cost** are required in order to calculate the transporting cost. **Transporting time** (in hours) consumed by transporting the residues from roadside to the plant gate is calculated by the app.

In box **Forwarding** the user can input information regarding forwarding the biomass residues to the roadside. ***Load volume*** is the capacity size of the forwarder, ***Forwarding distance*** is the average distance in meter from the center of the logging site to the roadside; ***Forwarder cost*** is the per hour cost for forwarding. ***Forwarding time*** (gross effective hour, G15, note: G0-h/G15-h = 0.92, ref: Olovsson, 2014) is the time consumed by forwarding activity and is calculated by the app.

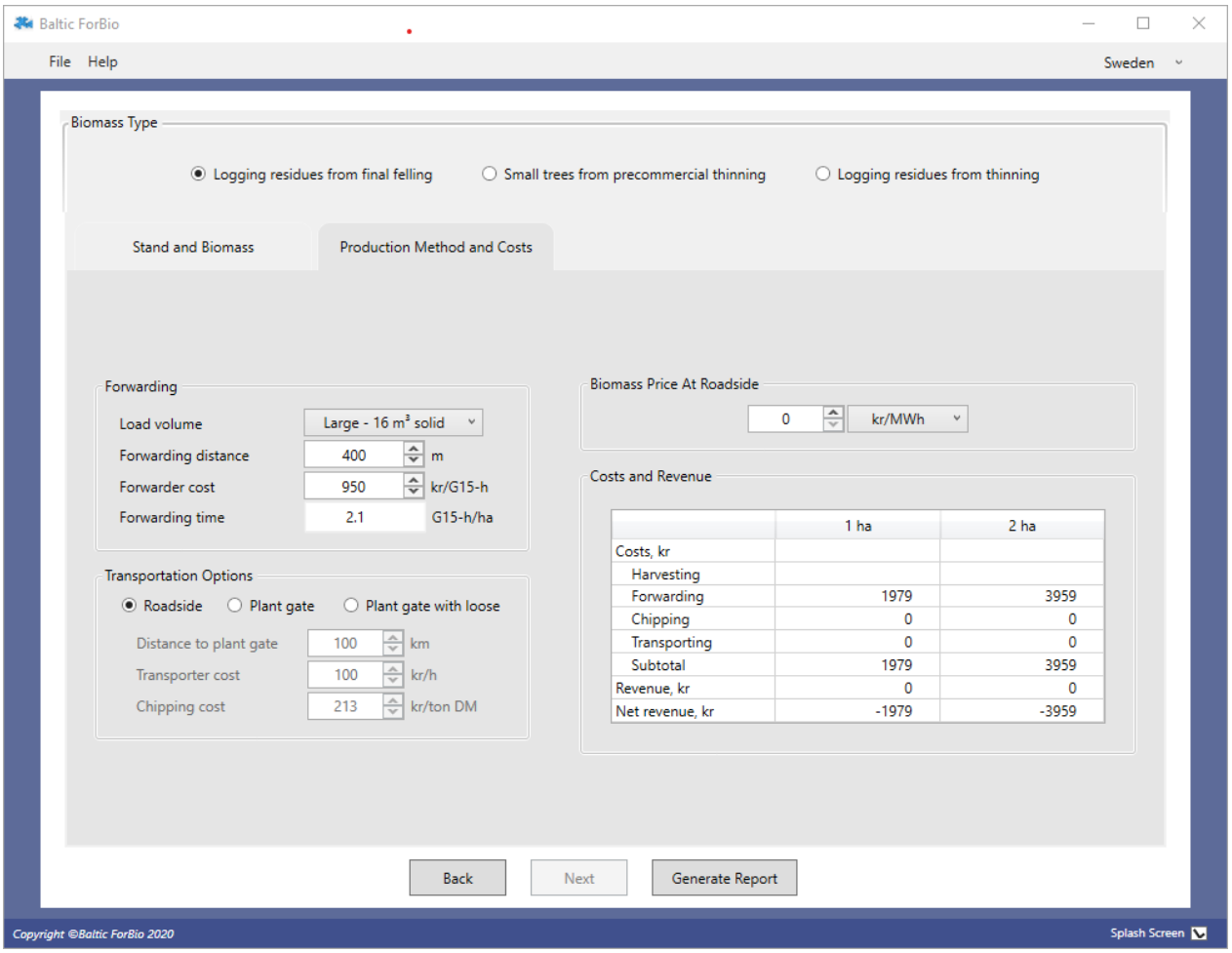


Figure 3

In box **Biomass Price**, the user can give the price for the biomass corresponding to the chosen delivery option in order to obtain the **Revenue** from selling the biomass. When price is not known, leave it be zero, then revenue will not be calculated.

In box **Costs and Revenue** is a summary shown. Costs may include harvesting cost (which is zero, when logging residues from final felling is chosen), forwarding cost, chipping cost and transporting cost. The sum of these costs are given in row subtotal. The net revenue is revenue minus total cost. In the table the first column shows the values in per ha, while the second column shows the total values for the whole stand.

Press the button **Generate Report**, a report page will be generated and the tab **Report** is open. The reports provides three tables (Figure 4). The first table summarizes the revenue and cost table; the second presents the stand data; the third presents the technical and economic data. The user can save the report in a pdf file, or print it to paper.

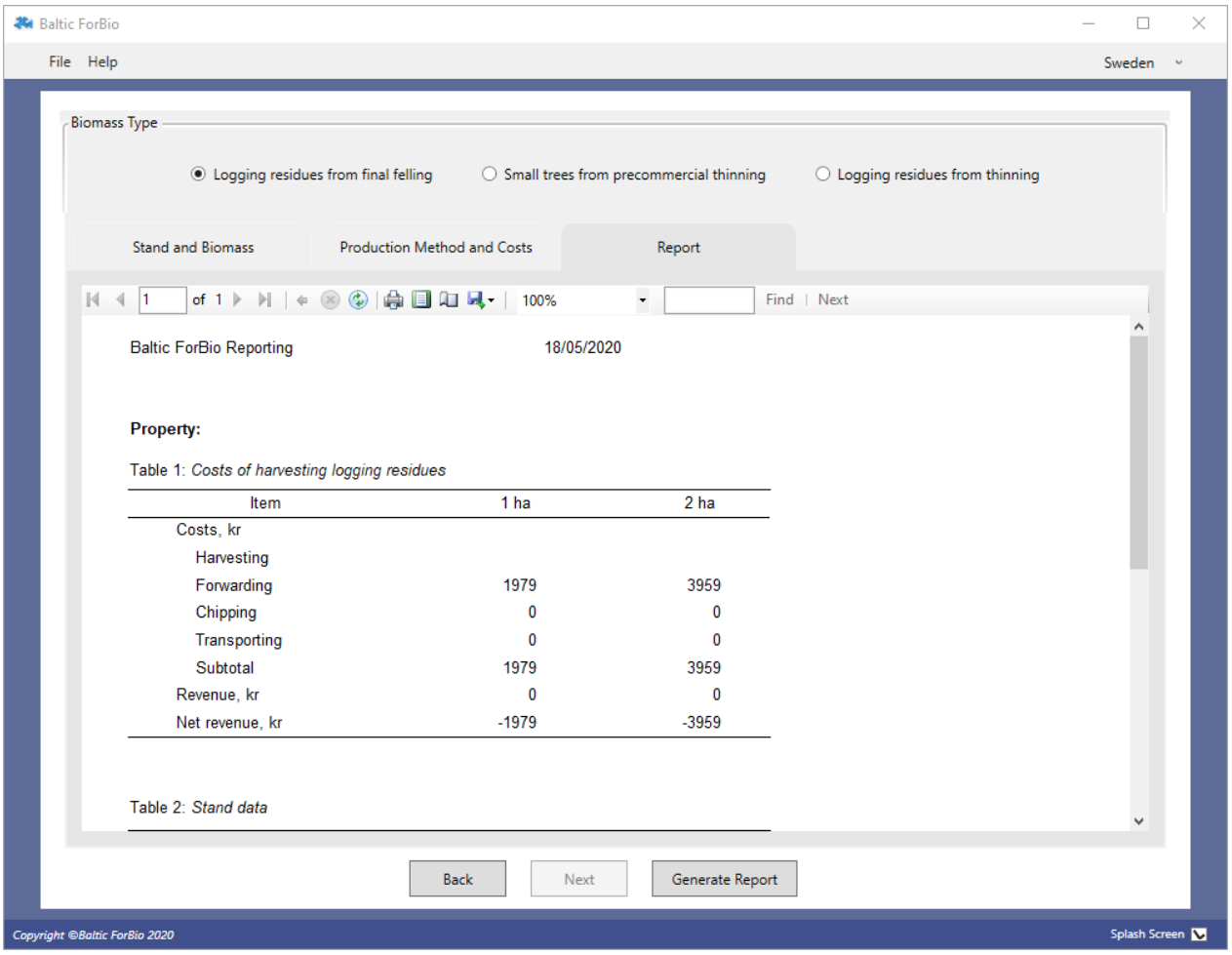


Figure 4

2.2 Small trees from pre-commercial thinning

Utilizing small trees from from pre-commerical thinning as bioenergy is to use all biomass of the trees removed from precommerical thinning. The costs can include cutting the small trees, forwarding the trees to roadside, and/or chipping and transporting the biomass further to plant gate. Harvest machines includes standard machine or small machine. When standard machine is used, alternative cutting methods includes whole trees method and delimbed wood wood.

To perform costs analysis, select **small trees from pre-commercial thinning** in **Biomass Type** in the top of the page (Figure 5). In Tab page **Stand and Biomass**, provide stand-level data describing the stand for final felling. This includes the following information. ***Property name*** - name for the stand (optional); ***Area*** - size of the stand to harvest; ***Age*** - the age at which the stand for pre-commercial thinning.

In box **Stem**, **Thinning intensity** is the rato of the removed stem number to the stem number before precommericail thinning; Data decribing the stand before thinning and after are required. **Stem per ha** -

the total stem number of the stand per ha before thinning in column before, and the stem numbe after thnning. **Species share** - the stem share of each trees species in the total stem number. Mean diameter is the diamter of the stand before and after thinning, where qudratic mean diameter (which is correspoind the diameter of a tree with mean basal area) should be used.

The biomass of the removed small tress is shown on the right hand side. It is assumed all the biomass are extracted as bioenergy.

As all the necessary information are filled, the user can either select the tab **Production Method and Costs** or press the button **Next (**located at the bottom of page), switch to *page* **Production Method and Costs**.

In box **Harvesting** (Figure 6), the user needs choose which type of machine from standard machine or small machine. If samll machne is selected, the user is asked to input the productivity of the machine, i.e., the solid volume harvested per working hour by the machine. If standared machine is chosen, additional information is required. Which type of **Cutting Method** is used either whole trees or delimbed wood. ***Harvester cost*** is per hour cost and needs input by the user. ***Harvesting time*** is the time taking in cutting the small tree in thinning and be calculated by the program.

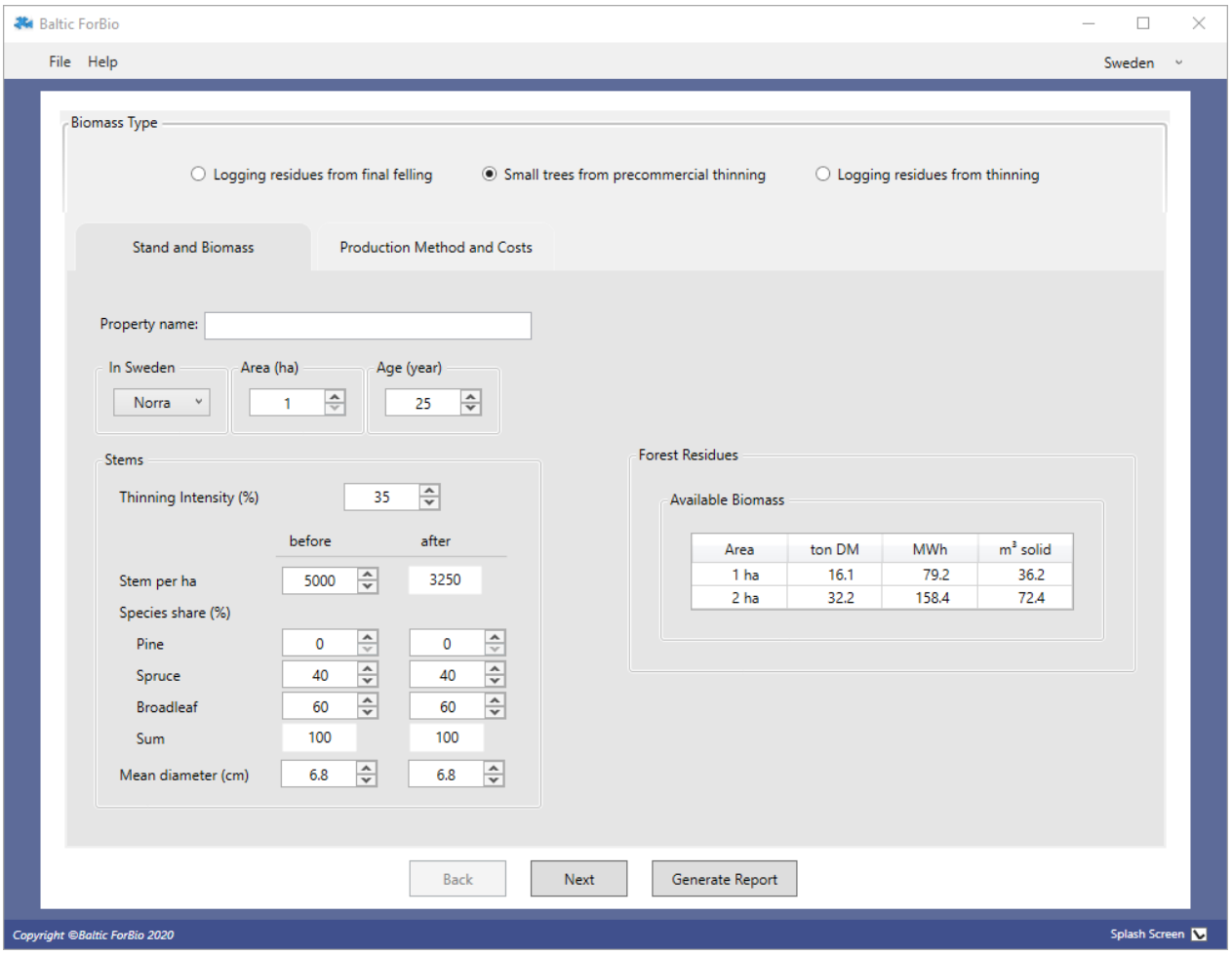
In box **Forwarding** the user can input information regarding forwarding the biomass residues to the roadside. ***Load volume*** is the capacity size of the forwarder, ***Forwarding distance*** is the average distance in meter from the center of the logging site to the roadside; ***Forwarder cost*** is the per hour cost for forwarding. ***Forwarding time*** is the time consumed by forwarding activity and is calculated by the app.

In box **Transportation Options**, choose where the biomass residues are sold and transportation method. ***At roadside***, the residues are paid at the roadside and no further transportation to carry out. This option accounts for only forwarding cost; ***at plant gate***, the residues are chipped at the roadside, then chips are further transported by chip truck to plant, at which the biomass is paid. This option accounts for forwarding cost, chipping cost and transportation cost. When selected, data on **Distance to plant gate**, **Transporter cost,** and **Chipping cost** are required to specify; ***at plant gate with loose***, the biomass is further transported in the form of loose residues to plant and is paid at the gate. This option accounts for forwarding cost and transportation cost. When selected, data on **Distance to plant gate and transporter cost** are required in order to calculate the transporting cost. **Transporting time** (in hours) consumed by transporting the residues from roadside to the plant gate is calculated by the App.

In box **Biomass Price**, the user can give the price for the biomass corresponding to the chosen option in order to obtain the **Revenue** from selling the biomass. When price is not known, leave it be zero, then revenue will not be calculated.

In box **Costs and Revenue** is a summary shown. The costs may include harvesting cost (if there is), forwarding cost, chipping cost and transporting cost. The sum of these costs are given in row subtotal. The net revenue is revenue minus total cost. In the table the first column shows the values in per ha, while the second column shows the total values for the whole stand.

Press button **Generate Report**, a report page will be generated and the tab **Report** is open. The reports provides three tables (Figure 7). The first table summarizes the revenue and costs; the second presents the stand data; the third presents the technical and economic data. The user can save the report in a pdf file, or print it to paper.


Baltic ForBio
File
Help
Sweden
Biomass Type
Logging residues from final felling
Small trees from precommercial thinning
Logging residues from thinning
Stand and Biomass
Production Method and Costs
Property name:
In Sweden
Norra
Area (ha)
1
Age (year)
25
Stems
Thinning Intensity (%)
35
before
after
Stem per ha
5000
3250
Species share (%)
Pine
0
0
Spruce
40
40
Broadleaf
60
60
Sum
100
100
Mean diameter (cm)
6.8
6.8
Forest Residues
Available Biomass
Area
ton DM
MWh
m³ solid
1 ha
16.1
79.2
36.2
2 ha
32.2
158.4
72.4
Back
Next
Generate Report
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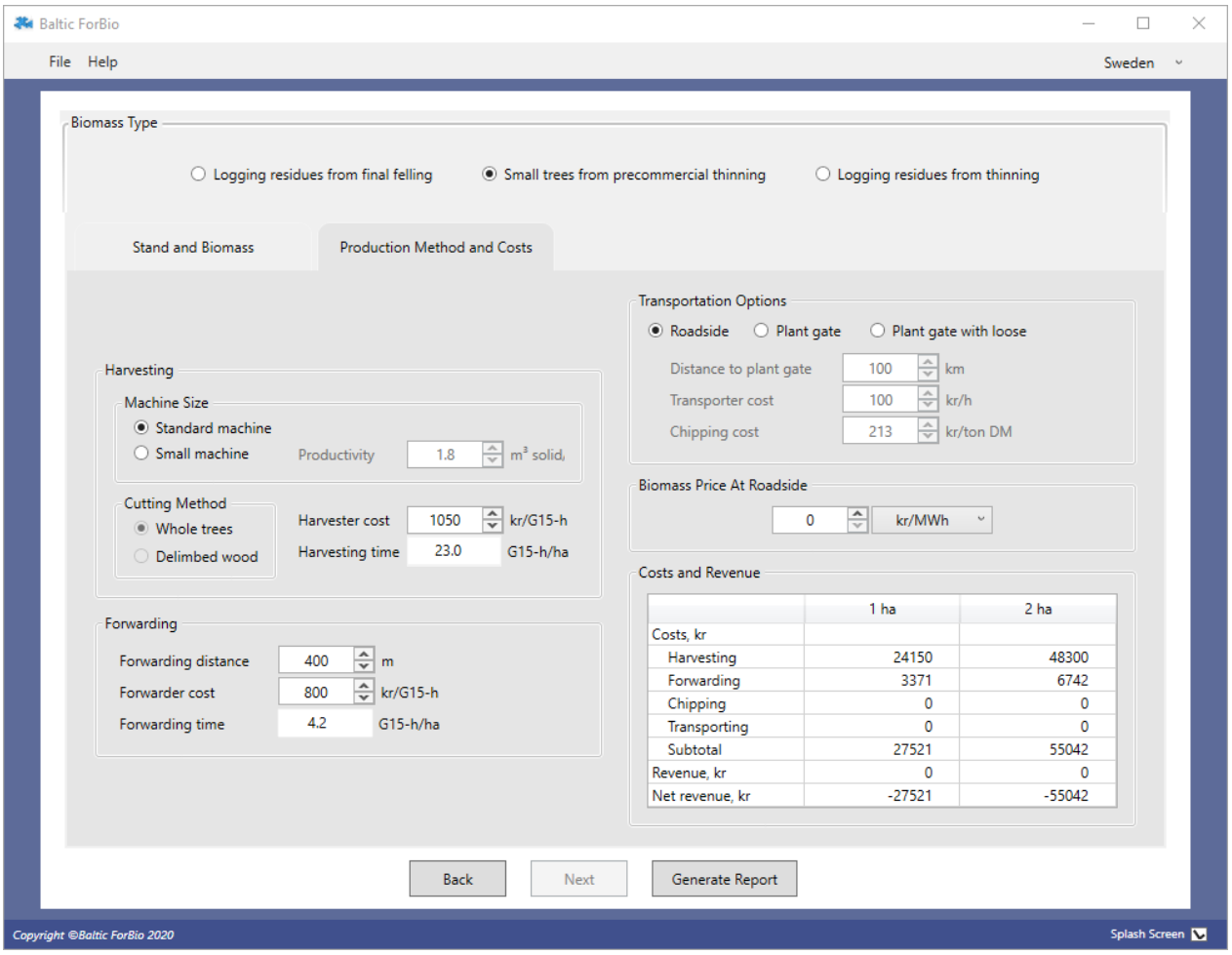
Splash Screen

Figure 5


Baltic ForBio
File
Help
Sweden
Biomass Type
Logging residues from final felling
Small trees from precommercial thinning
Logging residues from thinning
Stand and Biomass
Production Method and Costs
Harvesting
Machine Size
Standard machine
Small machine
Productivity
1.8
m³ solid,
Cutting Method
Whole trees
Delimbed wood
Harvester cost
1050
kr/G15-h
Harvesting time
23.0
G15-h/ha
Forwarding
Forwarding distance
400
m
Forwarder cost
800
kr/G15-h
Forwarding time
4.2
G15-h/ha
Transportation Options
Roadside
Plant gate
Plant gate with loose
Distance to plant gate
100
km
Transporter cost
100
kr/h
Chipping cost
213
kr/ton DM
Biomass Price At Roadside
0
kr/MWh
Costs and Revenue
1 ha
2 ha
Costs, kr
Harvesting 24150 48300
Forwarding 3371 6742
Chipping 0 0
Transporting 0 0
Subtotal 27521 55042
Revenue, kr 0 0
Net revenue, kr -27521 -55042
Back
Next
Generate Report
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Splash Screen

Figure 6

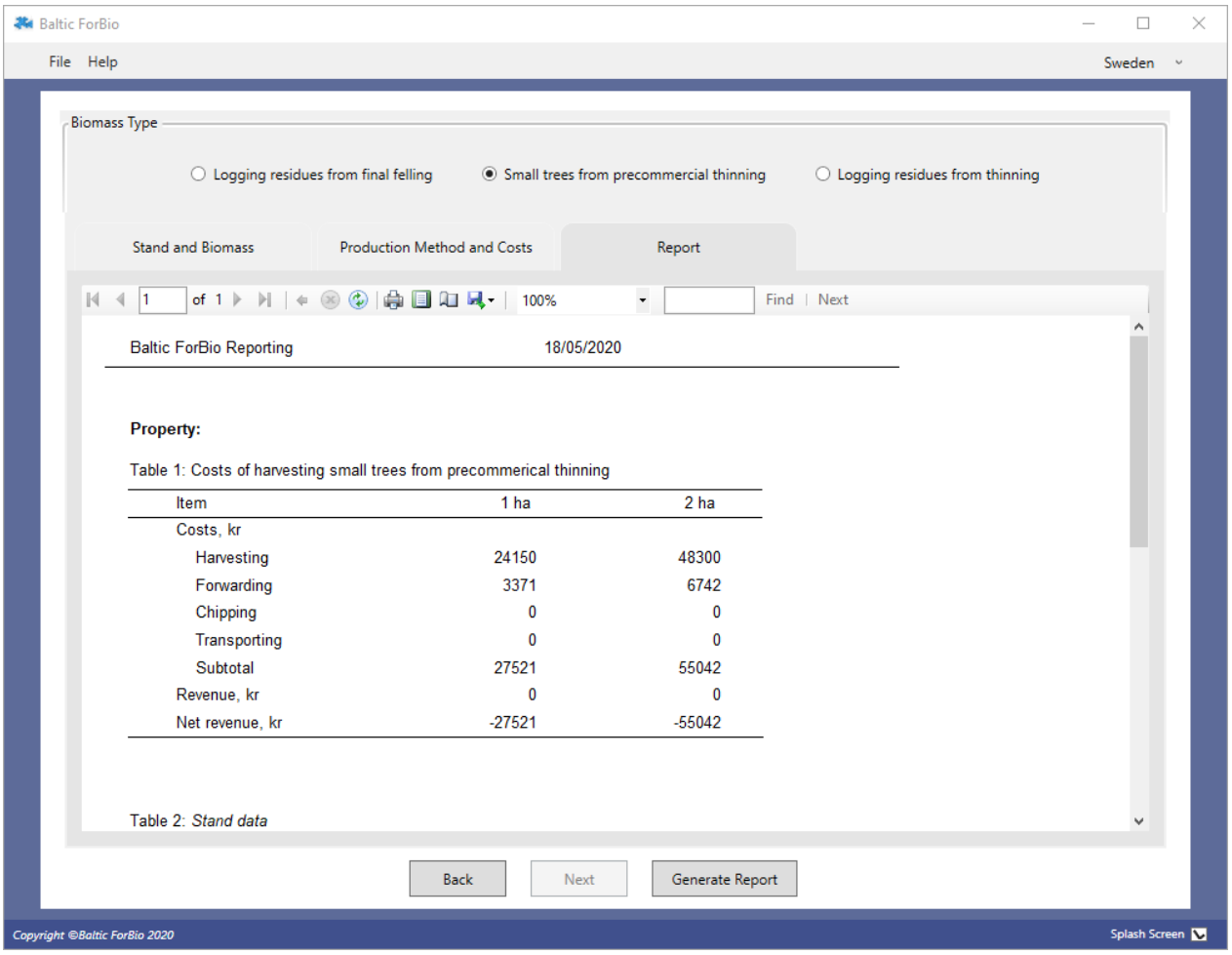


Figure 7

2.3 Logging residues from thinning

Residues from commerical thinning is the biomass that consists of tops and branches from the harvested trees in thinning. Costs of extracting such residues can include the cost of forwarding the residues to roadside, and/or chiping the residues at roadside, and transporting the biomass further to plant. Data are required to decribe the stand before and after thinning action.

To perform costs analysis, select **logging residues from thinning** in **Biomass Type** in the top of the page (Figure 8). In Tab page **Stand and Biomass**, provide stand-level data describing the stand for thinning. This includes the following information. ***Property name*** - name for the stand (optional); **In Country Name -** stand location in the country; ***Area*** - size of the stand to harvest; ***Age*** - the age at which the stand for thinning;

In page **Stand and Biomass**, data descring the stand before and after thinning is required. ***Property name*** is identity of the stand, which is optional. The ***Area*** of the stand for thinning, and **Age** of the stand.

Stem per ha - the total stem number per ha of the stand before thinning. **Thinning intensity** - the ratio of removed stem number to the stem number before thinning. **Species share** - the share of each tree species in the total stem number in percent. The shares should be given for the stand before (column before) and after (cloumn after) thinning. Mean diameter is the mean diameter in the term of quadric mean of the trees in the stand before or after thinning.

The biomass of residues is provided in the box **Logging residues**. It is assumed all the biomass is extracted out for energy use.

As all the necessary information are filled, the user can either select the tab **Production Method and Costs** or press the button **Next (**located at the bottom of page), switch to *page* **Production Method and Costs**.

At the right-hand side of the page (Figure 9), in box **Forwarding** the user can input information regarding forwarding the biomass residues to the roadside. ***Load volume*** is the capacity size of the forwarder, ***Forwarding distance*** is the average distance in meter from the center of the logging site to the roadside; ***Forwarder cost*** is the per hour cost for forwarding. ***Forwarding time*** is the time consumed by forwarding activity and is calculated by the app.

In box **Transportation Options**, choose where the biomass residues are sold and transportation method, if needed. ***At roadside*** should be selected if the residues are paid at the roadside and no further transportation. This option accounts for only forwarding cost; ***at plant gate*** should be selected if the residues are chipped at the roadside, then chips are further transported by chip truck to plant, at which the biomass is paid. This option accounts for forwarding cost, chipping cost and transportation cost. Data on **Distance to plant gate**, **Transporter cost,** and **Chipping cost** are required to specify; ***at plant gate with loose*** should be selected if the residues is further transported in the form of loose residues to plant and is paid at the gate. This option accounts for forwarding cost and transportation cost. Data on **Distance to plant gate and transporter cost** are required in order to calculate the transporting cost. **Transporting time** is the hours consumed by transporting the residues from roadside to the plant gate calculated by the app.

In box **Biomass Price**, the user can give the price for the biomass corresponding to the chosen option in order to obtain the **Revenue** from selling the biomass. When price is unknown, leave it be zero, and revenue will not be accounted.

In box **Costs and Revenue** is a summary shown. The costs may include harvesting cost (if there is), forwarding cost, chipping cost and transporting cost. The sum of these costs are given in row subtotal. The net revenue is revenue minus total cost. In the table the first column shows the values in per ha, while the second column shows the total values for the whole stand.

In page **Report**, a summuary on the costs and revenue is provided. The report consists of three tables. The first table summarizes the costs and revenue for extracting logging residues from thinning; the second table provides a summary of the stand data; the third table for the economcia and operational data.

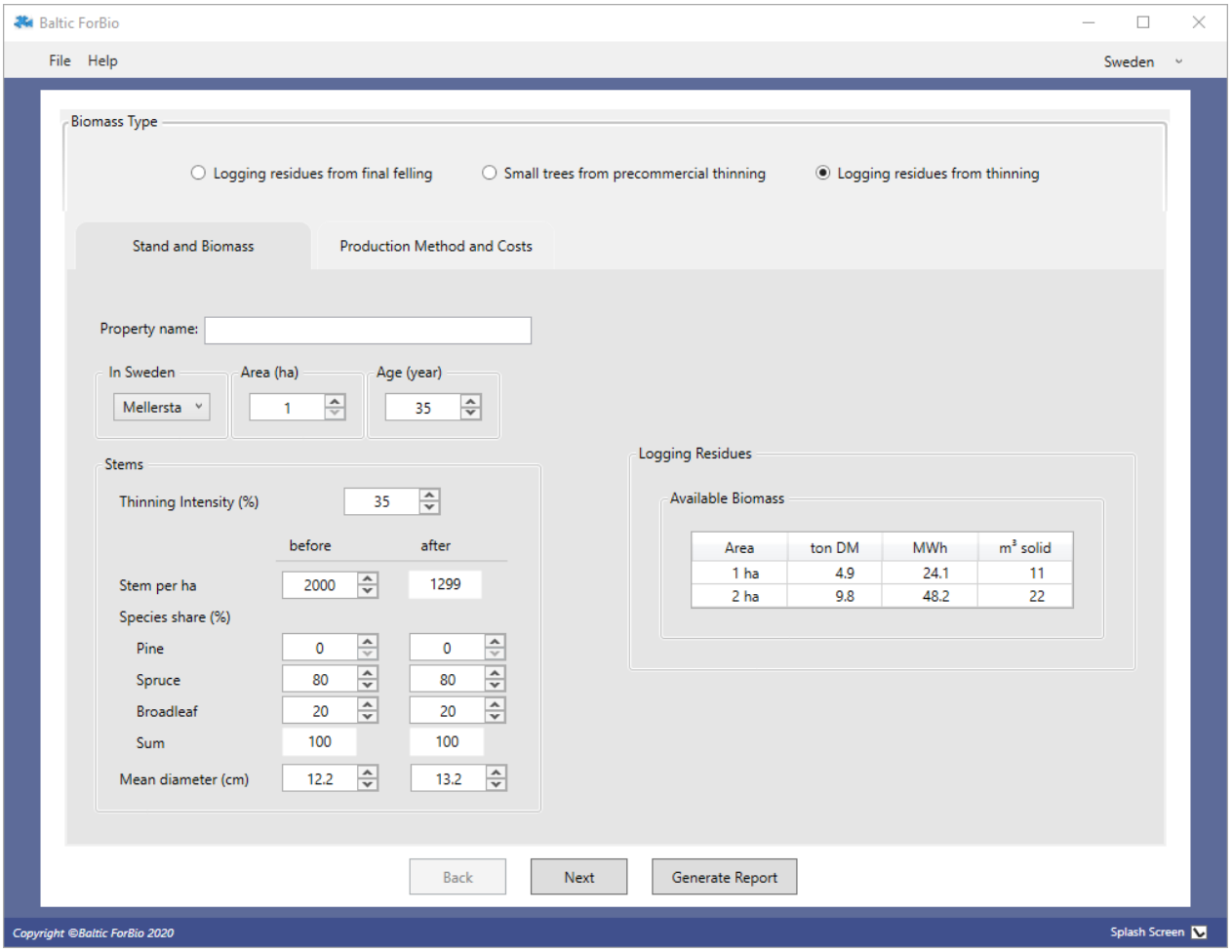


Figure 8

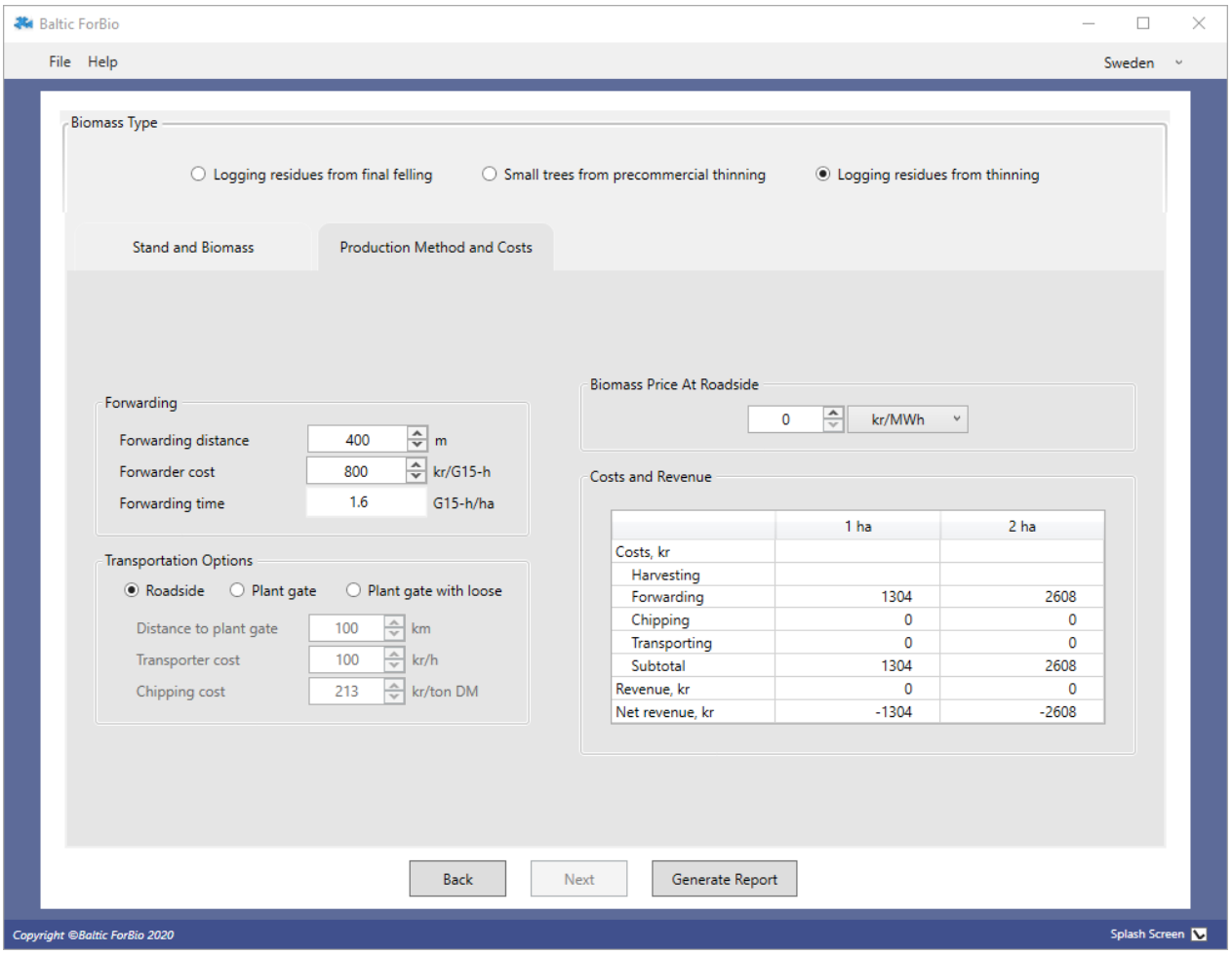
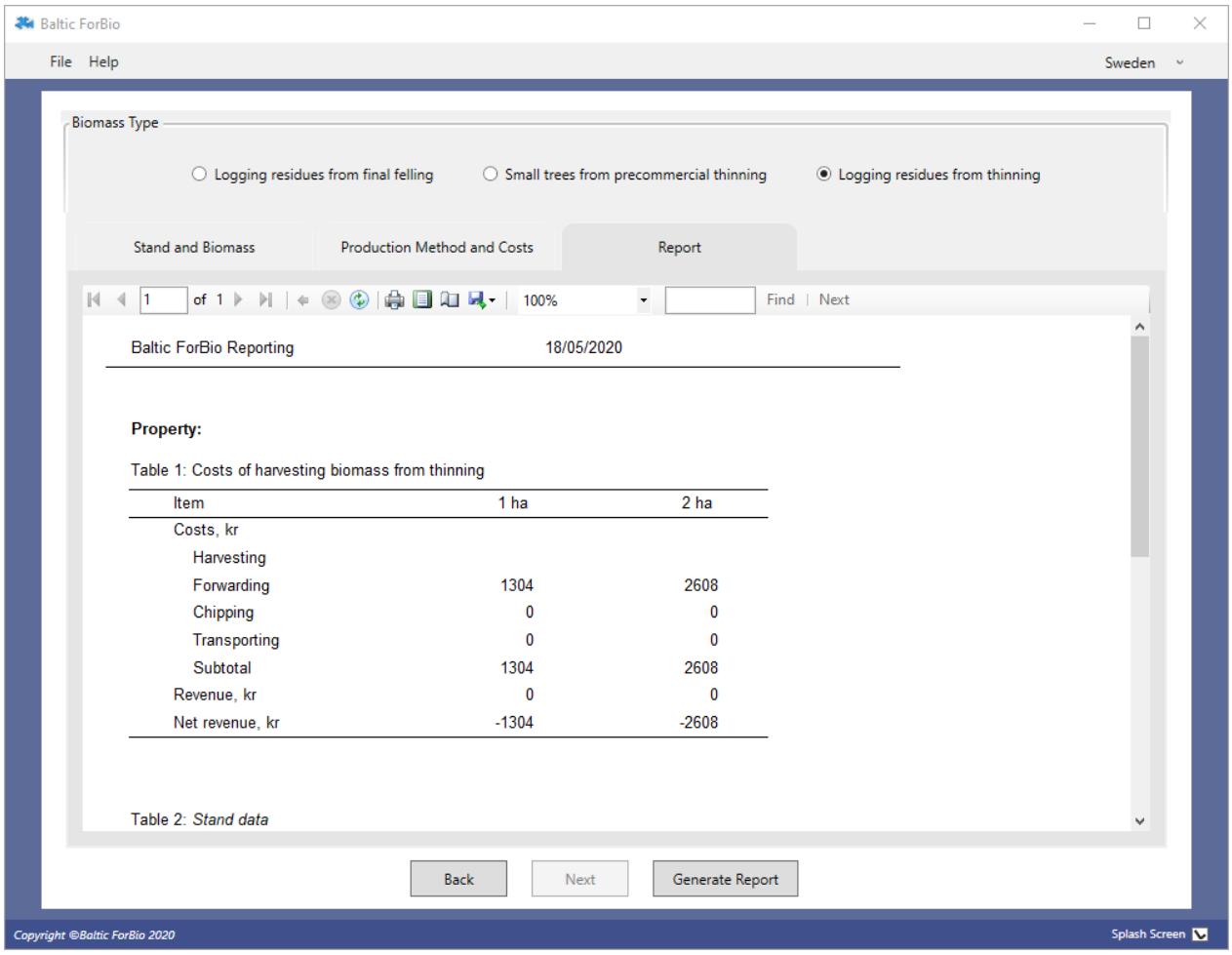


Figure 9

Press the button **Generate Report**, a report page will be generated and the tab **Report** is open. The reports provides three tables (Figure 10). Table 1 is the revenue and cost table, table 2 presents the stand data, table 3 presents the technical and economic data. The user can save the report in a pdf file, or print it to paper.


Baltic ForBio
File Help
Sweden
Biomass Type
Logging residues from final felling
Small trees from precommercial thinning
Logging residues from thinning
Stand and Biomass
Production Method and Costs
Report
1 of 1
100%
Find | Next
Baltic ForBio Reporting 18/05/2020
Property:
Table 1: Costs of harvesting biomass from thinning
Item 1 ha 2 ha
Costs, kr
Harvesting
Forwarding 1304 2608
Chipping 0 0
Transporting 0 0
Subtotal 1304 2608
Revenue, kr 0 0
Net revenue, kr -1304 -2608
Table 2: Stand data
Back
Next
Generate Report
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Splash Screen

Figure 10

3. FQA

1.1 How can I start a cost analysis for harvesting forest residues using default values set by the App?

Choose File > New. Then, all are set to default values.

1.2 How can I save my current work to file?

To save your current data, choose File > Save. By default, the property name, if you typed, will be suggested as a file name. Anyhow, you can always type a name.

1.3 How can I use my saved data?

To start with your data previously saved by the App, choose File > Open. Then find the file you saved before.

1.4 What happens if I quit the App by choosing File > Exit?

If you close the App by clicking Exit, the App will automatically save your current work. The advantage is that the App will recover you work, when you run it next time and without choose a different country.

1.5 What happens if I skip selecting a country at the welcome page?

In this case, the App will recover the work when you quit the App by clicking Exit previously.

1.6 What happens if quit the App by choosing File > Exit and Clear?

In this case, you close the App without saving your work. Additionally, the App will clean the work and set all to default values.

1.7 Is it possible to disable the welcome page?

Yes. At the bottom right corner of the main window, uncheck the splash box, the welcome page will not show up.

1.8 How can I enable the welcome page?

At the bottom right corner of main window, check the splash box, then the welcome page will show up next time when you run the App.

1.9 Can I update the default values in the tool?

Yes.

Choose Help > Configuration File Manger > Select a Country

Click button Download to download the Configuration File for the country, and save the file.

Edit the values in the download xml file using Notepad or WordPad. (note: only values can be changed. Any others like unit are not allowed to change.) Save the file.

Click button Upload to update the file.

4. References

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Appendix

Appendix 1.1 Calculation of biomass from logging residues from final felling

Logging residues from final felling consist of branches and tops, needles and stumps. The amount is estimate using the stand-level biomass function for tree components Lehtonen etc al. (2004). In calculation, only biomass from tops and branches are accounted for. The biomass of branches and stems are estimated based on standing volume and using function (3) of Lehtonen etc al. (2004), where components' biomass is a function of stem volume. The biomass of branches and stems are estimated using the function separately; the tops biomass is assumed to be 5% of the stem biomass.

Appendix 1.2 Estimation of biomass from small trees from pre-commercial thinning

To calculate the biomass of removed small trees, individual tree biomass functions of Marklund (1988) are used. The tree biomass consists of branches, stems and tops. The biomass of branches, and stems are estimated from tree's diameter, separately. The amount of tree's top biomass is assumed to be 5% of its stem biomass. The diameter of removed trees is calculated by using the following formula:

$$d_h = \sqrt{\frac{d_b^2 - (1-\theta)d_a^2}{\theta}}$$

Where d_b, d_a are quadratic mean diameter (i.e., dg, basal area mean diameter) of the stand before and after thinning, respectively? θ is thinning intensity, the ratio of the stem number of removed trees to the stem number before thinning. For pine trees, Marklund (1988)'s functions T13, T17, T21 and T1 are used for living branches including needles, for needles, for dead braches and for stem, respectively; For spruces tree, Marklund (1988)'s functions G11, G15, G19, and G1 are used for living branches including needles, needles, dead branches, and for stem, respectively; for broadleaf trees, Marklund (1988)'s function B11, B15, and B1 are used for living branches, dead branches, and stem, respectively.

Appendix 1.3 Estimation of biomass from logging residues from commercial thinning

The biomass of logging residues from thinning is estimated by using the same function of Marklund (1988) as for small trees from pre-commercial thinning.

Appendix 1.4 Estimation of average volume of growing trees

In calculating time consumption of cutting small trees, the single tree volume functions of Brandel (1990) are used to calculate the average volume of removed trees. We use functions (nr: 100-01) with two independent variables diameter and height. The height of trees is estimated by using height-diameter relationship function of Sharma and Breidenbach (2015), where OLS estimation of Eq. 4 are used.

Appendix 1.5 Calculation of transporting time

The time spending on transporting chipped residues or residues with loose are estimated using following formula.

$$\frac{2*D}{S} * UT/L$$

Where D is the distance in km from the roadside to the plant, S is the speed of transport vehicle in km/hour, UT is the amount of residues in m^3 solid, and L is the load space of the vehicle in m3 solid.

Appendix 2 Conversion factors

	ton DM	MWH	m^3 loose	m^3 solid
Logging residues	1	4.812	15.664	2.193
Whole trees	1	4.771	10.823	2.381

Source: https://www.skogskunskap.se/rakna-med-verktyg/skogsbransle/wecalc---energisnurran/

Appendix 3 Definitions

List of term definitions

G15-hour	Gross effective working hour with breaking time less than 15 minutes
Logging residues	Tops and branches of felled trees, usually left in the forest
Small trees	Small sized trees removed in pre-commercial thinning
Mean diameter	The mean diameter in the term of quadric mean of the trees in the stand, which corresponding the diameter of a tree with average basal area
Thinning intensity	The ratio of removed stem number to the stem number before thinning.