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Climate change mitigation potential of trees in shelter belts of drainage ditches in cropland and grassland

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Latvian State Forest Research Institute SILAVA

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Ltd "Latvian Rural Consultation and Education Center"

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REPORT

Optimization of assortments structure and removals of CO_2 in harvested wood products[1]

Salaspils, 2023

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Contents

Introduction

The Paris agreement temperature targets takes massive cuts to GHG emissions within following decades. Even more, the (EU) regulation 2018/841 proposes GHG neutrality target after 2050 to implement flexibility rules implemented in the regulation. These policies increases demand of biomass for bioeconomy needs inducing energy, industry and even agriculture sector. Implementation of these policies requires urgent actions already now to increase efficiency of utilization of land resources and to develop new pools of biomass.

Increasing demand and prices of solid biofuel, risks associated with deliveries of imported energy carriers and climate change mitigation targets set by the Paris agreement (Krug, 2018) determine the necessity to utilize more actively alternative sources of energy including the shelter belts by transforming them from windbreaks and low valuaded rows of trees into intensively producing biomass factories, while providing other ecosystem functions crucially important for agricultural landscapes. The growing role of bioeconomy and biomass as a primary resource enhances creation of new and improvement of existing technologies necessary for the production targeted shelter belts.

Use of biomass in energy sector in Latvia in 2022 was 54 PJ (29% of the total energy consumption) and it should be **increased in 2030 by 42%** (to 91 PJ). To reach this target new types of resources should be developed, as well as new technologies should be implemented to increase efficiency of biofuel production.

The potential area of the biomass producing shelter belts in Latvia in cropland and grazing land is about 44 kha. The climate change mitigation potential of the shelter belts is about **0.75 mill. CO_2 eq. yr**. The potential area of the biomass producing shelter belts depends from design of planting, which in its turn depends from width of a belt necessary to ensure nutrient retention from farm fields and optimal conditions for mechanization of production.

The scope of this study is to elaborate tool for optimization for climate smart management of the shelter belts by playing with different tree species and rotation periods, as well as by changes of proportion of shubs and trees based shelter belts.

Calculation of timber production and GHG emissions in woody shelter belts

Basic assumptions

The assumptions in Table 1 are used for the forecast of the yield of wood products, including lumber [1] and panel wood [2] yield from saw logs, amount of woodworking residues [3] transformed into wood biofuel after processing, as the relative proportion of round timber produced, as well as paper production by-products transformed into wood biofuel [5], as the relative proportion of pulpwood produced, and losses in the preparation of logging residues, as the relative proportion of crown biomass left in felling [6]. Preparation of stump biomass for biofuel production is not evaluated in the calculation. The coefficients are specific for the species and type of felling. Table 1 values are expert judgment. The proportion of bark is calculated from the volume of round timber. An expert's assumption is used in the calculation of the proportion of bark. Dominant tree species is parameter [1].

Table 1. Assumptions for characterizing the yield of wood products and logging residues

The dominant species	Type of chisel	Lumber yield from saw logs	Board wood yield from saw logs	Output of woodworking residues	The proportio n of bark	By-products of paper production	Logging residue losses
id		[1]	[2]	[3]	[4]	[5]	[6]
Spruce	Thinning	25%	25%	50%	9%	50%	50%
Pine tree		25%	25%	50%	9%	50%	50%
Birch		25%	25%	50%	9%	50%	50%

The dominant species	Type of chisel	Lumber yield from saw logs	Board wood yield from saw logs	Output of woodworking residues	The proportion of bark	By-products of paper production	Logging residue losses
Poplar hybrid		25%	25%	50%	9%	-	50%
Aspen		25%	25%	50%	9%	50%	50%
Black alder		25%	25%	50%	9%	-	50%
Other species		25%	25%	50%	9%	-	50%
Spruce	The main cut	25%	25%	50%	9%	50%	30%
Pine tree		25%	25%	50%	9%	50%	30%
Birch		25%	25%	50%	9%	50%	30%
Poplar hybrid		25%	25%	50%	9%	-	30%
Aspen		25%	25%	50%	9%	50%	30%
Aspen		25%	25%	50%	9%	50%	30%
Black alder		25%	25%	50%	9%	-	30%
Other species		25%	25%	50%	9%	-	30%

A timber yield forecast calculation is required if this data is not prepared by the AGM tool. Purpose of timber yield calculations The coefficients for predicting the yield of timber types are prepared according to the equations developed by JSC "Latvia's state forests", which take into account the type of felling, the dominant tree species and the average volume of the cut tree trunk without bark (JSC "Latvia's state forests", 2010). Calculation coefficients are given in Table 2.

Table 2. Coefficients for calculating the yield of timber types

Type of chisel	Species	Assortment	a	b	c	d
id			[7]	[8]	[9]	[10]
Main felling	Aspen	12-17.9	0.0339	-0.1105	0.0659	0.0250
		Firewood	-0.2724	1.1721	-1.4547	0.8198
		18-23.9	0.0626	-0.2308	0.2012	0.0076
		24 <	0.1093	-0.5102	0.6688	-0.0511
		PM 7-49.9	0.0666	-0.3206	0.5188	0.1986
	Birch	12-17.9	0.0677	-0.2084	0.1458	-0.0080
		Firewood	-0.0477	0.1578	-0.1253	0.0598
		FIA 18<	-0.0496	0.0916	0.0034	-0.0009
		FBI 18<	0.2414	-1.1339	1.3990	-0.1136
		PM 7-49.9	-0.2119	1.0927	-1.4229	1.0627
	Black alder	12-17.9	0.7819	-1.7200	0.9175	-0.0196
		Firewood	-0.9365	2.6240	-2.1950	1.1127
		18-23.9	0.5889	-1.5957	1.1145	-0.0752
		24 <	-0.4343	0.6916	0.1630	-0.0179
	Poplar hybrid	12-17.9	0.6569	-1.4486	0.7090	0.0819

Type of chisel	Species	Assortment	a	b	c	d
		Firewood	-1.2127	3.0268	-1.9295	0.9740
		18-23.9	0.5558	-1.5782	1.2204	-0.0559
	Pine tree	10-13.9	0.0542	-0.1287	0.0462	0.0351
		14-17.9	0.2436	-0.6652	0.4115	0.0605
		Firewood	-0.5307	1.7369	-1.7533	0.5643
		18-27.9	0.6905	-2.3510	2.1808	-0.1459
		28<	-0.2041	0.5633	-0.0721	0.0015
		A 28<	-0.0709	0.1384	0.0043	-0.0022
		Poles 18<	0.0024	-0.0104	0.0113	-0.0022
		Low grade saw logs 18<	0.0209	-0.0571	0.0919	0.0039
		PM 7-49.9	-0.2060	0.7739	-0.9204	0.4850
	Spruce	10-13.9	0.2120	-0.0472	-0.2098	0.1186
		14-17.9	1.9789	-2.5517	0.7940	0.0626
		6-9.9	0.0627	-0.0360	-0.0214	0.0118
		Firewood	-0.1404	0.1497	-0.0500	0.0702
		18-27.9	3.2228	-5.0622	2.4443	-0.0550
		28<	-0.2904	0.1783	0.5099	-0.0321
		Low grade saw logs 18<	-0.0763	-0.0077	0.1452	0.0033
		PM 7-49.9	-4.9692	7.3769	-3.6122	0.8205
Thinning	Aspen	12-17.9	0.5592	-1.1869	0.6358	-0.0191
		Firewood	2.0856	-1.2707	-0.7086	0.7343
		18-23.9	0.5933	-1.1952	0.6079	-0.0311
		24 <	-0.3895	0.3742	0.0399	-0.0041
		PM 7-49.9	-2.8485	3.2786	-0.5750	0.3200
	Birch	12-17.9	0.6263	-0.6459	0.1659	-0.0037
		Firewood	3.4293	-1.4652	-0.0487	0.0901
		FBI 18<	-1.9262	1.5544	-0.0727	0.0022
		PM 7-49.9	-2.1299	0.5569	-0.0445	0.9114
	Black alder	12-17.9	3.9099	-6.1471	2.4010	-0.0820
		Firewood	0.4936	2.5091	-2.0793	1.0651
		18-23.9	-3.9167	3.3285	-0.3414	0.0202
		24 <	-0.4865	0.3092	0.0198	-0.0033
	Poplar hybrid	12-17.9	5.7592	-7.7544	2.7791	-0.0721
		Firewood	-6.4055	7.7060	-3.1357	1.0853
		18-23.9	0.6465	0.0483	0.3567	-0.0132
	Pine tree	10-13.9	1,1890	-2.3049	0.7424	0.0738
		14-17.9	1.8589	-4.0513	1.9056	-0.0330
		6-9.9	-0.3656	0.8966	-0.5953	0.1250

Type of chisel	Species	Assortment	a	b	c	d
		Firewood	-1.1057	2.1413	-0.8431	0.1926
		18-27.9	0.3739	-1.6720	1.7189	-0.0841
		28<	-0.3768	0.7335	-0.2015	0.0127
		A 28<	0.0074	-0.0163	0.0082	-0.0003
		Low grade saw logs 18<	0.5909	-0.6489	0.2101	-0.0085
		PM 7-49.9	-2.1720	4.9220	-2.9452	0.7218
	Spruce	10-13.9	11.6270	-9.5729	1.6378	0.0416
		14-17.9	13.2470	-12.5580	3.0184	-0.0612
		6-9.9	0.7843	0.0041	-0.4134	0.0957
		Firewood	-1.0618	0.3326	0.2256	0.0597
		18-27.9	4.4392	-5.8942	2.4259	-0.0883
		28<	0.7191	0.2455	-0.0370	0.0016
		Low grade saw logs 18<	-3.4646	2.8136	-0.3616	0.0181
		PM 7-49.9	-26.2910	24.6300	-6.4957	0.9328

Factors characterizing GHG emissions in forest lands for forest lands are given in Table 3. the values of the coefficients are determined by the dominant species, moisture regime and nutrient supply. GHG emissions from soil (CH_4 emissions from ditches, proportion of ditch area, CH_4 emissions from the rest of the area, N_2O emissions from soil and CO_2 emissions from soil) are calculated only for organic soils. Only in organic soils, the moisture regime and provision of nutrients are taken into account. Wood density, carbon content in wood, period of decomposition of dead wood, accumulation of carbon in the ground cover when reaching the equilibrium state, and the period of reaching the equilibrium state are species-specific indicators. However, in the GHG forecasting tool, all indicators can be predicted to be linked to moisture regime and nutrient supply, assuming that the empirical data set will improve in the future and the accuracy of forecasts can be improved.

GHG emissions and carbon accumulation circulation coefficients for non-forest lands are given in Table 4. Carbon accumulation of indicators in the biomass of ground cover plants in the steady state ([22] and [23]) is used in both mineral soils and organic soils. The other indicators are used only in organic soils. In the calculation, you can choose two variants of non-forest land – grassland and arable land. An additional parameter is organic soil or mineral soil. The calculation assumes that all organic soils in grasslands and arable lands have been meliorated.

Soil emission factors correspond to the results of LIFE REstore projects (Lazdiņa et al., 2019; Lazdiņš & Lupiķis, 2019; Lupiķis, 2019).

Table 3. Emission factors and coefficients characterizing carbon circulation in forest lands

The dominant species	Humidity mode	Provision of nutrients	Wood density, tons m^{-3}	Carbon in wood, tons per ton^{-1}	Decay period of dead wood, years	CH_4 emission factor for ditches, kg CH_4 ha^{-1} per year	Proportion of ditch area	CH_4 emission factor, kg CH_4 ha^{-1} per year	N_2O emission factor, kg N_2O ha^{-1} per year	CO_2 emission factor, tons of CO_2 ha^{-1} per year	Carbon storage in the ground cover, tons C ha^{-1}	Steady-state period, years
id			[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]
Spruce	Reclaimed	Good	0.4	0.5	40	217.0000	3%	-6.8992	1.7417	13.3409	12.1	150
Spruce	Reclaimed	Satisfactory	0.4	0.5	40	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Spruce	Too wet	Good	0.4	0.5	40			1.3467	0.5971	13.8380	12.1	150
Spruce	Too wet	Satisfactory	0.4	0.5	40			32.4505	0.0680	6.7820	12.1	150
Spruce	Dry	-	0.4	0.5	40						12.1	150
Pine tree	Reclaimed	Good	0.4	0.5	40	217.0000	3%	-6.8992	1.7417	13.3409	12.1	150
Pine tree	Reclaimed	Satisfactory	0.4	0.5	40.0	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Pine tree	Too wet	Good	0.4	0.5	40.0			1.3467	0.5971	13.8380	12.1	150
Pine tree	Too wet	Satisfactory	0.4	0.5	40.0			32.4505	0.0680	6.7820	12.1	150
Pine tree	Dry	-	0.4	0.5	40.0						12.1	150
Birch	Reclaimed	Good	0.5	0.5	20	217.0000	3%	-2.9200	1.5871	15.9170	12.1	150
Birch	Reclaimed	Satisfactory	0.5	0.5	20.0	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Birch	Too wet	Good	0.5	0.5	20.0			-1.1644	3.1114	13.2244	12.1	150
Birch	Too wet	Satisfactory	0.5	0.5	20.0			32.4505	0.0680	6.7820	12.1	150
Birch	Dry	-	0.5	0.5	20.0						12.1	150
Aspen	Reclaimed	Good	0.5	0.5	20	217.0000	3%	-2.9200	1.5871	15.9170	12.1	150
Aspen	Reclaimed	Satisfactory	0.5	0.5	20.0	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Aspen	Too wet	Good	0.5	0.5	20.0			-1.1644	3.1114	13.2244	12.1	150
Aspen	Too wet	Satisfactory	0.5	0.5	20.0			32.4505	0.0680	6.7820	12.1	150
Aspen	Dry	-	0.5	0.5	20.0						12.1	150

The dominant species	Humidity mode	Provision of nutrients	Wood density, tons m^{-3}	Carbon in wood, tons per ton^{-1}	Decay period of dead wood, years	CH_4 emission factor for ditches, kg CH_4 ha^{-1} per year	Proportion of ditch area	CH_4 emission factor, kg CH_4 ha^{-1} per year	N_2O emission factor, kg N_2O ha^{-1} per year	CO_2 emission factor, tons of CO_2 ha^{-1} per year	Carbon storage in the ground cover, tons C ha^{-1}	Steady-state period, years
Poplar hybrid	Reclaimed	Good	0.5	0.5	20	217.0000	3%	-2.9200	1.5871	15.9170	12.1	150
Poplar hybrid	Reclaimed	Satisfactory	0.5	0.5	20.0	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Poplar hybrid	Dry	-	0.5	0.5	20.0						12.1	150
Black alder	Reclaimed	Good	0.5	0.5	20	217.0000	3%	7.7714	0.9429	10.1017	12.1	150
Black alder	Reclaimed	Satisfactory	0.5	0.5	20.0	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Black alder	Too wet	Good	0.5	0.5	20.0			228.3429	3.9286	13.4200	12.1	150
Black alder	Too wet	Satisfactory	0.5	0.5	20.0			32.4505	0.0680	6.7820	12.1	150
Black alder	Dry	-	0.5	0.5	20.0						12.1	150
Other species	Reclaimed	Good	0.5	0.5	20	217.0000	3%	-2.9200	1.5871	15.9170	12.1	150
Other species	Reclaimed	Satisfactory	0.5	0.5	20.0	217.0000	3%	25.5898	-0.0751	4.2120	12.1	150
Other species	Too wet	Good	0.5	0.5	20.0			-1.1644	3.1114	13.2244	12.1	150
Other species	Too wet	Satisfactory	0.5	0.5	20.0			32.4505	0.0680	6.7820	12.1	150
Other species	Dry	-	0.5	0.5	20.0						12.1	150

Table 4. Emission factors and coefficients characterizing carbon cycle for organic soils in non-forest lands

Land use	**Steady-state carbon stock, tons C ha^{-1}**		**Carbon supply to the soil, tons C ha^{-1} per year**				**Proportion of ditch area**	**CH_4 emission factor for ditches, kg CH_4 ha^{-1} per year**	**CH_4 emission factor, kg CH_4 ha^{-1} per year**	**N_2O emission factor, kg N_2O ha^{-1} per year**	**CO_2 emission factor, tons of CO_2 ha^{-1} per year**
	surface	**undergrou nd**	**surface**	**undergrou nd**	**small roots**	**other income**					
id	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]
Arable land	4.4	0.9	2.7	0.6	0.3		5%	1165.0	2.0852	9.6643	15.9465
Lawn	3.2	1,2	0.9	0.5	0.7		5%	1165.0	26.5641	0.5029	11.7282

N_2O and CH_4 emissions are converted to CO_2 equivalents using the so-called IPCC Assessment report 5 (Table 5).

Table 5. CO_2 equivalents

GHG	id	CO_2 equivalent
CH_4	[32]	28
N_2O	[33]	265

The AGM tool can give calculation results in terms of stock, biomass or carbon stock or all of these indicators, but if the results are not available, the calculations are performed using coefficients from Table 6 that calculate trunk, above-ground, branch and underground biomass in the cross section of species. These coefficients were developed for the calculation of individual trees, and in this simplified calculation they are applied to the whole stand, so it is better to use the calculations of the AGM model, where the biomass can be calculated in the section of forest elements.

Table 6. Biomass conversion factors[2]

The dominant species	Biomass	a	b	c	d	e	m	k
id		[34]	[35]	[36]	[37]	[38]	[39]	[40]
Spruce	AGB	-0.5244	8.8563	0.0000	0.3879	0.0000	19.0000	1.0127
	SB	-2.5842	7.0769	0.0232	0.9631	0.0000	15.0000	1.0022
	BGB	-2.4967	10.8184	0.0000	0.0000	0.0000	14.0000	1.0388
Pine tree	AGB	-1.4480	8.7399	0.0000	0.5624	0.0000	16.0000	1.0086
	SB	-2.8125	7.1368	0.0118	1.1270	0.0000	15.0000	1.0053
	BGB	-3.2937	9.0334	0.0000	0.5353	0.0000	14.0000	1.0350
Birch	AGB	-2.1284	9.3375	0.0221	0.2838	0.0000	11.0000	1.0041
	SB	-2.9281	8.2943	0.0184	0.7374	0.0000	11.0000	1.0020
	BGB	-3.6432	0.0000	0.0000	0.0000	2.5127	0.0000	1.0060
Poplar hybrid	AGB	-1.9434	9.7506	0.0337	0.0000	0.0000	11.0000	0.9900
	SB	-2.8955	8.3896	0.0226	0.6148	0.0000	11.0000	1.0058
	BGB	-2.3114	10.3644	0.0000	0.0000	0.0000	15.0000	0.9917
Aspen	AGB	-1.9434	9.7506	0.0337	0.0000	0.0000	11.0000	0.9900
	SB	-2.8955	8.3896	0.0226	0.6148	0.0000	11.0000	1.0058
	BGB	-2.3114	10.3644	0.0000	0.0000	0.0000	15.0000	0.9917
Black alder	AGB	-1.6846	9.3412	0.0221	0.2489	0.0000	14.0000	0.9962
	SB	-2.4428	8.4713	0.0295	0.5315	0.0000	13.0000	1.0069
	BGB	-2.6672	0.0000	0.0000	0.0000	2.1004	0.0000	1.0145
Other species	AGB	-2.1284	9.3375	0.0221	0.2838	0.0000	11.0000	1.0041
	SB	-2.9281	8.2943	0.0184	0.7374	0.0000	11.0000	1.0020
	BGB	-3.6432	0.0000	0.0000	0.0000	2.5127	0.0000	1.0060

The carbon input with tree litter residues in forest lands in organic soils is calculated using Table 7 coefficients. Carbon input with ground cover plant residues in forest lands with organic soils is calculated using Table 8

[2]AGB – surface (SB+BB); SB – trunk; BGB – underground.

coefficients. These indicators are not calculated in mineral soils, where it is assumed that the soil carbon accumulation is in a state of equilibrium. Table 9, 10 and 11 includes maximum basal area values ([46], [52] and [58]). If the actual basal area area exceeds the maximum value, the maximum values from the relevant tables are used in the calculation.

Table 7. Coefficients for carbon input calculations with tree litter and fine roots

The dominant species	a	b	c	d	eh	Max. G, m^2 ha^{-1}
id	[41]	[42]	[43]	[44]	[45]	[46]
Spruce	-0.000008	0.000542	-0.011340	0.190236	0.000000	30.0
Pine tree	-0.000014	0.000969	-0.021880	0.245253	0.000000	30.0
Birch	0.000003	-0.000309	0.011431	-0.042937	0.000000	26.0
Aspen	0.000003	-0.000309	0.011431	-0.042937	0.000000	26.0
Poplar hybrid	0.000003	-0.000309	0.011431	-0.042937	0.000000	26.0
Black alder	0.000003	-0.000309	0.011431	-0.042937	0.000000	26.0
Other species	0.000003	-0.000309	0.011431	-0.042937	0.000000	26.0

Table 8. Coefficients for carbon input calculations with ground cover plant residues, litter and roots

The dominant species	a	b	c	d	eh	Max. G, m^2 ha^{-1}
id	[47]	[48]	[49]	[50]	[51]	[52]
Spruce	-0.000003	0.000199	-0.003232	0.024756	1.465097	30.0
Pine tree	-0.000014	0.000776	-0.014467	0.104824	2.540835	30.0
Birch	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Aspen	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Poplar hybrid	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Black alder	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Other species	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0

Carbon storage in forest land in ground cover plant biomass is calculated for all forest land to assess changes in carbon storage in case of land use change, for example afforestation of arable land or grassland. The coefficients of the equations for calculating the carbon accumulation are given in Table 9.

Table 9. Coefficients for calculations of carbon accumulation in ground cover plant biomass

The dominant species	a	b	c	d	e	Max. G, m^2 ha^{-1}
id	[53]	[54]	[55]	[56]	[57]	[58]
Spruce	-0.000003	0.000199	-0.003232	0.024756	1.465097	30.0
Pine tree	-0.000014	0.000776	-0.014467	0.104824	2.540835	30.0
Birch	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Aspen	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Poplar hybrid	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Black alder	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0
Other species	0.000009	-0.000494	0.008583	-0.083487	1.263489	26.0

Table 10 provides coefficients for carbon accumulation calculations in forest lands, depending on the basal area area of the stand. This indicator is not used in areas that are arable land or grassland before the implementation of the measure.

Table 10. Coefficients of carbon accumulation in dead wood for calculation in forest lands

The dominant species	a	b	c	d	e
id	[59]	[60]	[61]	[62]	[63]
Spruce	0.000424	-0.030501	0.710823	-7.083432	93.865713
Pine tree	0.000037	-0.006855	0.270987	-3.903290	61.217237
Birch	0.000178	-0.013469	0.312192	-2.664939	18.727676
Aspen	0.000178	-0.013469	0.312192	-2.664939	18.727676
Poplar hybrid	0.000178	-0.013469	0.312192	-2.664939	18.727676
Black alder	0.000178	-0.013469	0.312192	-2.664939	18.727676
Other species	0.000178	-0.013469	0.312192	-2.664939	18.727676

In forest lands, the carbon accumulation in the wood products prepared from the trees cut in the previous cycle is also calculated. Carbon stock is calculated using basal area area as a variable indicator. Calculation coefficients for calculations of carbon stored in lumber are given in Table 11, in slab wood – Table 12 and in paper and cardboard products – Table 13.

Table 11. Coefficients for carbon accumulation calculations in lumber (5.C & 5.NC) in forest lands

The dominant species	a	b
id	[64]	[65]
Spruce	-0.437336	20.840077
Pine tree	-0.476845	22.100373
Birch	-0.304579	12.090044
Aspen	-0.096996	4.826518
Poplar hybrid	-0.145217	29.000000
Black alder	-0.304579	12.090044
Other species	-0.304579	12.090044

Table 12. Coefficients for calculations of carbon accumulation in slab wood (6 1, 6 2, 6 3, 6.4.1, 6.4.2, 6.4.x, 6.4.3) in forest lands

The dominant species	a	b
id	[66]	[67]
Spruce	-0.420516	20.038535
Pine tree	-0.458505	21.250359
Birch	-0.292864	11.625042
Aspen	-0.093266	4.640883
Poplar hybrid	-0.139632	28.011337
Black alder	-0.292864	11.625042
Other species	-0.292864	11.625042

Table 13. Coefficients for carbon accumulation calculations in paper and cardboard products (10) in forest lands

The dominant species	a	b
id	[68]	[69]
Spruce	-0.008311	0.403860
Pine tree	-0.344292	1.253129
Birch	-1.495479	4.966780
Aspen	-0.805852	2.326979
Poplar hybrid	0.000000	0.000000
Black alder	0.000000	0.000000
Other species	0.000000	0.000000

Input data on an annual basis in Table 14 are generated by the AGM tool, using in the calculations a set of data corresponding to the calculation structure of the State Forest Register and assumptions for everyday forestry, preparing a scenario that characterizes the continuation of everyday forestry (alternative scenario). In the event implementation scenario use assumptions that describe the course of growth when implementing climate change mitigation measures at a maximum or user-defined scale. In the scenario of the implementation of the measures, it can be indicated whether additional measures are being implemented (forest melioration, use of fertilizers and wood ash), the implementation of these measures being foreseen in the calculation of the growth rate.

Table 14. Calculated parameters of the growth model for characterizing growth

No.	Parameter	Unit of measure	id	Transcript
1.	Bon	-	[70]	Site index
2.	A	Years	[71]	Plant age
3.	H	m	[72]	Average tree height
4.	D	cm	[73]	Average tree diameter
5.	G	m^2 ha^{-1}	[74]	Total basal area area of the stand
6.	N	pcs. ha^{-1}	[75]	The number of trees in the kingdom
7.	M	m^3 ha^{-1}	[76]	The total stock of the stand
8.	Incr.	m^3 ha^{-1} yr^{-1}	[77]	Actual (stand) current potential average periodic growth
9.	Hharv	m	[78]	The average height of the felled tree
10.	Dharv	cm	[79]	The diameter of the average sawn tree
11.	Gharv	m^2 ha^{-1}	[80]	Total basal area area of felled trees
12.	Nharv	pcs. ha^{-1}	[81]	The total number of trees cut down
13.	Mharv	m^3 ha^{-1}	[82]	Total stock of felled trees
14.	Mharv aver	m^3	[83]	Average sawn tree
15.	Hmort	m	[84]	Average dead tree height
16.	Dmort	cm	[85]	Diameter of average dead wood
17.	Gmort	m^2 ha^{-1} yr^{-1}	[86]	Total basal area area of dead trees
18.	Nmort	pcs. ha_{-1} yr_{-1}	[87]	The total number of dead trees in the canopy
19.	Mmort	m^3 ha^{-1} yr^{-1}	[88]	Total stock of dead trees

Parameter values in Table 15 are take from Table 4, based on the user's choice in parameter [89] (Table 15). The parameters in the user menu [89] is used to determine whether the carbon cycle calculation uses data on carbon input to the soil with plant residues and GHG emissions from the soil (parameter [107], Table 16). This parameter is not used in mineral soils.

Table 15. Input data for characterization of GHG emissions in non-forest lands

Parameter		Unit of measure	id	Value
Land use		-	[89]	Grassland or arable land
Soil type		-	[90]	Organic or mineral soil
Steady-state carbon accumulation	surface	tons C ha^{-1}	[91]	-
	underground	tons C ha^{-1}	[92]	-
Carbon input to the soil	surface	tons C ha^{-1} yr^{-1}	[93]	Use only on organic soils
	underground	tons C ha^{-1} yr^{-1}	[94]	Use only on organic soils
	small roots	tons C ha^{-1} yr^{-1}	[95]	Use only on organic soils
	other income	tons C ha^{-1} yr^{-1}	[96]	Use only on organic soils
Proportion of ditch area		%	[97]	Use only on organic soils
CH4 emission factor for ditches		kg CH_4 ha^{-1} yr^{-1}	[98]	Use only on organic soils
CH4 emission factor for the rest of the area		kg CH_4 ha^{-1} yr^{-1}	[99]	Use only on organic soils
N2O emission factor		kg N_2O ha^{-1} yr^{-1}	[100]	Use only on organic soils
CO2 emission factor		tons of CO_2 ha^{-1} yr^{-1}	[101]	Use only on organic soils

Calculations of GHG emissions in non-forest lands (alternative scenario)

In non-forest lands (arable lands and grasslands), the calculation of GHG emissions consists of GHG emissions from soil in organic soils (Table 16).

Table 16. Calculations of GHG emissions in non-forest lands in organic soils

GHG	Units of measurement	id
CO_2 emissions from living biomass *(carbon input to the soil)*	tons of CO_2 ha^{-1} yr^{-1}	[102]=[93]+[94]+[95]+[96]
CH_4 emissions from ditches	tons of CO_2 eq. ha^{-1} yr^{-1}	[103]=([98]*[97])/1000*[310]
CH_4 emissions from soil	tons of CO_2 eq. ha^{-1} yr^{-1}	[104]=([99]*(100%-[97]))/1000*[310]
N_2O emissions from soil	tons of CO_2 eq. ha^{-1} yr^{-1}	[105]=[100]/1000
CO_2 emissions from soil *(heterotrophic respiration)*	tons of CO_2 ha^{-1} yr^{-1}	[106]=[101]
Total GHG emissions	tons of CO_2 eq. ha^{-1} yr^{-1}	[107]=[102]+[103]+[104]+[105]+[106]

In mineral soils, only the indicator of carbon accumulation in ground cover plants is used ([299]+[22]) from Table 4, which is compared to carbon storage in ground cover plants from climate change mitigation measures.

Calculations of GHG emissions in shelter belts

The user menus required for GHG emissions are listed in Table 17. The dominant tree species are spruce, pine, birch, aspen, poplar hybrid, black alder and other species. The soil type in this case is mineral soil (all wetlands, fens and drylands) or organic soil (bogs and peats). The moisture regime affects the calculations of GHG emissions in organic soils - in peatlands the soil is drained, in bogs – restored. The supply of nutrients also applies only to organic soils – in broadleaved peats, bogs and swamps, the supply of nutrients is good, in the other types of bogs and peat forests – satisfactory. The afforestation or forest management menu belongs to the description of the climate change mitigation measure – in all scenarios related to the change of land use to forest land, "afforestation" should be selected in this parameter, and "forest management" in scenarios not related to the change of land use, if the coefficient [6] in Table 1, which characterizes the loss of logging residues, is not 100%.

Table 17. User menus in forest lands

Pointer	id	Notes
The dominant tree species	[108]	The dominant tree species grows
Soil type	[109]	Mineral soil or organic soil, in the afforestation scenario cannot differ between scenarios ([110]=[90])
Humidity mode	[111]	Reclaimed or waterlogged (according to the planned condition)
Provision of nutrients	[112]	Good or satisfactory, the parameter is used in organic soils.
Afforestation or forest management	[113]	Carbon storage characterization menu, applicable only in scenarios not related to planting trees on cropland or grassland
Use of logging residues	[114]	Mark ("yes" or "no") for the use of logging residues (left behind or used to make biofuel)

After calculating the equations in Table 18, excluding carbon storage in ground cover plants ([117]), used only in organic soils ([109]=”organic soil”, Table 17). The coefficient [41], [42], [43], [44], [45] and [46] values Table 18 select from Table 7, depending on the value of the dominant species in Table 17 ([108]). The coefficient [47], [48], [49], [50], [51] and [51] values Table 18 select from Table 8, depending on the value of the dominant species in Table 17 ([108]). The coefficient [53], [54], [55], [56], [57] and [58] values in Table 18 select from Table 9, depending on the value of the dominant species in Table 17 ([108]).

Table 18. Calculation of carbon input by forest litter and ground cover plants

Pointer	Parameter	Calculation
Carbon uptake by tree residues and litter	tons C ha^{-1} yr^{-1}	[115]=[41]*(IF([74]>[46];[46];[74]))^4+[42]*(IF([74]>[46];[46];[74]))^3+[43]*(IF([74]>[46];[46];[74]))^2+[44]*IF([74]>[46];[46];[74])+[45]
Carbon uptake by ground cover crop residues	tons C ha^{-1} yr^{-1}	[116]=[47]*(IF([74]>[52];[52];[74]))^4+[48]*(IF([74]>[52];[52];[74]))^3+[49]*(IF([74]>[52];[52];[74]))^2+[50]*IF([74]>[52];[52];[74])+[51]
Carbon storage in ground cover plants	tons C ha^{-1}	[117]=[53]*(IF([74]>[58];[58];[74]))^4+[54]*(IF([74]>[58];[58];[74]))^3+[55]*(IF([74]>[58];[58];[74]))^2+[56]*IF([74]>[58];[58];[74])+[57]
Total carbon input by plant residues	tons C ha^{-1} yr^{-1}	[118]=[115]+[116]

The calculation of GHG emissions in forest lands consists of changes in carbon accumulation in living and dead biomass of woody plants, wood products, ground cover (in case of afforestation) and the substitution effect of wood biofuel. In organic soils, GHG emissions caused by the carbon cycle in the soil, as well as CH_4 and N_2O emissions from the soil are additionally calculated. The parameters of carbon cycle and GHG emission calculations are summarized in Table 19. These parameters are selected from Table 1 and 3, based on the menus in Table 17.

Table 19. Calculation parameters of GHG emissions in forest lands

Parameter	Unit of measure	Calculation
Wood density	tons m^{-3}	[119]=[11]
Logging residue losses in maintenance felling	-	[120]=[6]
Logging residue losses in the main felling	-	[121]=[6]
Carbon content of biomass	tons C in ton^{-1}	[122]=[12]
CH_4 emission factor for ditches	kg CH_4 ha^{-1} per year	[123]=[292]
Proportion of ditch area	%	[124]=[293]
CH_4 emission factor	kg CH_4 ha^{-1} per year	[125]=[294]
N_2O emission factor	kg N_2O ha^{-1} per year	[126]=[295]

Parameter	Unit of measure	Calculation
CO_2 emission factor	tons of CO_2 ha^{-1} per year	[127]=[296]
Carbon accumulation in ground cover at steady state	tons C ha^{-1}	[128]=[297]
The period of carbon accumulation in the ground cover	years	[129]=[298]
Decay period of dead wood	years	[130]=[13]
Lumber yield from round timber (5.C & 5.NC)	%	[131]=[1]
Board wood yield from round timber (6.1, 6.2, 6.3, 6.4.1, 6.4.2, 6.4.x, 6.4.3)	%	[132]=[2]
Production of paper and cardboard products from pulpwood (10)	%	[133]=100%-[5]
Proportion of bark from round timber	%	[134]=[4]

Tree biomass calculation (Table 20) is performed when such information cannot be obtained from the AGM tool. The equations use specific coefficients of the dominant species and biomass category ([34], [35], [36], [37], [38], [39] and [40]), given in Table 6. Biomass can be calculated according to biomass categories Table 6 – SB (stem biomass), AGB (aboveground biomass), BB (branch biomass), BGB (underground biomass).

Table 20. Calculation of tree biomass

Parameter	Unit of measure	Calculation
Growing trees, stem biomass (SB)	tons ha^{-1} yr^{-1}	[135]=([40]*EXP([34]+[35]*([73]/([73]+[39]))+[36]*[72]+[37]*LN([72])+[38]*LN([73])))*[75]/1000
Growing trees, above ground biomass (AGB)	tons ha^{-1} yr^{-1}	[136]=([40]*EXP([34]+[35]*([73]/([73]+[39]))+[36]*[72]+[37]*LN([72])+[38]*LN([73])))*[75]/1000
Growing trees, branch biomass (BB)	tons ha^{-1} yr^{-1}	[137]=[136]-[135]
Growing trees, below ground biomass (BGB)	tons ha^{-1} yr^{-1}	[138]=([40]*EXP([34]+[35]*([73]/([73]+[39]))+[36]*[72]+[37]*LN([72])+[38]*LN([73])))*[75]/1000
Stock growth, stem biomass (SB)	tons ha^{-1} yr^{-1}	[139]=[135]/[76]*[77]
Stock growth, aboveground biomass (AGB)	tons ha^{-1} yr^{-1}	[140]=[136]/[76]*[77]
Stock growth, branch biomass (BB)	tons ha^{-1} yr^{-1}	[141]=[137]/[76]*[77]
Stock growth, below ground biomass (BGB)	tons ha^{-1} yr^{-1}	[142]=[138]/[76]*[77]
Fell trees, trunk biomass (SB)	tons ha^{-1} yr^{-1}	[143]=([40]*EXP([34]+[35]*([79]/([79]+[39]))+[36]*[78]+[37]*LN([78])+[38]*LN([79])))*[81]/1000
Fell trees, aboveground biomass (AGB)	tons ha^{-1} yr^{-1}	[144]=([40]*EXP([34]+[35]*([79]/([79]+[39]))+[36]*[78]+[37]*LN([78])+[38]*LN([79])))*[81]/1000
Fell trees, branch biomass (BB)	tons ha^{-1} yr^{-1}	[145]=[144]-[143]
Fell trees, belowground biomass (BGB)	tons ha^{-1} yr^{-1}	[146]=([40]*EXP([34]+[35]*([79]/([79]+[39]))+[36]*[78]+[37]*LN([78])+[38]*LN([79])))*[81]/1000
Dead wood, stem biomass (SB)	tons ha^{-1} yr^{-1}	[147]=([40]*EXP([34]+[35]*([85]/([85]+[39]))+[36]*[84]+[37]*LN([84])+[38]*LN([85])))*[87]/1000
Dead wood, above ground biomass (AGB)	tons ha^{-1} yr^{-1}	[148]=([40]*EXP([34]+[35]*([85]/([85]+[39]))+[36]*[84]+[37]*LN([84])+[38]*LN([85])))*[87]/1000
Dead wood, branch biomass (BB)	tons ha^{-1} yr^{-1}	[149]=[147]-[146]
Dead wood, belowground biomass (BGB)	tons ha^{-1} yr^{-1}	[150]=([40]*EXP([34]+[35]*([85]/([85]+[39]))+[36]*[84]+[37]*LN([84])+[38]*LN([85])))*[87]/1000

Table 21 calculates the carbon accumulation in the biomass, if it is not already calculated in the AGM model. The carbon content of biomass is the coefficient [12] from Table 3. The value of the coefficient is determined depending on the dominant species [108], humidity mode [111] and nutrient provision [112] choices according to Table 17.

Table 21. Calculation of carbon accumulation in tree biomass

Parameter	Unit of measure	Calculation
Growing trees, trunk biomass	tons C ha^{-1}	[151]=[151]*[12]
Growing trees, above ground biomass	tons C ha^{-1}	[152]=[152]*[12]
Growing trees, branch biomass	tons C ha^{-1}	[153]=[153]*[12]
Growing trees, underground biomass	tons C ha^{-1}	[154]=[154]*[12]
Stock growth, stem biomass	tons C ha^{-1}	[155]=[155]*[12]
Stock growth, above ground biomass	tons C ha^{-1}	[156]=[156]*[12]
Stock growth, branch biomass	tons C ha^{-1}	[157]=[157]*[12]
Stock growth, underground biomass	tons C ha^{-1}	[158]=[158]*[12]
Cut down trees, trunk biomass	tons C ha^{-1}	[159]=[159]*[12]
Cut down trees, above ground biomass	tons C ha^{-1}	[160]=[160]*[12]
Cut down trees, branch biomass	tons C ha^{-1}	[161]=[161]*[12]
Cut down trees, underground biomass	tons C ha^{-1}	[162]=[162]*[12]
Dead wood, stem biomass	tons C ha^{-1}	[163]=[163]*[12]
Dead wood, aboveground biomass	tons C ha^{-1}	[164]=[164]*[12]
Dead wood, branch biomass	tons C ha^{-1}	[165]=[165]*[12]
Dead wood, underground biomass	tons C ha^{-1}	[166]=[166]*[12]

Changes in carbon accumulation, as well as the total carbon accumulation in the living biomass of woody plants, are calculated in Table 22.

Table 22. Changes in carbon accumulation in the biomass of living trees

Parameter	Unit of measure	Calculation
Changes in carbon accumulation in living biomass during the reporting year	tons C ha^{-1} yr^{-1}	[167]=([173]+[184])-([186]+[195]+[198]+[201])
Carbon accumulation in living biomass in the reporting year	tons C ha^{-1}	$[168]=[167]_1+...[167]_N$, WHERE $[167]_1$ – CHANGES IN CARBON ACCUMULATION IN LIVING BIOMASS IN YEAR 1; $[167]_N$ – CHANGES IN CARBON ACCUMULATION IN LIVING BIOMASS IN THE REPORTING YEAR.

In afforested areas and non-forest lands, carbon accumulation in dead wood before the implementation of the measure [169]o is equal to zero, so the initial carbon accumulation in this carbon store ([169]o) should be calculated only in the areas where the forest grew before the implementation of the measure. Calculation of carbon accumulation in dead wood can be done according to Table 23 for the given equations. Carbon accumulation in dead wood, which was formed as a result of logging, is already included in year zero [169]o in the calculation.

Table 23. Changes in carbon stock in dead wood

Parameter	Unit of measure	Calculation in year zero (if different from the others)	Calculation in the first year (if different from the others)	Calculation in future years
Carbon uptake by dead wood	tons C ha^{-1} yr^{-1}	[169]O=[59]*[74]^4+[60]*[74]^3+[61]*[74]^2+[62]*[74]+[63]	[169]=[198]+[201]	
Carbon uptake by logging residues	tons C ha^{-1} yr^{-1}	-	[170]=[187]+[195]	
Carbon loss in dead wood	tons C ha^{-1} yr^{-1}	-	$[171]_1$=-($[169]_O$+[169]+[204])/[130]), WHERE $[169]_O$ – CARBON ACCUMULATION IN DEAD WOOD IN ZERO YEAR.	$[171]_X$=-(($[169]_O$+$[169]_1$...$[169]_N$)+($[204]_1$+$[204]_N$)+($[171]_1$+$[171]_{N-1}$))/[130], WHERE $[169]_O$ – CARBON ACCUMULATION IN DEAD WOOD IN ZERO YEAR; $[169]_1$ – CARBON INTAKE IN DEAD WOOD WITH DEAD WOOD IN THE FIRST YEAR; $[169]_N$ – CARBON INTAKE IN DEAD WOOD WITH DEAD WOOD IN THE REFERENCE YEAR; $[170]_1$ – CARBON INPUT WITH LOGGING RESIDUES IN THE FIRST YEAR; $[170]_N$ – CARBON INPUT WITH LOGGING RESIDUES IN THE REFERENCE YEAR; $[171]_1$ – CARBON LOSSES FROM DEAD WOOD IN THE FIRST YEAR; $[171]_{N-1}$ – CARBON LOSS FROM DEAD WOOD IN THE YEAR BEFORE THE REPORTING YEAR.
Changes in carbon stock in dead wood	tons C ha^{-1} yr^{-1}	-	[172]=[169]+[204]+[171]	
Carbon accumulation in dead wood	tons C ha^{-1}	-	[173]=$[172]_O$+$[172]_1$...$[172]_N$, WHERE $[172]_O$ – CHANGES IN CARBON ACCUMULATION IN DEAD WOOD IN ZERO YEAR; $[172]_1$ – CHANGES IN CARBON ACCUMULATION IN DEAD WOOD IN THE FIRST YEAR; $[172]_N$ – CHANGES IN CARBON ACCUMULATION IN DEAD WOOD IN THE REPORTING YEAR.	

Equations for calculating GHG emissions for organic soils (peats and bogs) are given in Table 24, but Table 25 gives recalculation of GHG emissions to CO_2 equivalents and calculation of total CO_2 emissions from the soil.

Table 24. GHG emissions from soil

GHG	Unit of measure	Calculation
CH_4 emissions from ditches	kg CH_4 ha^{-1} yr^{-1}	[174]=[123]*[124]
CH_4 emissions from the rest of the area	kg CH_4 ha^{-1} yr^{-1}	[175]=[125]*(100%-[124])
N_2O emissions	kg N_2O ha^{-1} yr^{-1}	[176]=[126]
CO_2 emissions	tons of CO_2 ha^{-1} yr^{-1}	[177]=[127]

Table 25. Conversion of GHG emissions from soil into CO_2 equivalents

GHG	Unit of measure	Calculation
CH_4 emissions from ditches	tons of CO_2 eq. ha^{-1} yr^{-1}	[178]=[174]*[310]
CH_4 emissions from the rest of the area	tons of CO_2 eq. ha^{-1} yr^{-1}	[179]=[175]*[310]
N_2O emissions	tons of CO_2 eq. ha^{-1} yr^{-1}	[180]=[176]*[311]
CO_2 emissions	tons of CO_2 ha^{-1} yr^{-1}	[181]=[177]
Total GHG emissions from soil	tons of CO_2 eq. ha^{-1} yr^{-1}	[182]=[178]+[179]+[180]+[181]

The amount of carbon introduced into the produced wood products is calculated using the equations in Table 26. The proportion of bark is taken into account when calculating the yield of round timber.

Table 26. Calculation of carbon input from the produced wood products

Wood products	Unit of measure	Calculation
Round timber, 1.2.C & 1.2.NC	tons C ha^{-1} yr^{-1}	[183]=[276]*[185]/[82]*(100%-[134])
Lumber, 5.C & 5.NC	tons C ha^{-1} yr^{-1}	[184]=[183]*[131]
Panel wood, 6 1, 6 2, 6 3, 6.4.1, 6.4.2, 6.4.x, 6.4.3	tons C ha^{-1} yr^{-1}	[185]=[183]*[132]
Paper and cardboard, 10	tons C ha^{-1} yr^{-1}	[186]=[277]*[185]/[82]*[133]
In total	tons C ha^{-1} yr^{-1}	[187]=[184]+[185]+[186]

Coefficients for wood product decomposition calculations are given in Table 27 and 28. Coefficients in Table 28 are calculated for each type of wood product separately. Calculation equations for GHG emissions from wood products correspond to the methodology adapted in the national GHG inventory (Rüter, 2011).

Table 27. Calculation of common coefficients of carbon contribution by wood products

Coefficient	id	Value
e	[188]	2.7
ln(2)	[189]	LN(2)

Table 28. Coefficients specific to the type of wood products, calculation of carbon contribution by wood products

Coefficient	id	Sawn materials (5.C & 5.NC)	Panel wood (6 1, 6 2, 6 3, 6.4.1, 6.4.2, 6.4.x, 6.4.3)	Paper and cardboard (10)
HL – half-life	[190]	35.0	25.0	2.0
	[191]=[189]/[190]			
e^{-k}	[192]=[188]^-[191]			
	[193]=(1-[191])/[192]			

The carbon accumulation in wood products in the zero year is calculated if the alternative scenario is forest land, ie the initial carbon accumulation in wood products is not calculated for measures related to afforestation.

Changes in carbon accumulation in wood products are calculated separately for three categories of wood products according to Table 29 for the given equations.

Table 29. Calculation of carbon cycle in wood products

Type of timber	Process	Unit of measure	Carbon stock in year zero (if different from others)	Calculation of changes in carbon stock
Sawn materials; 5.C & 5.NC	c(s)	tons C ha^{-1} yr^{-1}	[194]O=[64]*[74]+[65]	$[194]_N$=([192]*$[194]_{N-1}$)+([193]*$[195]_{N-1}$)
	inflow(s)	tons C ha^{-1} yr^{-1}	-	$[195]_N$=$[219]_N$
	ΔC(i)	tons C ha^{-1} yr^{-1}	-	$[196]_N$=$[194]_{N+1}$-$[194]_N$
Panel wood; 6 1, 6 2, 6 3, 6.4.1, 6.4.2, 6.4.x, 6.4.3	c(s)	tons C ha^{-1} yr^{-1}	[197]O=[66]*[74]+[67]	[197]=([192]*$[197]_{N-1}$)+([193]*$[198]_{N-1}$)
	inflow(s)	tons C ha^{-1} yr^{-1}	-	$[198]_N$=$[220]_N$
	ΔC(i)	tons C ha^{-1} yr^{-1}	-	$[199]_N$=$[197]_{N+1}$-$[197]_N$
Paper and cardboard; 10	c(s)	tons C ha^{-1} yr^{-1}	[200]O=[68]*[74]+[69]	[200]=([192]*$[200]_{N-1}$)+([193]*$[201]_{N-1}$)
	inflow(s)	tons C ha^{-1} yr^{-1}	-	$[201]_N$=$[221]_N$
	ΔC(i)	tons C ha^{-1} yr^{-1}	-	[202]=$[200]_{N+1}$-$[200]_N$
In total	ΔC(i)	tons C ha^{-1} yr^{-1}	-	[203]=[196]+[199]+[202]

Carbon in wood biofuel is calculated according to Table 30 for the given equations, separately for recycled wood, bark, wood processing residues, logging residues and firewood. Carbon input with logging residues is billed separately in the maintenance section $[207]_{kc}$ and in the main cut $[207]_{gc}$ for the obtained wood, if the input parameters indicate that logging residues are used for the preparation of wood biofuel.

Table 30. Carbon content of wood biofuel

Pointer	Unit of measure	Calculation
Recycled wood	tons C ha^{-1} yr^{-1}	[204]=(1-[192])*[194]+(1-[193])*[223]+(1-[192])*[197]+(1-[193])*[225]+(1-[192])*[200]+(1-[193])*[227]
Peels	tons C ha^{-1} yr^{-1}	[205]=[185]-[209]-[221]-[208]
Woodworking residues	tons C ha^{-1} yr^{-1}	[206]=[185]-([219]+[220]+[221])-[208]
Logging residues	tons C ha^{-1} yr^{-1}	$[207]_{KC}$=[187]*(1-[120]) $[207]_{GC}$=[187]*(1-[121])
Firewood	tons C ha^{-1} yr^{-1}	[208]=[278]*[122]
In total	tons C ha^{-1} yr^{-1}	[209]=[230]+[232]+[233]+[208]

In the calculation of the substitution effect of wood biofuel, it is assumed that wood processing residues, firewood, recycled wood and logging residues (if it is indicated that logging residues are used for the preparation of biofuel). The coefficients used by default to calculate the reduction of GHG emissions compare wood in district heating and natural gas (Table 31). The calculated equations correspond to the default emission factor values given in the IPCC guidelines (Eggleston et al., 2006).

Table 31. Coefficients for the calculation of the biofuel substitution effect

Parameter	Unit of measure	id	Numerical value
Emission factors for natural gas			
The lowest calorific value	MWh m^{-3}	[210]	0.0094
Efficiency coefficient of the boiler	-	[211]	85%
CO_2 emission factor	tons of CO_2 MWh^{-1}	[212]	0.1984
N_2O emission factor	tons of N_2O MWh^{-1}	[213]	0.00000036
CH_4 emission factor	tons of CH_4 MWh^{-1}	[214]	0.00000360
Characterization of biofuel			
The lowest calorific value	MWh per ton^{-1}	[215]	4.9000

Parameter	Unit of measure	id	Numerical value
Efficiency coefficient of the boiler	-	[216]	80%
N2O emission factor	tons of N_2O MWh^{-1}	[217]	0.000014
CH4 emission factor	tons of CH_4 MWh^{-1}	[218]	0.000108

The first step of the calculation is the calculation of the amount of wood biofuel in dry tons and the amount of energy produced, as well as the amount of N_2O and CH_4 emissions in the biomass burning process (Table 32). CO_2 emissions in the form of carbon losses from living biomass are already included in the equations of carbon circulation in living biomass.

Table 32. Calculation of the amount of energy replaced

Parameter	Unit of measure	Calculation
Biofuel:	tons per year	[219]=[220]+[221]+[222]+[223]+[224]
recycled wood	tons per year	[220]=[230]/[122]
peels	tons per year	[221]=[231]/[122]
woodworking residues	tons per year	[222]=[232]/[122]
logging residues	tons per year	[223]=[233]/[122]
firewood	tons per year	[224]=[208]/[122]
The net amount of energy replaced	MWh per year	[225]=[219]*[215]*[216]
N_2O emissions in the combustion process	tons N_2O yr^{-1}	[226]=[225]*[217]
CH_4 emissions in the combustion process	tons CH_4 yr^{-1}	[227]=[225]*[218]

The fossil fuel replaced is calculated by estimating how much fossil fuel is needed to produce the amount of energy that can be produced from woody biomass. Then calculate the GHG emissions that would be generated by burning fossil fuels (Table 33). In the next step, GHG emissions are converted into CO_2 equivalents (Table 34).

Table 33. Calculation of the substitution effect in biofuels

Parameter	Unit of measure	id
Replaced natural gas	m^3 per year	[228]=[245]/[210]/[211]
CO|$_2$ emissions from substituted fossil fuels	tons CO_2 yr^{-1}	[229]=[228]*[210]*[212]
N_2O emissions from substituted fossil fuels	tons N_2O yr^{-1}	[230]=[228]*[210]*[213]
CH_4 emissions from substituted fossil fuels	tons CH_4 yr^{-1}	[231]=[228]*[210]*[214]

Table 34. Conversion of substitution effect to CO_2 equivalents

Parameter	Unit of measure	id
Reduction of CO_2 emissions	tons CO_2 eq. yr^{-1}	[232]=[228]
Reduction of N_2O emissions	tons CO_2 eq. yr^{-1}	[233]=([230]-[226])*[33]
Reduction of CH_4 emissions	tons CO_2 eq. yr^{-1}	[234]=([231]-[227])*[32]
Net emission reduction	tons CO2 eq. yr^{-1}	[235]=[232]+[233]+[234]

The summary of GHG emissions includes CO2 emissions from living woody biomass, CO2 emissions from ground cover in forested areas (in areas where the forest grew before the implementation of the measure, this storage is not taken into account), CO2 emissions from dead wood, CO2 emissions from harvested wood products, CO2, CH4 and N2O emissions from organic soil, biofuel substitution effect and total annual GHG emissions (Table 35).

Table 35. Summary of GHG emissions calculation

Parameter	Units of measurement	Calculation in the first year (if different from the others)	Calculation in future years
CO_2 emissions from tree biomass	tons CO_2 ha^{-1} yr^{-1}	[236]=[202]*44/12	
CO_2 emissions from ground cover in forested areas	tons CO_2 ha^{-1} yr^{-1}	[237]1=-[129]/[130]*44/12, WHERE $[237]_1$ – CO_2 EMISSIONS FROM THE GROUND COVER IN THE FIRST YEAR	[237]N=IF(ABS($[237]_1$+...+$[237]_{N-1}$)>=[129]*44/12;0;-[129]/[130]*44/12), WHERE $[237]_N$ – CO_2 EMISSIONS FROM THE GROUND COVER IN THE REFERENCE YEAR; $[237]_1$ – CO_2 EMISSIONS FROM THE GROUND COVER IN THE FIRST YEAR; $[237]_{N-1}$ – CO_2 EMISSIONS FROM THE GROUND COVER IN THE YEAR BEFORE THE REVIEW.
CO_2 emissions from dead wood	tons CO_2 ha^{-1} yr^{-1}	[238]=[206]*44/12	
CO_2 emissions from wood products	tons CO_2 ha^{-1} yr^{-1}	[239]=[229]*44/12	
CO_2 emissions from organic soil	tons CO_2 ha^{-1} yr^{-1}	[240]=[181]-[118]*44/12	
CH_4 emissions from organic soil	tons CO_2 eq. ha^{-1} yr^{-1}	[241]=[178]+[179]	
N_2O emissions from organic soil	tons CO_2 eq. ha^{-1} yr^{-1}	[242]=[180]	
Biofuel substitution effect	tons CO_2 eq. ha^{-1} yr^{-1}	[243]=[235]	
Total GHG emissions	tons CO_2 eq. ha^{-1} yr^{-1}	[244]=[236]+[237]+[238]+[239]+[240]+[241]+[242]+[243]	
Cumulative total GHG emissions	tons CO_2 eq. ha^{-1}	[245]=$[244]_1$+...+$[244]_N$ WHERE $[244]_1$ – TOTAL GHG EMISSIONS IN THE FIRST YEAR; $[244]_N$ – TOTAL GHG EMISSIONS IN THE REPORTING YEAR.	

The breakdown into timber types is calculated if this information is not provided by the AGM tool. The coefficients corresponding to the type of timber, the type of felling and the tree species can be found in Table 2. Assumptions that determine the choice of coefficients are located in Table 17. To prevent a negative result, as well as a result that exceeds 100%, according to Table 36 the relative timber distribution calculated for the given equations is corrected using Table 37 given equations. In Table 38 the yield of round timber, pulpwood and firewood in the volume of logging is calculated. All calculations are made on the volume of logging without bark, excluding firewood.

Table 36. Calculation of the relative distribution of timber types

Type of timber	Calculation
Poles 18<	[246]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
A 28<	[247]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
28<	[248]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
18-27.9	[249]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
FIA 18<	[250]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
FBI 18<	[251]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
24 <	[252]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
18-23.9	[253]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
Low grade saw logs 18<	[254]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
14-17.9	[255]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
10-13.9	[256]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
12-17.9	[257]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
6-9.9	[258]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
PM 7-49.9	[259]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]
Firewood	[260]=[7]*[83]^3+[8]*[83]^2+[9]*[83]+[10]

Table 37. Correction of the relative distribution of different types of timber

Type of timber	Calculation
Poles 18<	[261]=IF([246]<0;0;[246])
A 28<	[262]=IF([247]<0;0;[247])
28<	[263]=IF([248]<0;0;[248])
18-27.9	[264]=IF([249]<0;0;[249])
FIA 18<	[265]=IF([250]<0;0;[250])
FBI 18<	[266]=IF([251]<0;0;[251])
24 <	[267]=IF([252]<0;0;[252])
18-23.9	[268]=IF([253]<0;0;[253])
Low grade saw logs 18<	[269]=IF([254]<0;0;[254])
14-17.9	[270]=IF([255]<0;0;[255])
10-13.9	[271]=IF([256]<0;0;[256])
12-17.9	[272]=IF([257]<0;0;[257])
6-9.9	[273]=IF([258]<0;0;[258])
PM 7-49.9	[274]=IF([259]<0;0;[259])
Firewood	[275]=100%-([261]+[262]+[263]+[264]+[265]+[266]+[267]+[268]+[269]+[270]+[271]+[272]+[273]+[274])

Table 38. Summary of Timber Yield Calculations

Parameter	Unit of measure	id
Saw logs (1.2.C & 1.2.NC)	m^3 ha-1	[276]=([261]+[262]+[263]+[264]+[265]+[266]+[267]+[268]+[269]+[270]+[271]+[272])*[82]*(100%-[134])
Paper wood (10)	m^3 ha-1	[277]=[274]*[82]*(100%-[134])
Firewood	m^3 ha-1	[278]=[275]*[82]

Additional productivity and GHG flux modelling in willow plantations

Growth rate of willows – shrubs in shelter belts

The growth course of willow seedlings is characterized by the duration of the cycle (management cycle from mowing to mowing) and the number of management cycles before regeneration of the seedlings. The increase in the stock included in the calculation corresponds to the minimum increase in the stock for receiving state aid for the cultivation of offspring in Sweden. In well-managed plantations, the average annual growth can be 50% higher. In the calculation, it is assumed that the death of the underground biomass after development corresponds to 90% of the carbon bound in the root biomass and its decomposition takes place within 10 years. Characteristics of the growth process and related equations for calculating changes in biomass accumulation are given in Table 39.

Coefficients and assumptions for characterizing biomass and carbon accumulation are given in Table 40.

Table 39. Characterization of the growth process of the shoot

Parameter	Units of measurement	Calculation in the first year (if different from the others)	Calculation in other years
Age of trees	years	$[279]_1=0$	$[279]_N$=IF($[279]_{N-1}$=[298]*[299];0;$[279]_{N-1}$+1)
Age of offspring	years	$[280]_1=[279]_1$	$[280]_N$=IF($[279]_N$=0;0;IF($[280]_{N-1}$=[298];1;$[280]_{N-1}$+1))
Stock growth	m^3 ha^{-1} yr^{-1}	[281]=-0,23059*[22]^3+0.87782*[22]^2+6.04873*[22]	
Above ground biomass stock	m^3 ha^{-1}	[282]=($[280]_1$+...+$[280]_N$)-($[289]_1$+...+$[289]_N$)	
Above ground biomass increase	tons ha^{-1} yr^{-1}	[283]=[281]*[292]	
Growth of belowground biomass	tons ha^{-1} yr^{-1}	[284]=[283]*[295]	
Aboveground and belowground biomass growth	tons ha^{-1} yr^{-1}	[285]=[283]+[284]	
Above ground biomass	tons ha^{-1}	[286]=[282]*[292]	
Below ground biomass	tons ha^{-1}	[287]=[286]*[292]	
Total biomass	tons ha^{-1}	[288]=[286]+[287]	
Harvested stock	m^3 ha^{-1} yr^{-1}	$[289]_1=0$	[289]=IF([280]=[298];($[281]_1$+...+$[281]_N$)-($[289]_1$+...+$[289]_{N-1}$);0)
Harvested biomass	tons ha^{-1} yr^{-1}	[290]=[289]*[292]	
Decay of underground biomass	tons ha^{-1} yr^{-1}	[291]=IF([289]>0;[287]*[296];0)	

Table 40. Characterization of biomass

Parameter	Units of measurement	Value
Wood density	tons m^{-3}	[292]=0.5
The density of the pile of chips	LV m^3 m^{-3}	[293]=2.5
Carbon content of biomass	tons C ton^{-1}	[294]=0.5
Belowground to aboveground biomass ratio	-	[295]=0.3
Decay rate of belowground biomass after development	-	[296]=0.9
Decay period of dead wood	years	[297]=10
Circulation period	years	[298]=5
Number of circulation cycles	-	[299]=6

Calculation of carbon stock changes

Equations for characterizing changes in carbon accumulation in living biomass are given in Table 41. Equations for characterizing carbon accumulation are given in Table 42.

Table 41. Changes in carbon accumulation in the biomass of living plants

Parameter	Units of measurement	Calculation in the first year (if different from the others)	Calculation in other years
Carbon in above ground biomass	tons C ha^{-1}	[300]=[307]*[294]	
Carbon in belowground biomass	tons C ha^{-1}	[301]=[279]*[294]	
Carbon in aboveground and belowground biomass	tons C ha^{-1}	[302]=[300]+[301]	
Changes in carbon stock in biomass	tons C ha^{-1} per year	$[303]_1=[302]_1$	$[303]_N=[302]_N-[302]_{N-1}$

Table 42. Changes in carbon stock in dead wood

Parameter	Units of measurement	Calculation in the first year (if different from the others)	Calculation in other years
Carbon uptake by dead wood	tons C ha^{-1} per year	[304]=[283]*[294]	
Carbon loss from dead wood	tons C ha^{-1} per year	$[305]_1=-[304]_1/[297]$	$[305]_N=-(([304]_1+...+[304]_N)+([305]_1+...+[305]_{N-1})/[297]$
Changes in carbon stock in dead wood	tons C ha^{-1} per year	[306]=[304]+[305]	
Carbon accumulation in dead wood	tons C ha^{-1}	$[307]=[306]_1+...+[306]_N$	

Calculation of the GHG substitution effect

In the calculation of the biofuel substitution effect, it is assumed that the biomass obtained from the shoots is used in centralized heat supply or combined heat and electricity production systems, which would otherwise use natural gas. The reduction of GHG emissions is calculated as a comparison between the two scenarios.

Calculation assumptions, including GHG emissions as a result of biofuel and fossil fuel combustion are given in Table 43. The carbon content in wood chips is calculated using the equation given in Table 44. The emission calculation equations and the emission factors used correspond to the factors used in the guidelines of the Intergovernmental Panel on Climate Change (Eggleston et al., 2006).

Table 43. Carbon in biofuels

Parameter	Units of measurement	Calculation
Splinters	tons C ha-1	[308]=[281]*[292]*[294]

Table 44. Characterization of biofuels and substitute fossil fuels (default values)

Parameter	Units of measurement	Calculation
Emission factors for natural gas		
Heat capacity	MWh m^{-3}	[309]=0.0094
Efficiency coefficient of the boiler	-	[310]=85%
CO_2 emission factor	tons of CO_2 MWh^{-1}	[311]=0.1984
N_2O emission factor	tons of N_2O MWh^{-1}	[312]=0.00000036
CH_4 emission factor	tons of CH_4 MWh^{-1}	[313]=0.00000360
Characterization of biofuel		
Heat capacity	MWh ton^{-1}	[314]=4.9000
Efficiency coefficient of the boiler	-	[315]=80%
N_2O emission factor	tons of N_2O MWh^{-1}	[316]=0.000014
CH_4 emission factor	tons of CH_4 MWh^{-1}	[317]=0.000108

Equations for calculating emissions caused by burning biomass are given in Table 45. Equations for calculating GHG emissions caused by the burning of replaceable fossil fuels are given in Table 46. Equations for calculating the reduction of GHG emissions are given in Table 47.

Table 45. GHG emissions from biomass burning

Parameter	Units of measurement	Calculation
Splinters	tons per year	[318]=[321]/[294]
Amount of energy replaced	MWh per year	[319]=[318]*[314]*[315]
N_2O emissions from biofuel combustion	tons of N_2O	[320]=[319]*[316]
CH_4 emissions from biofuel combustion	tons of CH_4	[321]=[319]*[317]

Table 46. GHG emissions from replaceable fossil fuels

Parameter	Units of measurement	Calculation
Amount of fossil fuel replaced	m^3	[322]=[327]/[309]/[310]
CO_2 emissions from replaceable fossil fuels	tons of CO_2	[323]=[322]*[309]*[311]
N_2O emissions from replaceable fossil fuels	tons of N_2O	[324]=[322]*[309]*[312]
CH_4 emissions from replaceable fossil fuels	tons of CH_4	[325]=[322]*[309]*[313]

Table 47. Reduction of GHG emissions by replacing fossil fuels

Parameter	Units of measurement	Calculation
Reduction of CO2 emissions	tons of CO_2 eq. year	[326]=[331]
Reduction of N2O emissions	tons of CO_2 eq. year	[327]=([332]-[328])*298
Reduction of CH4 emissions	tons of CO_2 eq. year	[328]=([333]-[329])*25
Net emissions reduction	tons of CO_2 eq. year	[329]=[326]+[327]+[328]

Summary – GHG mitigation due to growth and biofuel use in willow plantation

The summary calculation of GHG emissions includes living biomass, dead biomass in the belowground biomass, and the substitution effect caused by biofuels, which account for most of the GHG emissions reduction in willow seedlings. The summary calculation of annual emissions is shown in Table 48. Cultivation of seedlings increases the growth of carbon accumulation in the soil (Krēsliņa et al., 2020; Rose-Marie, 2012), but in Latvia, the impact of cultivation of seedlings on the soil has not been evaluated in long-term observations, so it is not taken into account in the calculation.

Table 48. Summary of GHG emissions

Parameter	Units of measurement	Calculation
CO_2 emissions from tree biomass	tons of CO_2 ha^{-1} per year	[330]=-[293]*44/12
CO_2 emissions from dead wood	tons of CO_2 ha^{-1} per year	[331]=-[319]*44/12
Biofuel substitution effect	tons of CO_2 eq. ha^{-1} per year	[332]=-[3]
Net GHG emissions	tons of CO_2 eq. ha^{-1} per year	[333]=[330]+[331]+[332]
Cumulative GHG emissions	tons of CO_2 eq. ha^{-1}	$[334]=[333]_1+...+[333]_N$

An example of GHG emission calculations for a willow plant is shown in Figure 1, but the cumulative GHG emissions with the forest biofuel substitution effect – Figure 2.

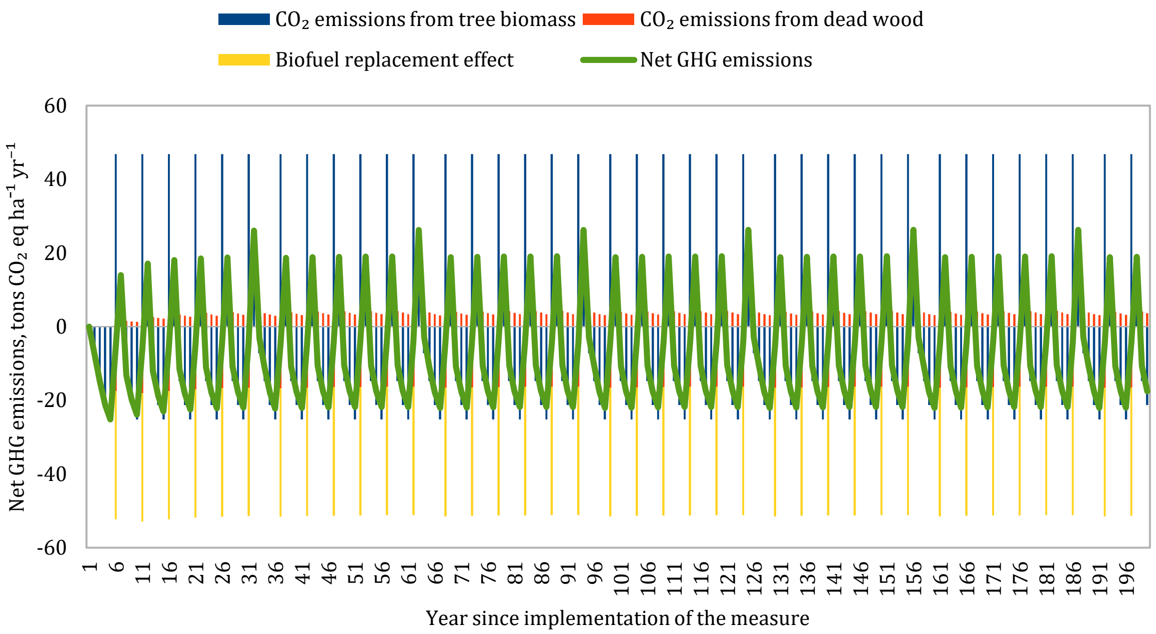

Figure 1. Summary of annual GHG emissions.

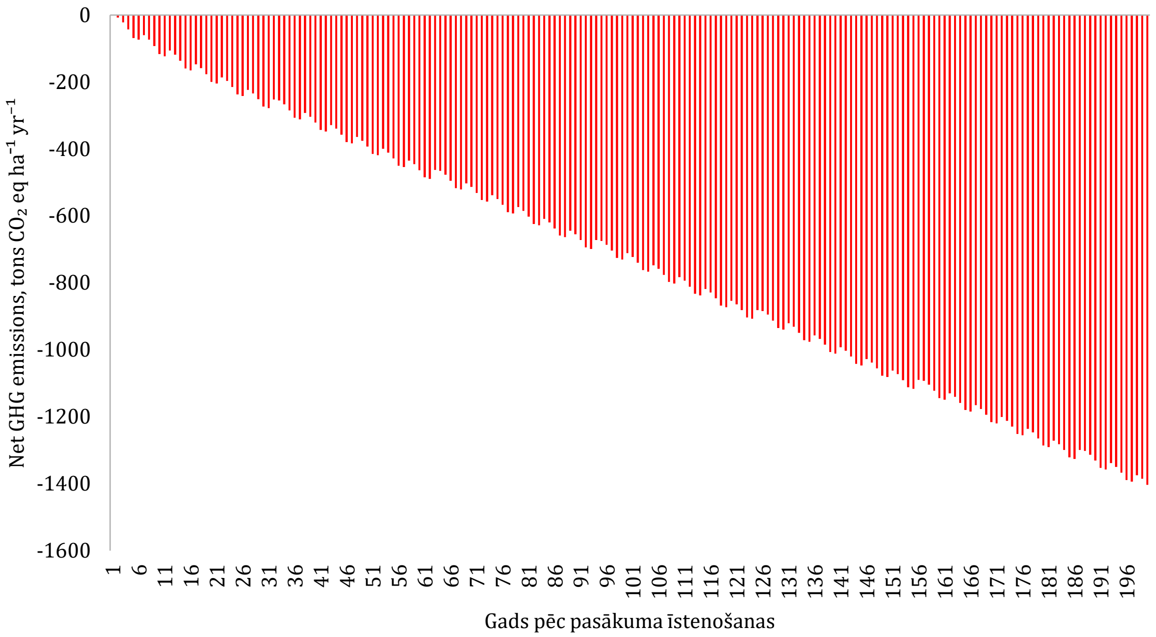

Figure 2. Cumulative GHG emissions.

Calculation of reduction of GHG emissions in shelter belts

The reduction of GHG emissions is determined by differences in carbon accumulation in ground cover plant vegetation, as well as changes in carbon accumulation in other carbon stores and GHG emissions from the soil. Ground cover plants are evaluated separately, because they are not included in the living biomass cycle equation and the impact on this storage is evaluated as the difference between two equilibrium states.

An example of a two-scenario calculation for an afforestation or other project related to the planting of trees in non-forest lands is given in Table 49. The calculation separates the reduction of GHG emissions with or without the emission reduction effect of wood biofuel. In scenarios where no change of land use is foreseen (measures in forest management), GHG emissions in the alternative scenario must be presented in the same way as in the scenario of the implementation of the measure – with and without the substitution effect.

Table 49. Example of GHG emission reduction calculation

Parameter	Unit of measure	Calculation in the first year (if different from the others)	Calculation in other years
Alternative scenario			
Net GHG emissions	tons CO_2 eq. ha^{-1} yr^{-1}	[335]=[107]	
Carbon accumulation in ground cover plant biomass	tons C ha^{-1}	[336]=[299]+[22]	
Event implementation scenario			
Net GHG emissions	tons CO_2 eq. ha^{-1} yr^{-1}	[337]=[244]	
Net GHG emissions, excluding the substitution effect of forest biofuels	tons CO_2 eq. ha^{-1} yr^{-1}	[338]=[337]-[243]	
Carbon accumulation in ground cover plant biomass	tons C ha^{-1}	[339]=[117]	
Impact of the implementation of the measure			
Changes in carbon accumulation in ground cover plant biomass	tons CO_2 eq. ha^{-1} yr^{-1}	$[340]_1=([339]_1-[336]_1)*44/12$ WHERE [340]1 – CHANGES IN CARBON ACCUMULATION IN THE FIRST YEAR; $[339]_1$ – CARBON ACCUMULATION IN THE BIOMASS OF GROUND COVER PLANTS IN THE FIRST YEAR OF IMPLEMENTING THE MEASURE; $[336]_1$ – CARBON ACCUMULATION IN THE BIOMASS OF GROUND COVER PLANTS IN THE FIRST YEAR IN THE ALTERNATIVE SCENARIO.	$[340]_N=([339]_N-[336]_N)*44/12-([340]_1+...+[340]_{N-1})$ WHERE [340]N – CHANGES IN CARBON ACCUMULATION IN THE REPORTING YEAR; $[339]_N$ – CARBON ACCUMULATION IN THE BIOMASS OF GROUND COVER PLANTS IN THE REPORTING YEAR, WHEN IMPLEMENTING THE MEASURE; $[336]_N$ – CARBON ACCUMULATION IN GROUND COVER PLANT BIOMASS IN THE REPORTING YEAR IN THE ALTERNATIVE SCENARIO; $[340]_1$ – CHANGES IN CARBON ACCUMULATION IN THE FIRST YEAR; $[340]_{N-1}$ – CHANGES IN CARBON ACCUMULATION IN THE YEAR BEFORE THE REPORTING YEAR.
Reduction of GHG emissions, excluding the substitution effect of wood biofuels	tons CO_2 eq. ha^{-1} yr^{-1}	[341]=[335]-[338]+[340]	
Reduction of GHG emissions through the substitution effect of wood biofuel	tons CO_2 eq. ha^{-1} yr^{-1}	[342]=[335]-[337]+[340]	
Cumulative reduction of GHG emissions, excluding the substitution effect of wood biofuel	tons CO_2 eq. ha^{-1}	[343]=[341]1+...+[341]N WHERE $[341]_1$ – REDUCTION OF GHG EMISSIONS IN THE FIRST YEAR; $[341]_N$ – REDUCTION OF GHG EMISSIONS IN THE REPORTING YEAR.	
Reduction of GHG emissions cumulatively with the substitution effect of wood biofuel	tons CO_2 eq. ha^{-1}	$[344]=[342]1+...[342]_N$ WHERE $[342]_1$ – REDUCTION OF GHG EMISSIONS IN THE FIRST YEAR; $[342]_N$ – REDUCTION OF GHG EMISSIONS IN THE REPORTING YEAR.	

Optimization of assortments structure

Calculation is based on comparison of management costs and incomes from roundwood and biofuel production and optimization of management by selection of harvest age. For shrubs there are no additional optimization proposed since they have to be harvested periodically and the possibilities to omtimize management regime are limited and highly uncertain.

Value of assortments and wood chips produced from willow is provided (real figures are provided in spreadsheet) in Table 50. Calculation of annual income in current prices is described in Table 51.

Table 50. Value of timber assortments

Sortiments	Unit	Value
Poles 18<	€ m^{-3}	[345]
A 28<	€ m^{-3}	[346]
28<	€ m^{-3}	[347]
18-27.9	€ m^{-3}	[348]
FIA 18<	€ m^{-3}	[349]
FBI 18<	€ m^{-3}	[350]
24 <	€ m^{-3}	[351]
18-23.9	€ m^{-3}	[352]
Low grade saw logs 18<	€ m^{-3}	[353]
14-17.9	€ m^{-3}	[354]
10-13.9	€ m^{-3}	[355]
12-17.9	€ m^{-3}	[356]
6-9.9	€ m^{-3}	[357]
PM 7-49.9	€ m^{-3}	[358]
Firewood	€ m^{-3}	[359]
Wood chips	€ LV m^{-3}	[360]

Table 51. Calculations of income due to management of shelter belt

Assortment	Unit	Calculation
Poles 18<	€ ha^{-1} yr^{-1}	[361]=[261]*[83]*[345]
A 28<	€ ha^{-1} yr^{-1}	[362]=[262]*[83]*[346]
28<	€ ha^{-1} yr^{-1}	[363]=[263]*[83]*[347]
18-27.9	€ ha^{-1} yr^{-1}	[364]=[264]*[83]*[348]
FIA 18<	€ ha^{-1} yr^{-1}	[365]=[265]*[83]*[349]
FBI 18<	€ ha^{-1} yr^{-1}	[366]=[266]*[83]*[350]
24 <	€ ha^{-1} yr^{-1}	[367]=[267]*[83]*[351]
18-23.9	€ ha^{-1} yr^{-1}	[368]=[268]*[83]*[352]
Low grade saw logs 18<	€ ha^{-1} yr^{-1}	[369]=[269]*[83]*[353]
14-17.9	€ ha^{-1} yr^{-1}	[370]=[270]*[83]*[354]
10-13.9	€ ha^{-1} yr^{-1}	[371]=[271]*[83]*[355]
12-17.9	€ ha^{-1} yr^{-1}	[372]=[272]*[83]*[356]
6-9.9	€ ha^{-1} yr^{-1}	[373]=[273]*[83]*[357]
PM 7-49.9	€ ha^{-1} yr^{-1}	[374]=[274]*[83]*[358]
Firewood	€ ha^{-1} yr^{-1}	[375]=[275]*[83]*[359]

Wood chips	€ ha^{-1} yr^{-1}	[376]=[289]*[293]*[83]*[360]
Total income	€ ha^{-1} yr^{-1}	[377]=[361]+[362]+[363]+[364]+[365]+[366]+[367]+[368]+[369]+[370]+[371]+[372]+[373]+[374]+[375]+[376]

Cost of establishment and management of the shelter belts is estimated according to involved operations. In Table 52 bolded costs are investments associated with establishment and management of shelter belts consisting of woody crops harvested as trees. By default it is assumed that these crops are hybrid poplar. Table 53 contains positions considered in calculation of costs of establishment and management of willow plantations.

Table 52. Cost of management of shelter belts of poplars

Costs	Unit	Value
Soil scarification	€ ha^{-1}	[378]
Seedlings	€ ha^{-1}	[379]
Long cuttings	€ ha^{-1}	[380]
Short cuttings	€ ha^{-1}	[381]
Planting	€ ha^{-1}	[382]
Mechanized planting	€ ha^{-1}	[383]
Tending	€ ha^{-1}	[384]
Pre-commercial thinning	€ ha^{-1}	[385]
Harvest in commercial thinning	€ m^{-3}	[386]
Harvest in regenerative felling	€ m^{-3}	[387]
Forwarding in thinning	€ m^{-3}	[388]
Forwarding in regenerative felling	€ m^{-3}	[389]
Production of harvesting residues	€ tonna^{-1}	[390]
Road transport	€ m^{-3}	[391]
Administration	% of total costs	[392]

Table 53. Cost of management of shelter belts of willows

Parameter	Unit	Value
Soil preparation and startup fertilization	€ ha^{-1}	[393]
Planting material and planting	€ ha^{-1}	[394]
Early tending	€ ha^{-1}	[395]
Wastewater sludge transport and spreading	€ ha^{-1}	[396]
Harvesting	€ LV m^{-3}	[397]
Forwarding	€ LV m^{-3}	[398]
Loading chips	€ LV m^{-3}	[399]
Wood chip transport to customer	€ LV m^{-3}	[400]
Removal of previous generation stumps	€ LV m^{-3}	[401]

Expenditures are calculated according to equations in Table 54 for trees and in Table 55 – for shrubs. Cumulative net income calculation is done according to Table 56. Example of cash flow is provided in Figure 3 for hybrid poplar planting with 20 years rotation cycle.

Table 54. Calculation of expenses due to management of shelter belts of trees

Type of cost	Unit	Calculation
Soil scarification	€ ha^{-1}	[402]=IF([71]=1;[378];0)
Seedlings	€ ha^{-1}	[403]=IF(AND([1]="HYBRID POPLAR";[71]=1);[380];IF([71]=1;[379];0))
Planting	€ ha^{-1}	[404]=IF(AND([1]="HYBRID POPLAR";[71]=1);[383];IF([71]=1;[382];0))
Tending	€ ha^{-1}	[405]=IF([71]<=4;[384];0)
Pre-commercial thinning	€ ha^{-1}	[406]=IF([1]="HYBRID POPLAR";0;IF(OR([71]=19;[71]=20;[71]=21);[385];0))
Harvesting	€ ha^{-1}	[407]$_{KC}$=IF([82]=0;0;[386]*[82]) [407]$_{GC}$=IF([82]=0;0;[387]*[82])
Forwarding	€ ha^{-1}	[408]$_{KC}$=IF([82]=0;0;[388]*[82]) [408]$_{GC}$=IF([82]=0;0;[389]*[82])
Production of harvesting residues	€ ha^{-1}	[409]=[204]*[390]
Road transport	€ ha^{-1}	[410]=[82]*[391]
Administration	€ ha^{-1}	[411]=([402]+[403]+[404]+[405]+[406]+[407]+[408]+[409]+[410])*[392]
Total	€ ha^{-1}	[412]=[402]+[403]+[404]+[405]+[406]+[407]+[408]+[409]+[410]+[411]

Table 55. Calculation of expenses due to management of shelter belts of bushes

Parameter	Unit	Calculation
Soil preparation and startup fertilization	€ ha^{-1}	[413]=IF([279]=0;[393];0)
Planting material and planting	€ ha^{-1}	[414]=IF([280]=0;[394];0)
Early tending	€ ha^{-1}	[415]=IF(OR([280]=0;[280]=1;[280]=2);[395];0)
Wastewater sludge transport and spreading	€ ha^{-1}	[416]=IF(AND([280]=1;[279]>1);[396];0)
Harvesting	€ ha^{-1}	[417]=IF([290]>0;[290]*[293]*[397])
Forwarding	€ ha^{-1}	[418]=IF([290]>0;[290]*[293]*[398])
Loading chips	€ ha^{-1}	[419]=IF([290]>0;[290]*[293]*[399])
Wood chip transport to customer	€ ha^{-1}	[420]=IF([290]>0;[290]*[293]*[400])
Removal of previous generation stumps	€ ha^{-1}	[421]=IF(AND([279]$_{N}$=0;[279]$_{N-1}$>0);[401];0)
Total	€ ha^{-1}	[422]=[413]+[414]+[415]+[416]+[417]+[418]+[419]+[420]+[421]

Table 56. Calculation of net income

Type	Unit	Calculation
Expenses	€ ha^{-1}	[423]=([412]$_{1}$+...+[412]$_{N}$)+([422]$_{1}$+...+[422]$_{N}$)
Income	€ ha^{-1}	[424]=([377]$_{1}$+...+[377]$_{N}$)
Net income	€ ha^{-1}	[425]=[424]-[423]

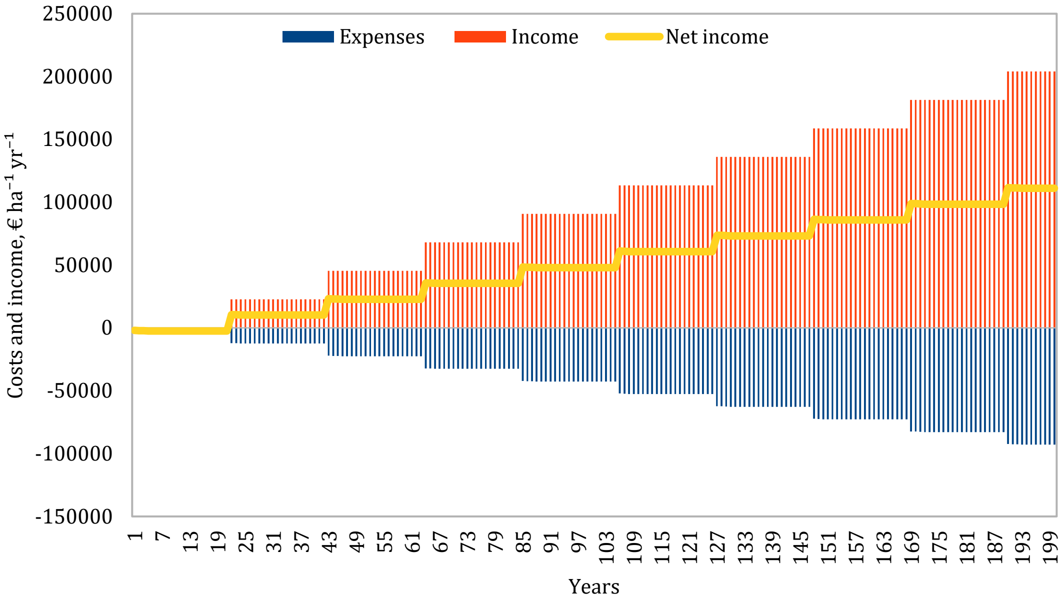

Figure 3. Example of cash flow calculation in shelter belts planted by hybrid poplars.

Optimization can be done for rotation of woody crops, maximum recommended duration is provided in the default tables, and it can be reduced by the user or other growth projections can be entered according to format provided in Table 14. Optimizing can be done using linear optimization functions buit-in the modern spreadsheet applications. Since the purpose in our project is to reduce GHG emissions, we optimized them by calculation of the smallest CO_2 mitigation cost.

It is also important to consider the substitution effect; as shown in Figure 4 in hybrid poplar plantations it is more than half of the total effect and in willow plantations it is more than 90% of the effect.

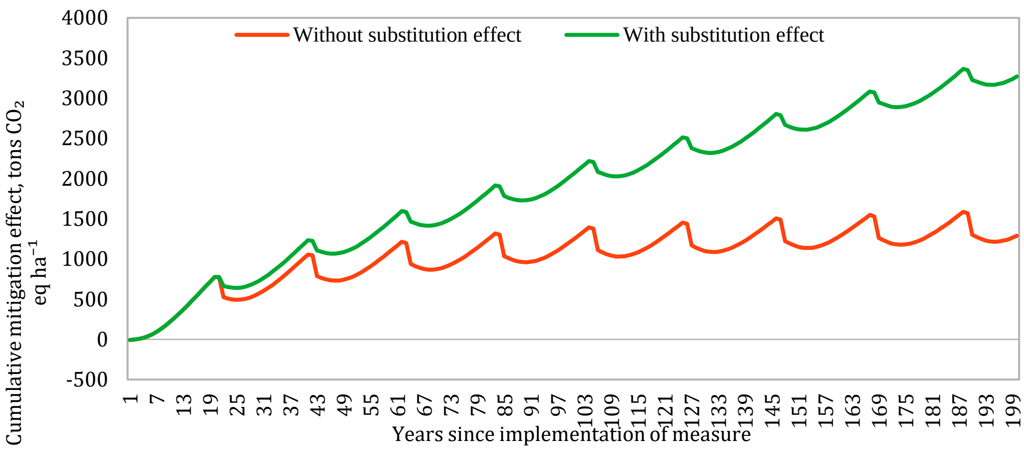

Figure 4. Climate change mitigation.

Discount rate is another important factor considered in calculation. We can optimize costs for current prices, and cash flow discounted at four interest rates as shown in example in Figure 5. This example also points out importance of the discount rate and calculation period.

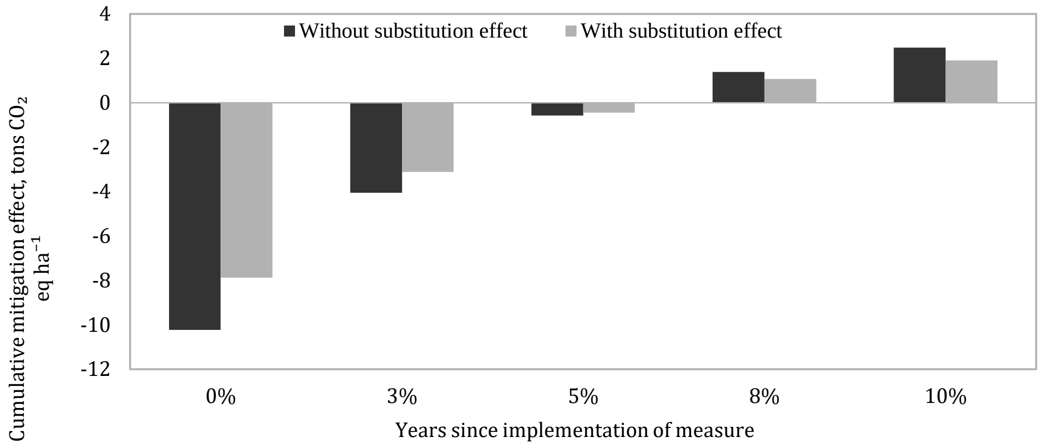

Figure 5. Climate change mitigation cost under different interest rates for 25 years calculation period.

Conclusions

1. The elaborated optimization model is simple (adoptable to any modern spreadsheet application) and easy to use. Strengths of the model is integration with methodologies applied in national GHG inventory and scientific substantiation of effect on the most of the carbon pools and GHG emissions.
2. Weakness of the model is insufficient information on soil carbon stock changes and forest floor vegetation. Most probably, removals in these pools are underestimated by using equations elaborated for the forest lands. Another weakness is insufficient knowledge about natural disturbances in shelter belts, which can become a significant source of underestimation of the potential carbon losses.
3. Optimization results depends drom the discount rate. The increase of the discount rate significantly reduces the actual role of CO_2 removals and mitigation of GHG emissions; therefore, our recommendation is to use actual static prices and income rates in optimization of the shelter belt management.
4. The EU regulation 2022/996 Annex 7 recommends to use discount rate 3.5% for the climate change mitigation projects in the countries with high income; however, at this point duration of the caculation period becomes important – longer period increases profitability of the project, but it is inconsistant with the short calculation periods in other sectors. We recommend to use commitment period based optimization range, respectively, till 2035, till 2050 and till 2100, ensuring realistic projection of contribution to national GHG mitigation targets.

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