Projections of greenhouse gas (GHG) emissions and CO2 removals in land use, land use change and forestry (LULUCF) sector in Latvia until 2035

<u>PĒTĪJUMA NOSAUKUMS:</u> **Latvijas tiešo un netiešo siltumnīcefekta gāzu emisiju un piesaistes prognožu sagatavošana 2015., 2020., 2025., 2030., 2035. un 2050. gadam ZIZIMM sektoram saskaņā ar Apvienoto Nāciju Organizācijas Vispārējās konvencijas par klimata pārmaiņām, Kioto protokola un Eiropas Savienības tiesību aktos noteiktām prasībām**

<u>PASŪTĪTĀJS</u> **Vides aizsardzības un reģionālās attīstības ministrija**

<u>IZPILDES LAIKS</u> **15.02.2015-15.12.2015**

<u>PROJEKTA NR.</u> **9**

<u>REDAKCIJA</u> **2015/02 (07.07.2015)**

<u>PROJEKTA VADĪTĀJS</u>

A. Lazdiņš

Summary

Land use, land use change and forestry (LULUCF) sector has considerable role in reduction of the greenhouse gas (GHG) emissions, boosting of CO_2 removals and constitution of fossil fuels in energy and transport sector. Growing plants means accumulating atmospheric CO_2 in photosynthesis process. After trees die or they are harvested carbon accumulated in living biomass moves to dead wood or harvested wood products (HWP) carbon pools. Further it transforms into litter and soil organic substances, contributing to regeneration of soil organic carbon pool. Carbon stock in living trees, HWP, dead biomass and soil is rapidly regenerating. Purposeful forest management can contribute to considerable increase of carbon stock in all pools in every next forest generation making forest resources fully renewable, even if fossil fuel consumption for biomass production is considered. Examples of the purposeful forest management is utilization of high quality adopted planting material (depending from tree species can increase carbon stock in living biomass in the next forest generation by 15-30 %), drainage of mineral as well as organic forest soils in conjunction with implementation of forest value targeted management practices, afforestation of abandoned farmlands, establishment of short rotation plantations for solid biofuel production, fertilization of forests and recycling of wood ash. Similarly, carbon sequestration targeted measures can be implemented in agriculture sector. The potential to increase CO_2 removals in Latvia in LULUCF sector is considerable, generally by drainage of wet forests, fertilization of forests and ash recycling as well as purposeful forest regeneration and afforestation of abandoned farmlands; however, a lot of activities, particularly the most efficient ones, are partially implemented in the past, therefore further increase of CO_2 removals will cost more and more in future. At the same time, restoration of economic activity in rural regions will increase GHG emissions from farmlands due to conversion of forest lands and grasslands into croplands. This situation requires very accurate specifying of priorities in carbon sequestration targeted activities and identification of potential cross-sectoral synergies, for instance with energy and transport sector, to support implementation of really sustainable and efficient solutions to reach climate change mitigation targets.

Table of Contents

Introduction

LULUCF sector is important in Latvia's GHG balance due to a long history of sustainable forest management which secures continuous increase of carbon stock in terrestrial ecosystems contributing at the same time to development of national economics and creation of labour places in rural regions. According to data provided by National statistical forest inventory (NFI) total forest area (including afforested lands) in 2013 is 3 325.58 kha (52 % of total country area). Total area of land converted to forest from 1990 to 2013 is 204.28 kha.

Latvia reports carbon stock changes and GHG emissions from forest land, wetland, cropland and grassland. In the forest land CO_2 removals and GHG emissions associated with living biomass and soil are estimated using mixed approach of Tier 1 and Tier 2 of the IPCC 2006 and country specific activity data, like increment and harvesting figures, mortality rate in forests, wood density values, BEFs, carbon stock in biomass, as well as the land use information. Calculations are done by Latvian State Forest Research Institute "Silava" (LSFRI Silava) with support of Ministry of Agriculture of Republic of Latvia (MoA). Emissions from organic soils (cropland, grassland, forest land, wetlands), controlled burning (forest land) and wildfires (forest land and grassland) are estimated using Tier 1 and Tier 2 methods of the IPCC 2006 and country specific activity data. Emissions due to conversion of forest land to other land use categories (living and dead wood, litter and soil carbon pools) are calculated using mostly the Tier 1 methods. In forest land converted to other land use categories living biomass, dead wood and litter is accounted using instant oxidation method. Carbon stock changes in soil due to conversion of cropland to grassland are accounted as difference of carbon stock in cropland and grassland (Lazdiņš, 2012).

The accounting methods in LULUCF sector are continuously improved; major changes are introduced in 2015 due to conversion to newer reporting guidelines (IPCC 2006; IPCC 2014a; b), due to development of the GHG accounting and projection tool for LULUCF sector and due to implementation of results of several scientific studies. The most important improvements in 2015 are implementation of country specific wood density values, carbon stock in different fractions of biomass, BEFs, as well as recalculation of losses due to commercial harvesting and natural mortality in forests. The most important guidelines related changes in accounting is implementation of soil emission factors in wetlands, as well as forest land, cropland, grassland and settlements on drained organic soils.

In the GHG accounting system forest is land of a minimum area of 0.1 ha with potential tree crown cover of more than 20 % and with the potential of trees to reach a minimum height of 5 m at maturity. Cropland refers to the area of arable land, including orchards and extensively managed arable lands. Grassland consists of land used as pastures, as well as glades and bush-land which do not fit to forest definition, including vegetated areas on non-forest lands complying to forest definition where land use type can be easily switched back to grassland without legal requirement of transformation of the land use, but except grassland used in forage production and extensively managed cropland. Wetlands category includes all inland water bodies, swamps and mires, flood-lands, alluvial lands and peat extraction sites.

The information about area of all land use categories since 2009 comes from the NFI. Information about grassland, cropland, wetlands and other lands provided by the State land service (SLS) and Central statistical bureau (CSB) are used for reference. Conversion of cropland to grassland is estimated using remote sensing method comparing vegetation index in the NFI sample plots listed as cropland or grassland (Lazdiņš &Zariņš, 2012).

Spatial approach is used to represent area of forest land, grassland, cropland, wetlands, settlements and other lands. Activity data are provided by the National forest inventory (NFI)[1]. Source data of the inventory (about 16000 plots representing 400 ha each) are used in calculations of land use and land use changes, as well as drainage and rewetting of forest land. Two cycles of the NFI (2004-2008 and 2009-2013) are used in calculations.

Research data (LANDSAT images based remote sensing studies) are used to identify forest and woody areas converted to cropland to settlement as well as extensively managed croplands where considerable area of arable land is set aside for a longer time period and can be reported by the NFI teams as grassland or forest land. Summary of land use changes according to comparison of the 1st and 2nd NFI cycle is shown in Table 1.

Table 1 Summary of land use changes according to the NFI data

Status	**Initial land use**	**Final land use**					**Total**
		cropland	**settlements**	**forest**	**wetlands**	**grassland**	
Land use changes 2009-2013	**cropland**		836				**836**
	settlements	2 596			1 686	8 420	**12 702**
	forest		10 689				**10 689**
	wetlands		1 329				**1 329**
	grassland		12 701				**12 701**
	Total	**2 596**	**25 555**		**1 686**	**8 420**	**38 257**
Sum total		**157 021**	**25 555**	**80 578**	**15 317**	**133 588**	**412 060**

1 *Source: http://www.silava.lv/userfiles/file/Meza%20statistiska%20inventarizacija/Kopsavilkumi %202014%20I%20cikls%20(2).xlsx; http://www.silava.lv/userfiles/file/Meza%20statistiska %20inventarizacija/Kopsavilkumi%202014%20II%20cikls%20(2).xlsx*

GHG emissions and CO_2 removals in LULUCF sector in 1990-2013

Net emissions of aggregated GHG (CO_2, CH_4 and N_2O) in LULUCF sector in 2013 are -147.78 Gg of CO_2 equivalents. Aggregated net removals of the GHG reduced by 98 % in 2013 compared to 1990 (Figure 1).

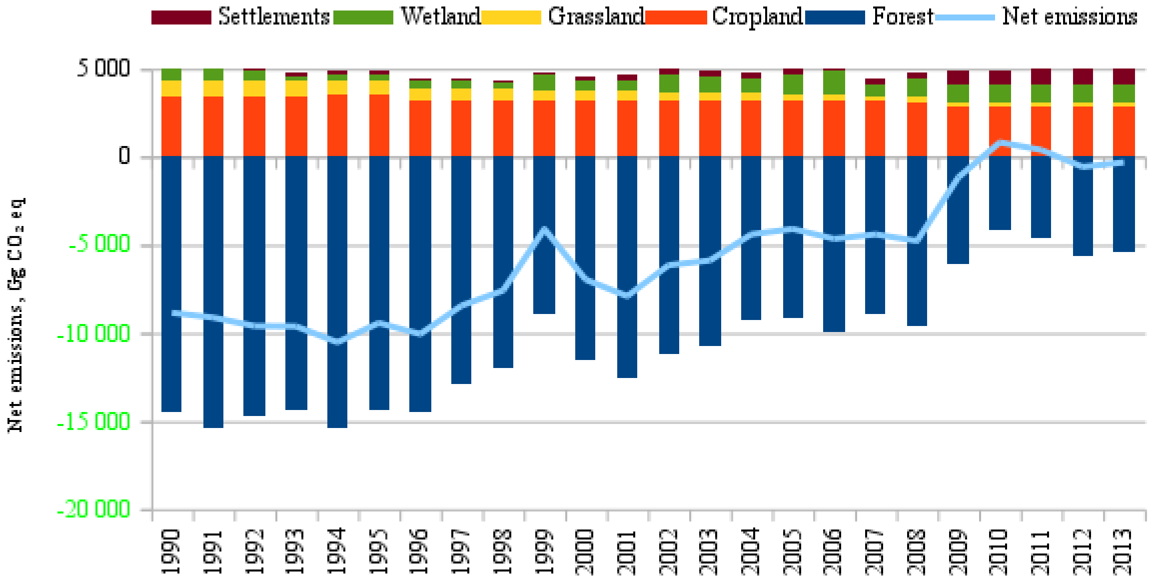

Figure 1 Summary of GHG emissions in LULUCF sector

The aggregated net emissions from forest land are -5420 Gg of CO_2 eq. in Latvia in 2013 (Figure 1). Nearly half of the net removals in forest land is HWP.

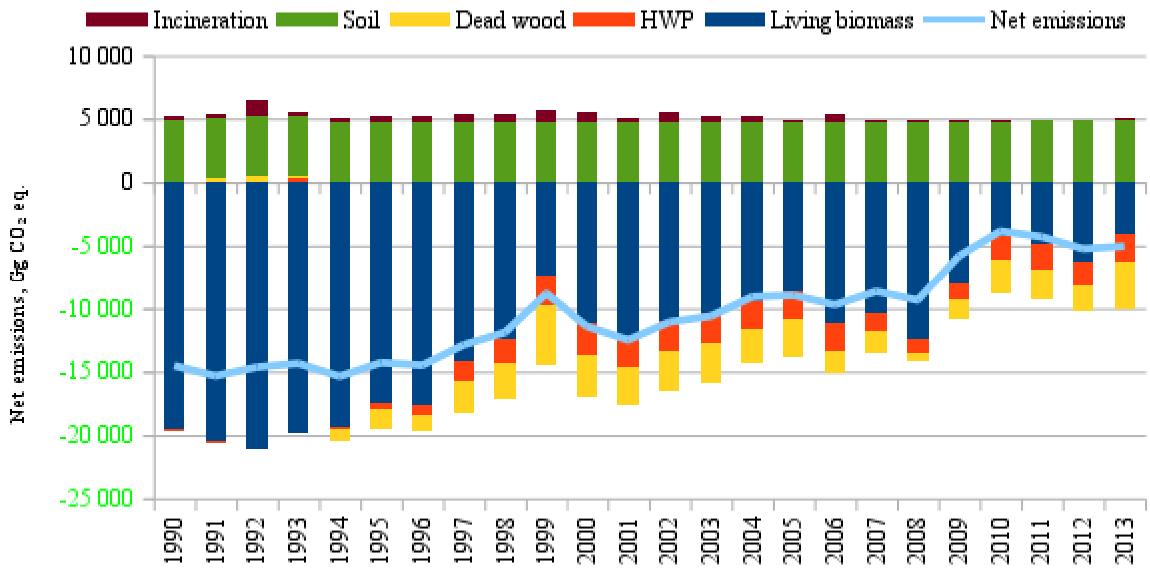

Figure 1 Summary of GHG emissions in forest land

Under the cropland category emissions from organic soils (CO_2, N_2O and CH_4), living and dead woody biomass (CO_2) are reported. Net aggregated emissions from cropland are 2839 Gg of CO_2 eq. in 2013 (Figure 1).

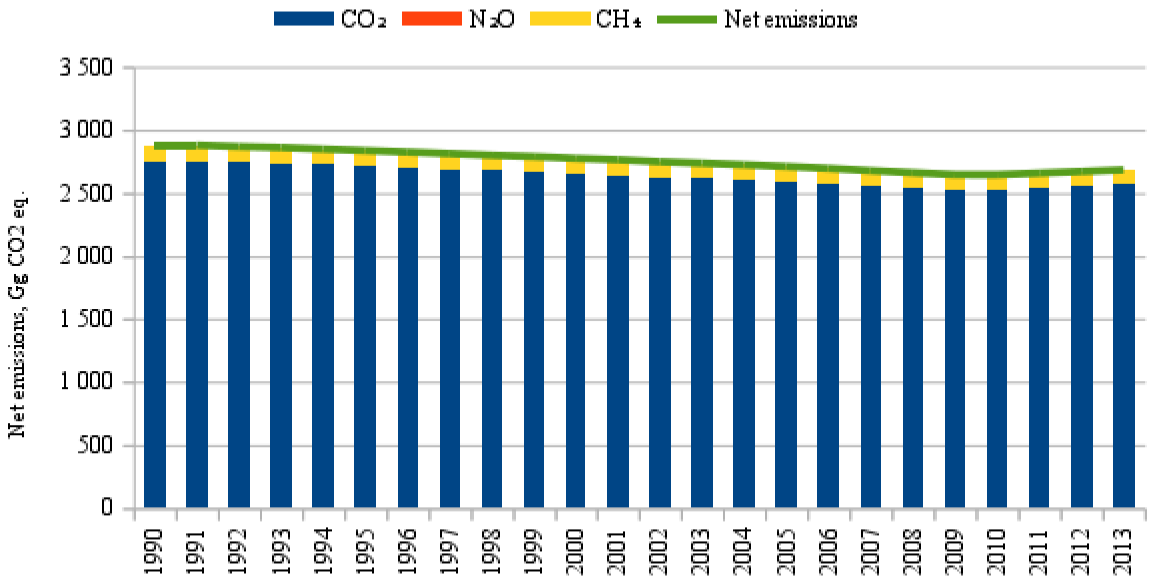

Figure 1 Summary of GHG emissions in cropland remaining cropland

The net emissions from grassland are 300 Gg CO_2 eq. (Figure 1). The CO_2 removals are accounted in living and dead biomass in forest lands not fulfilling criteria of forest definition. The most of the emissions are associated with organic soils. Reduction of the GHG emissions in 90^{ths} is associated with conversion of considerable area of cropland to grassland due to reduction of economic activity in husbandry sector.

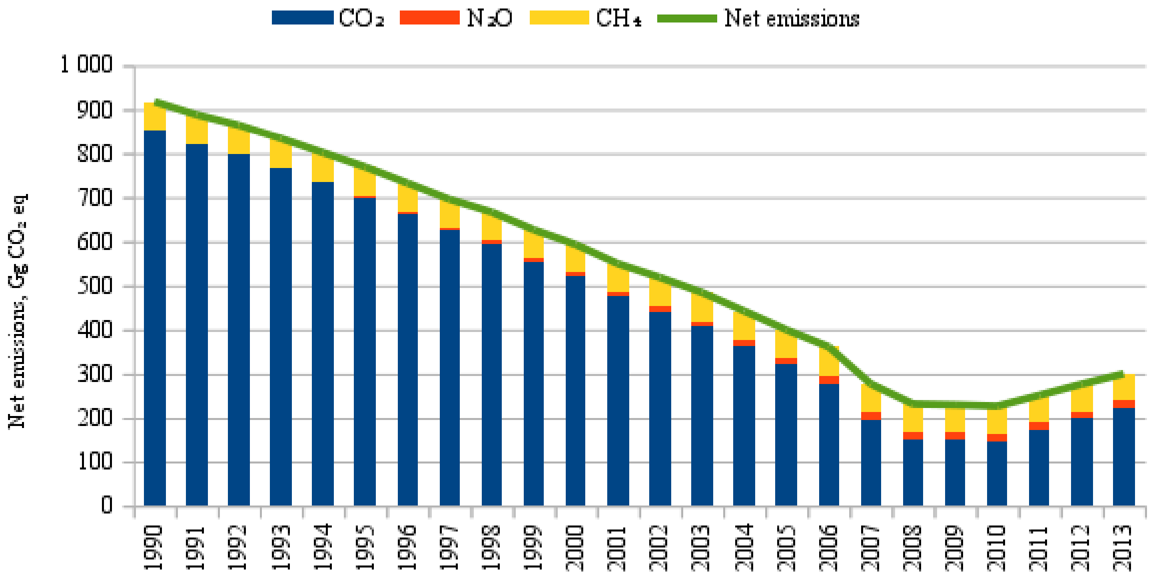

Figure 1 Summary of GHG emissions from grassland

Net emissions from settlements remaining settlements in 2013 are 924 Gg CO_2 (Figure 1). Removals in woody vegetation and dead biomass in settlements are compensated by emissions due to land use change (land converted to settlements category). Net emissions from land converted to settlements in 2013 are 1156.61 Gg CO_2 eq. Total area of settlements in 2013 is 264.10 kha, including 227.90 kha of settlements remaining settlements since 1990.

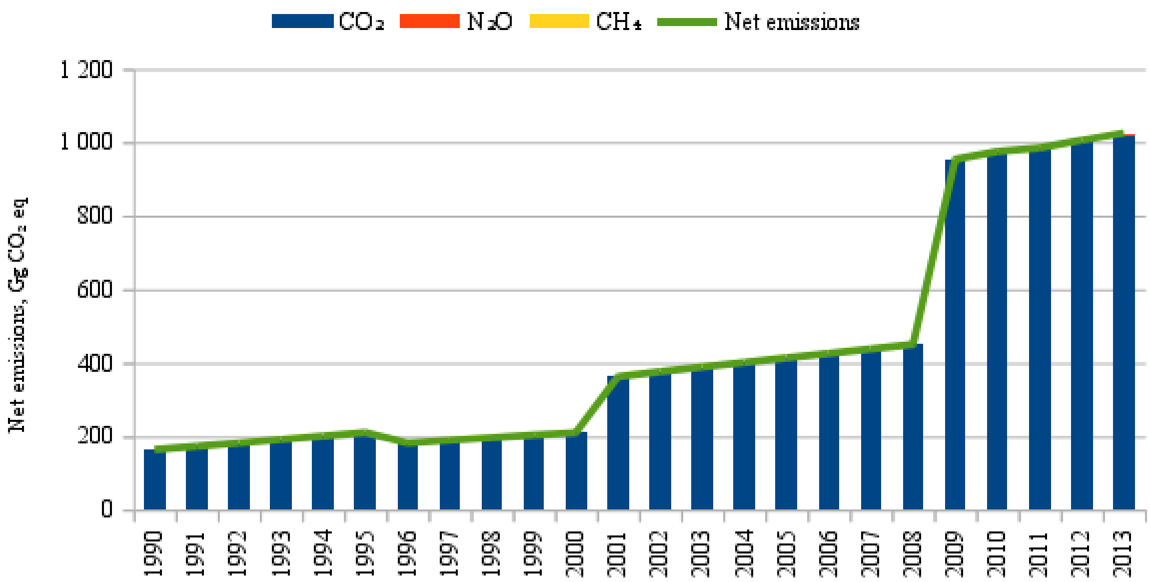

Figure 1 Summary of GHG emissions from settlements

The net GHG emissions in wetlands in 2013 are 1036 Gg CO_2 eq. (Figure 1). The most of the emissions are associated with commercial peat production for horticulture.

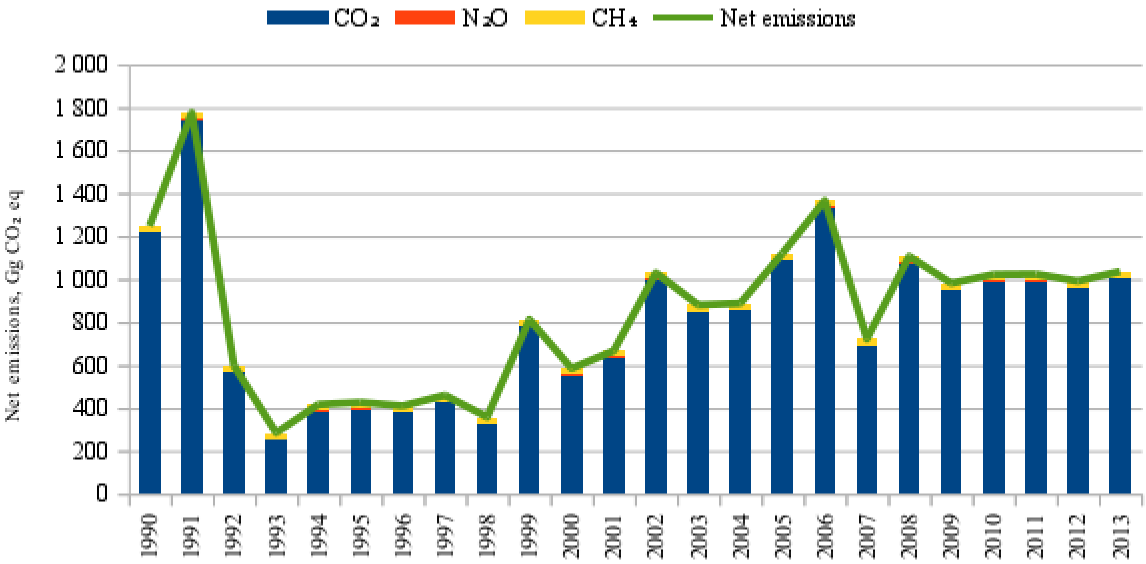

Figure 1 Summary of GHG emissions from wetlands

Assumptions and methodologies

Main assumptions

The main data source for land use and carbon stock changes is National forest monitoring program. Other data sources and research data are used as supplementary data sources, for quality assurance purposes as well as to provide activity data for those sources which are not covered by the National forest monitoring programme.

Area of organic soils in croplands and grasslands is updated according to the inventory of historical data about farmlands implemented in 2009 (L.U. Consulting, 2010). Area of cropland and grassland in LULUCF reporting is synchronized with Agriculture reporting, including recalculation of cultivated organic soils. Summary of land use change matrices is provided in Table 2. Information about area of drained mineral and organic soils in forest land is taken from the NFI (total area of forest types on drained soils).

Table 1Summary of land use change matrix

Changes	To Forest land	To Cropland	To Grassland	To Settlements	To Wetland	To Other land
1990	3 165.92	1 840.33	760.16	238.23	448.35	4.32
From Forest land		20.91	0.00	23.71	0.00	0.00
From Cropland	0.00		146.65	0.84	0.00	0.00
From Grassland	204.28	0.00		12.70	0.00	0.00
From Settlements	0.00	2.60	8.42		1.69	0.00
From Wetland	0.00	0.00	0.00	1.33		0.00
From Other land	0.00	0.00	0.00	0.00	0.00	
2013	3 325.58	1 716.34	698.25	264.10	448.71	4.32

The NFI and research data are used to estimate time series for areas and gross increment. Mortality data are calculated on the base of the NFI data and mortality factors, considering linear correlation between the modelled mortality in 2009-2013 and actual mortality data for the whole period (Lazdiņš *et al.*, 2012b). Distinction between forest land remaining forest land and areas converted to forest land is made according to the age of dominant species in forests on afforested land – if age of dominant species is less than zero in 1990, it is considered as land converted to forest, in other cases it is considered as forest land remaining forest land.

Decay factor for dead wood including harvesting residues not incinerated on-site is considered 20 years. Changes of organic carbon in litter and soil organic matter in naturally dry and wet soils are assumed to be zero according to research data on carbon stock in forest soil in 2006 and 2012 (Lazdiņš *et al.*, 2013b).

Carbon stock changes are reported separately on naturally dry and wet mineral and organic soils and drained mineral and organic soils. Conversion of forest stands on drained mineral or organic soil to naturally wet soil is accounted as rewetting.

Considerable part of non-CO_2 emissions is associated with incineration of harvesting residues in clear-cuts. The activity data for this calculation is based on an outdated study until 2010 (Līpiņš, 2004). Now a questionnaire for private forest owners on utilization of harvesting residues is used (Lazdiņš &Zariņš, 2013). According to this questionnaire in 2005-2009 about 7 % of residues are left for incineration and in 2010-2013 – 4.13 % of the residues are incinerated.

The total commercial felling of trees is very much affected by commercial felling. The demand for timber products is low at the beginning of the 1990s; therefore, felling is also at a low level and the CO_2 sink of trees is high. The felling stock increased during 1990s and reached top average in early 2000s.

In case of on-site incineration of harvesting residues during commercial harvesting, all emissions also are applied to the forest land remaining forest land category, because no commercial felling takes place in young stands (younger than 20 years) on land converted to forest land.

Forest land area and deforested area is estimated in 2009 using remote sensing approach – vegetation index are estimated in all the NFI points, including those outside forest lands in satellite image (LANDSAT) series from 1990, 1995 and 2000 to identify points where vegetation index permanently changed from values characteristic for forest lands to the one's characteristic for settlements, grassland and cropland.

Source data are provided by the NFI. The same rules are applied to the forest land remaining forest and land converted to forest. The last category is identified by the age of dominant tree species in the NFI category afforested lands – if age of the stand is above zero in 1990, it is accounted under the Forest land remaining forest category, and otherwise it stays in the converted land category. Recalculation of age of forest marked as forests growing on farmlands is the reason, why area of managed forest increased since 1990.

Forest under LULUCF accounting is land of a minimum area of 0.1 ha with potential tree crown cover of more than 20 % and with the potential of trees to reach a minimum height of 5 m at maturity. Young natural stands and all plantations established for the forestry purposes, which have to reach a crown density of 20 % or tree height of 5 m are considered under forest land; as well as the areas normally forming part of the forest area, which are temporarily unstocked as a result of human intervention or natural causes, but which are expected to revert to forest. For linear formations, a minimum width of 20 m is applied. Area estimates are derived from the NFI data[2].

Activity data

The areas of IPCC land-use categories and Latvia's official land area are given in Table 3.

Table 1 Areas of IPCC land-use classes in 1990-2013, 1000 ha[3]

Year	Total country area	Forest land	Cropland	Grassland	Settlements	Wetland	Other land
1990	6 457.30	3 168.56	1 842.24	755.01	238.82	448.35	4.32
1991	6 457.30	3 174.97	1 837.27	752.97	239.41	448.35	4.32
1992	6 457.30	3 179.04	1 833.98	751.61	240.01	448.35	4.32
1993	6 457.30	3 185.57	1 828.93	749.53	240.60	448.35	4.32
1994	6 457.30	3 192.65	1 823.50	747.29	241.19	448.35	4.32
1995	6 457.30	3 200.04	1 817.85	744.96	241.78	448.35	4.32
1996	6 457.30	3 210.13	1 810.36	741.89	242.26	448.35	4.32
1997	6 457.30	3 220.12	1 802.95	738.84	242.73	448.35	4.32
1998	6 457.30	3 227.86	1 797.12	736.44	243.20	448.35	4.32
1999	6 457.30	3 238.67	1 789.13	733.16	243.67	448.35	4.32
2000	6 457.30	3 247.70	1 782.39	730.39	244.15	448.35	4.32
2001	6 457.30	3 259.79	1 773.20	726.61	245.04	448.35	4.32
2002	6 457.30	3 268.30	1 766.53	723.87	245.92	448.35	4.32
2003	6 457.30	3 277.47	1 759.41	720.94	246.81	448.35	4.32
2004	6 457.30	3 288.49	1 750.97	717.47	247.70	448.35	4.32
2005	6 457.30	3 299.88	1 742.26	713.90	248.59	448.35	4.32
2006	6 457.30	3 311.64	1 733.30	710.21	249.48	448.35	4.32
2007	6 457.30	3 323.77	1 724.07	706.43	250.36	448.35	4.32
2008	6 457.30	3 336.27	1 714.58	702.53	251.25	448.35	4.32
2009	6 457.30	3 334.13	1 714.93	701.68	253.82	448.42	4.32
2010	6 457.30	3 331.99	1 715.29	700.82	256.39	448.49	4.32
2011	6 457.30	3 329.85	1 715.64	699.96	258.96	448.56	4.32
2012	6 457.30	3 327.71	1 715.99	699.11	261.53	448.64	4.32
2013	6 457.30	3 325.58	1 716.34	698.25	264.10	448.71	4.32

Forest land

Calculations of carbon stock changes and GHG emissions in forest lands are based on activity data provided by the NFI (area, living biomass and dead wood) and Level I forest monitoring data (soil organic carbon). National statistics (State forest service) are used to estimate forest fires and commercial felling related emissions and removals. The calculation of GHG

[2] *http://www.silava.lv/userfiles/file/2010%20nov%20MRM_visi%20mezi_04-08g.xls*

[3] *Based on the NFI data.*

emissions and CO_2 removals in historical forest lands is based mainly on research report "Elaboration of the model for calculation of the CO_2 removals and GHG emissions due to forest management" (Lazdiņš *et al.*, 2012a; b) and factors and coefficients elaborated within the scope of the research program on impact of forest management on GHG emissions and CO_2 removals (Lazdiņš *et al.*, 2013d).

Cropland

The total area of croplands is estimated using the remote sensing approach described in National inventory report on direct and indirect GHG emissions (Latvian Environment, Geology and Meteorology Centre, 2014). Activity data for calculations of emissions from organic soils are provided by research project (L.U. Consulting, 2010). Area of land remaining cropland is estimated using remote sensing based research data (Lazdiņš &Čugunovs, 2013)on the base of the NFI. Area of organic soils in farmland according to summaries of land surveys is 5.18 ± 0.5 %. This value characterizes area of cropland before 1990, because it is based on field measurements completed in 60^{ths}, 70^{ths} and early 80^{ths}. It is assumed that share of organic soil in cropland remaining cropland, cropland converted to grassland, grassland converted to cropland and grassland remaining grassland is equal. The study data on distribution of organic soil show that only about 2.2 % of farmlands are located on organic soil, including 1.0 % of cropland and 2.9 % of grassland; however, this study does not demonstrate, what are the driving forces of reduction of area of cropland on organic soil (Lazdiņš *et al.*, 2013c).

Grassland

Total area of grassland in Latvia in 2013 is 698 kha, including 562 kha of grassland remaining grassland. Grassland remaining grassland is divided into mineral and organic soils. Area of the grassland is estimated using research data (Lazdiņš &Čugunovs, 2013)on the base of remote sensing data analysis.

Grassland remaining grassland is divided into mineral (95% of total area of grassland remaining grassland) and organic (5% of total area of grassland remaining grassland[4]) soils. It is assumed that mineral soils are neither a source or sink of CO_2. Organic soils and drainage ditches in grasslands are accounted as a source of methane also as it is recommended in IPCC 2014a Chapter 2.

Settlements

Under the settlements category emissions from soils, litter, living and dead biomass due to conversion of land use type are reported. In 2013 removals in living and dead biomass in settlements are accounted using the NFI data on increment of growing stock in settlements,

4 *These figures are based on soil mapping data and characterizes situation before 1990 (data utilized in calculation are obtained from the 60^{ths} to early 80^{ths}).*

which is represented mostly by overgrowing of roadsides, power lines and other infrastructure.

The total area of settlements is estimated according to the information provided by the NFI. According to the expert estimation, increase of area of settlements during last 20 years took place due to conversion of forest land. Increase of area of settlements (deforestation) is generally associated with road construction. All roads, including forest roads are reported in the settlements category; therefore, the deforested area is considerably higher than official statistics, where forest roads are not accounted as deforested area.

Area of land remaining settlements is assumed constant until 2009 (227.90 kha) according to the NFI data, including 0.32 kha of organic soils. In 2010-2013 areas converted to settlements in 1990-1993 are accounted under settlements remaining settlements).

Area of land converted to settlements is estimated by evaluation of vegetation index of the NFI points (23 thousand plots across the country) in series of satellite images produced in 1990, 1995 and 2000. Final land use is considered according to empiric data obtained during field visits (2004-2008).

Linear regression based on remote sensing data is used to elaborate projection for conversion of forest land to other land uses in 2004-2008. NFI data are used to estimate land converted to settlements in 2009-2013.

Wetlands

According to the IPCC 2006 wetlands include land that is covered or saturated by water for all or part of the year and that does not fall into the forest land, cropland, and grassland or settlement categories. Total area of wetlands (449 kha) is reported according to the research results, including 27.0 kha of peat-lands drained for peat extraction (Table 3a.3.3 of the Penman, 2003).

Methodologies and emission factors

Methodologies in calculation of the GHG emissions are based on the newest working version of the National inventory report on direct and indirect GHG emissions in 1990-2013.

Direct N_2O emissions

Direct N_2O emissions from drainage of organic soils are estimated for forest lands, croplands, grasslands, settlements and wetlands land-use categories. Direct emissions of N_2O due to drainage of organic soils are calculated according equation No. 1 (Equation 2.7 of the IPCC 2014a).

$$N_2O-N_{OS}=\left[\left(F_{OS,CG,Temp}\cdot EF_{2CG,Temp}\right)+\left(F_{OS,F,Temp,NR}\cdot EF_{2F,Temp,NR}\right)\right];where$$
$$N_2O-N_{OS}=Annualdirect N_2O-Nemissionsfrommanaged/drainedorganicsoil,$$
$$kgN_2O-Nyr^{-1}$$
$$F_{OS}=Annualareaofmanaged/drainedorganicsoils,ha.ThesubscriptsCG,F,Temp,NR$$
$$refertocroplandandgrassland,forestland,temperateandnutrientrich,respectively.$$
$$EF_2=EmissionfactorforN_2Oemissionsfromdrained/managedorganicsoils,$$
$$kgN_2O\text{–}Nha^{-1}yr^{-1} \qquad (1)$$

Activity data consist of areas of land remaining in a land-use category and land converted to other land-use category on drained organic soils. Default N_2O emission factors for drained organic soils are shown in Table 1 according Table 2.5 of the IPCC 2014a.

Table 1: N_2O emission/removal factors for drained organic soils in all land-use categories

Land-use category	Climate/ vegetation zones	Emission factor (kg N_2O-Nha^{-1} yr^{-1})	95% Confidence interval	
Forest land, drained	Temperate	2.8	-0.57	6.1
Cropland, drained	Boreal and temperate	13	8.2	18
Grassland, deep-drained, nutrient-rich	Temperate	8.2	4.9	11
Peatland managed for extraction	Boreal and temperate	0.3	-0.03	0.64

N_2O emissions from land converted to another land-use category on drained organic soils are calculated in the same way as emissions from land remaining in a land-use category.

Direct N_2O emissions from N inputs to managed soils and from N mineralisation resulted from loss of soil organic C stocks in mineral soils due to land-use change are estimated by Tier 1 methodology using equation No. 2 (equation 11.1 of IPCC 2006):

$$N_2O-N_{N\ inputs}=F_{SOM}*EF_1;where$$
$$N_2O-N_{N\ inputs}-annualdirectN_2O-NemissionsfromNinputstomanaged$$
$$soils,kgN_2O-Nyr^{-1}$$
$$EF_1-emissionfactorforNmineralisedfrommineralsoilasaresultofloss$$
$$ofsoilcarbon,kgN_2O-N\left(kgN\right)^{-1} \qquad (1)$$

The equation No. 2 is supplemented by equation 11.8 from IPCC 2006 (equation No.4 in this document). Default factor for N mineralised from mineral soil as a result of loss of soil carbon (0.01 kg N_2O-N (kg N)$^{-1}$) from table 11.1 is used. Default C:N ratio (15) for soil organic matter is used for estimation of annual amount of N mineralised in mineral soils as a result of loss of soil carbon due to land use change to cropland (IPCC 2006). As there is no fixed default emission factors for settlements provided by IPCC guidelines, default emission factors of croplands land-use category are applied, C:N ratio for soil organic matter applied based on expert judgement is 15, and annual carbon losses in organic soil in settlements are accounted using emissions factor from cropland – 7.9 tonnes C ha^{-1} yearly (IPCC 2014a).

Indirect N_2O emissions

Indirect N_2O emissions corresponding to land-use change from N mineralisation associated with loss of soil organic matter from change of land use or management are estimated for land-use change to croplands and settlements on mineral soils. Indirect N_2O emissions from land use change to cropland are calculated according to IPCC 2006. Amount of N_2O-N emissions produced from leaching and run-off as a result from land use change to cropland are estimated by Tier 1 methodology using equation 11.10 (equation No. 3), which is supplemented by equation 11.8 from IPCC 2006 (equation No. 4).

$$N_2O_{(L)} - N = F_{SOM} * Frac_{LEACH\text{-}H} * EF_5; where$$
$$N_2O_{(L)} - N - annualamountofN_2O - Nproduced\ from\ leaching\ and\ runoff$$
$$of\ N\ additions\ to\ managed\ soils\ where\ leaching/runoff\ occurs, kgN_2O - Nyr^{-1}$$
$$Frac_{LEACH\text{-}(H)} - fractionofallNaddedto/mineralised\ in\ managed\ soils\ in$$
$$regionswhereleaching/runoff\ occurs\ that\ is\ lost\ through\ leaching\ and\ runoff,$$
$$kgN\left(kgofNadditions\right)^{-1}$$
$$EF_5 - emissionfactorforN_2Oemissions\ from\ leaching\ and\ runoff,$$
$$kgN_2O - N\left(kgNleached\ and\ runoff\ \right)^{-1}\Big) \quad (1)$$

$$F_{SOM} = \left(\Delta C_{Mineral} * \frac{1}{R}\right) * 1000; where$$
$$F_{SOM} - the\ net\ annual\ amount\ of\ N\ mineralised\ in\ mineral\ soils\ as\ a\ result$$
$$of\ \ loss\ of\ soil\ carbon\ throught\ chenge\ in\ land\ use\ or\ management,\ kg\ N\ .$$
$$\Delta C_{Mineral} - averageannuallossofsoilcarbonforland - usetype, tonnesC$$
$$R - C : Nratioofthesoilorganicmatter \quad (1)$$

Default C:N ratio (15) for soil organic matter is used for estimation of annual amount of N mineralised in mineral soils as a result of leaching/run-off associated with loss of soil carbon through land use change to cropland. Default values of fraction of all N added to/mineralised in managed soils due to leaching and run-off (0.3 kg N (kg of N additions)$^{-1}$) and emission factor for N_2O emissions from N leaching and run-off (0.0075 kg N_2O-N (kg N leached and run-off)$^{-1}$) are taken from table 11.3 of IPCC 2006.

Indirect N_2O emissions from land use change to settlements are also accounted using the IPCC 2006 Tier 1 method. Amount of N_2O-N emissions produced from leaching and run-off as a result from land use change to settlements are estimated using equation 11.10 supplemented by equation 11.8 from IPCC 2006. For estimation of annual amount of N mineralised in mineral soils as a result of leaching/run-off associated with loss of soil carbon thorough land use change to settlements, C:N ratio 15 for soil organic matter based on expert judgement is utilized. Loss of 20 % of soil carbon in land converted to settlement is used to estimate carbon stock changes.Default values of fraction of all N added to mineralised in managed soils due to leaching and run-off (0.3 kg N (kg of N additions)$^{-1}$) and emission factor for N_2O emissions from N leaching and run-off (0.0075 kg N_2O-N (kg N leached and run-off)$^{-1}$) are taken from table 11.3 of IPCC 2006.

CH_4 emissions

Drained organic soil in forest land is source of CH_4 emissions. CH_4 emissions are calculated by equation 2.6 in IPCC 2014a (equation No. 5).

$$CH_{4\_organic} = A * \left(\left(1 - Frac_{ditch} \right) * EF_{CH\_4\_land} + Frac_{ditch} * EF_{CH\_4\_ditch} \right); where$$
$$CH_{4\_organic} - annual CH_4 loss from drained organic soils, kg CH_4 yr^{-1}$$
$$A - land area of drained organic soils in a land-use category, ha$$
$$EF_{CH\_4\_land} - emission factor for direct CH_4 emissions from drained organic soils, kg CH_4 ha^{-1} yr^{-1}$$
$$EF_{CH\_4\_ditch} - emission factor for CH_4 emissions from drainage ditches, kg CH_4 ha^{-1} yr^{-1}$$
$$Frac_{ditch} - fraction of the total area of drained organic soil which is occupied by ditches \quad (1)$$

The CH_4 emission factor for organic soils of drained forest land (table 2.3 and table 2.4 in IPCC 2014a) is 2.5 kg CH_4 ha^{-1} yr^{-1} and emission factor for drainage ditches is 217 kg CH_4 ha^{-1} yr^{-1}. Data for fraction of drainage ditches of total drained area on organic soils is obtained by evaluation fraction of ditches in state managed forest lands to all drained forest organic soils.

Drained organic soil in cropland is another source of CH_4 emissions. CH_4 emissions are calculated by equation 2.6 in IPCC 2014a. The emission factor for organic soils (table 2.3 and table 2.4 in IPCC 2014a) is 0 ± 2.8 kg CH_4 ha^{-1} yr^{-1} and emission factor for drainage ditches 1165 ± 830 kg CH_4 ha^{-1} yr^{-1}; respectively, only CH_4 emissions from ditches are calculated.

Emission factors for CH_4 emissions from drained organic soil and drainage ditches in grassland are respectively 16 kg and 1165 kg CH_4 yearly according to tables 2.3 and 2.4 in IPCC 2014a.

CH_4 emissions from drained organic soils in settlements are estimated by the same methodology as in cropland using the same emission factors.

CH_4 emissions from drained organic soils in wetlands are calculated according to methodology applied in drained forests on organic soil. As drainage of wetlands in national conditions is occurring only in territories for peat extraction default emission factors for drained organic soil (6.1 kg CH_4 ha^{-1} yr^{-1}) and drainage ditches (542 kg CH_4 ha^{-1} yr^{-1}) for peat extraction are utilized.

Harvested wood products (HWP)

The net emissions from the harvested wood products are calculated according to the methodology elaborated by Rüter, 2011. The methodology corresponds to Tier 2 for HWP in IPCC 2014b. Three main HWP groups are used in calculations – sawnwod, wood based panels and paper and paperboard.

The proportion is calculated by equation No. 6 to estimate share of harvesting stock extracted due to deforestation and is used to calculate share of domestic industrial roundwood.

$$IRW_P(i) = \left(1 - \frac{D * M_{avg}}{MH_{total}}\right) * IRW_{total}(i)\ ;where$$

$IRW_P(i)$ = productionofindustrialroundwoodexcludingroundwoodfromdeforestedareain yeari, Gg Cyr^{-1};

D = annualdeforestedarea, ha;

M_{avg} = averagegrowingstockincountry, $m^3\ ha^{-1}$;

MH_{total} = totalharvestedstockvolume, m^3;

$IRW_{total}(i)$ = totalindustrialdomesticroundwoodproduction. (1)

The coefficients and numeric values used in calculation are default conversion factors recommended in IPCC 2014a (Table 1). Input data in calculation are extrapolated to 1900. Share of locally originated wood in harvested wood products is calculated using equation No. 7.

$$f_{IRW}(i) = \frac{IRW_P(i) - IRW_{EX}(i)}{IRW_P(i) + IRW_{(IM)}(I) - IRW_{EX}(i)}\ ;where$$

$f_{IRW}(i)$ = share of industrial roundwood for the domestic production of HWP originating from domestic forests in year i;

$IRW_P(i)$ = production of industrial roundwood excluding roundwood from deforested area in year i, Gg Cyr^{-1};

$IRW_{EX}(i)$ = exportofindustrialroundwoodinyeari, Gg Cyr^{-1};

$IRW_{(IM)}(I)$ = importofindustrialroundwoodinyeari, Gg Cyr^{-1}. (1)

Organic carbon in harvested wood products originated from local wood is calculated using equation No. 8.

$$CHWP = f_{IRW}(i) * HWP_D\ ;where$$

$CHWP$ = organic carbon in domestically produced HWP excluding HWP from wood produced in deforested area, Gg Cyr^{-1};

HWP_D = DomesticalproductionofHWP, Gg Cyr^{-1}. (1)

The rate of the CO_2 emissions and removals in harvested wood products is calculated using equations No. 9 and 10.

$$C(i+1)=e^{-k}*C(i)+\left[\frac{1-e^{-k}}{k}\right]*inflow(i);where$$
$$C(i+1)=annualcarbonstock,Gg\ Cyr^{-1};$$
$$e=exponentialconstant;$$
$$k=decayconstantforeachHWPcategory,unitsyr^{-1};$$
$$C(i)=carbonstock\in particularcategoryatthebeginingofyeari,Gg\ C;$$
$$inflow(i)=theinflowtotheparticularHWPcategoryduringyeari,Gg\ Cyr^{-1};$$

$$k=\frac{\ln(2)}{HL};where$$
$$HL=the\ number\ of\ years\ it\ takes\ to\ lose\ one\text{-}half\ of\ the\ material\ currently\ in\ the\ pool,\ yr \quad (1)$$

$$\Delta C(i)=C(i+1)-C(i);where$$
$$\Delta C(i)=carbonstockchangeoftheHWPcategoryduringyeari,\text{Gg C}\ yr^{-1}. \quad (1)$$

Table 1 Common coefficients to estimate balance between CO_2 emissions and removals in harvested wood products.

Factors	Numeric value		
Common coefficients			
e	2.718282		
ln(2)	0.6931		
Assortment specific coefficients:			
Assortment	**Sawnwood**	**Platewood**	**Pulpwood**
HL	35	25	2
k	0.02	0.03	0.35
e^{-k}	0.98	0.97	0.71
$k=\frac{1-\ln(2)}{H*L}$	0.99	0.99	0.85

Forest land

Carbon stock change in living and dead woody biomass is based on data provided by the NFI. Emissions from drained organic soils are accounted using emission factor 2.6 tonnes C ha^{-1} and 2.8 kg N_2O-N ha^{-1} (IPCC 2014a).

GHG emissions from rewetted organic soils are estimated according to the Tier 1 methods. CO_2 emissions are calculated using equation 3.3 (No. 11 here) complemented by equations 3.4 and 3.5 (12 and 13 here) of the IPCC 2014a.

$$CO_2-C_{rewetted\ org\ soil}=CO_2-C_{composite}+CO_2-C_{DOC};where$$
$$CO_2-C_{rewetted\ org\ soil}-CO_2-Cemissions/removalsfromrewettedorganicsoils,tonnesCyr^{-1}$$
$$CO_2-C_{composite}-CO_2-Cemissions/removalsfromthesoilandnon-treevegetation,$$
$$tonnesCyr^{-1}$$
$$CO_2-C_{DOC}-off-siteCO_2-Cemissionsfromdissolvedorganiccarbonexported$$
$$fromrewettedorganicsoils,tonnesCyr^{-1} \qquad (1)$$

$$CO_2-C_{composite}=\sum_{c,n}\left(A*EF_{CO2}\right);where$$
$$A_{c,n}-areaofrewettedorganicsoils\in climatezonecandnitrientstatusn,ha$$
$$EF_{CO2c,n}-CO_2-Cemissionfactorforrewettedorganicsoilsinclimatezonec,$$
$$nutrientstatusn,tonnesCha^{-1}yr^{-1} \qquad (1)$$

$$CO_2-C_{DOC}=\sum_{c}\left(A*EF_{DOC\_REWETTED}\right);where$$
$$A_c-areaofrewettedorganicsoilsinclimatezonec,ha$$
$$EF_{DOC\_rewetted,\,c}-CO_2-CemissionfactorfromDOCexportedfromrewettedorganicsoils$$
$$inclimatezonec,tonnesCha^{-1}yr^{-1} \qquad (1)$$

Emission factors for CO_2-C (0.5 tonnes CO_2-C ha^{-1} yr^{-1}) and DOC (0.24 tonnes CO_2-C ha^{-1} yr^{-1}) are taken from tables 3.1 and 3.2 of the IPCC 2014a. N_2O emissions from rewetted organic soils according to Tier 1 method are assumed to be negligible and are not estimated, CH_4 emissions are calculated applying Tier 1 method using equation 3.7 of the IPCC 2014a (equation No. 14 in this text). Default emission factor (216 kg CH_4-C ha^{-1} yr^{-1}) from table 3.3 is used (Table 1).

$$CH_4-C_{rewetted\ org\ soil}=\frac{\sum_{c,n}\left(A*EF_{CH4soil}\right)c,n}{1000};where$$
$$CH_4-C_{rewetted\ org\ soil}-CH_4-Cemissions/removalsfromrewettedorganicsoils,tonnesCyr^{-1}$$
$$A_c,n-areaofrewettedorganicsoilsinclimatezonecandnutrientstatusn,ha$$
$$EF_{CH4soil}-emissionfactorfromrewettedorganicsoilsinclimatezonecandnutrientstatusn,$$
$$kgCH_4-Cha^{-1}yr^{-1} \qquad (1)$$

Table 1 Emission factors for rewetted organic soils, tonnes C ha^{-1} yr^{-1}

No	GHG	Emission factor
1	CO_2	0.5
2	CH_4	0.216

Cropland

Carbon stock change in living and dead woody biomass is based on data provided by the NFI. Carbon stock in living and dead biomass is calculated using the same coefficients as in calculations of carbon stock changes in forested land.

Net carbon stock changes in mineral soil in cropland are reported as not occurring because no significant changes in management systems took place since 1990 and according to Tier 1 method of the IPCC 2006 Chapter 5[5] the carbon stock changes in mineral soil should be reported in case of changes in management practice.

CO_2 emissions from drained organic soils in croplands are calculated using IPCC 2014a Tier 1 method. Emission factor – 7.9 tonnes C ha^{-1} annually.

Unlike to cropland remaining cropland carbon stock change in living biomass in forest land converted to cropland is calculated as losses in living biomass due to felling of trees, considering average carbon stock in living biomass in forest land remaining forest in a particular year. Losses in dead wood are accounted similarly, as loss of average carbon stock in dead wood in a particular year. Carbon stock in litter is considered as constant value 12.14 ± 2.8 tonnes C ha^{-1} according to the BioSoil project results. Instant oxidation method is applied to living biomass, dead wood and litter carbon pools.

Carbon stock changes in mineral soil are estimated using Equation 2.25 of the IPCC 2006. Impact factors for calculations of the carbon stock change under different management activities are taken from Table 5.5 in IPCC 2006:

- FLU 0.69 (Long-term cultivated, Temperate moist);
- FMG 1.00 (Full tillage, Temperate dry and wet);
- FI 1.00 (Medium input, all).

The initial carbon stock in mineral forest soil at 0-30 cm depth (reference C stock) is 82.6 ± 7.8 tonnes ha^{-1} according to the forest soil monitoring project BioSoil (Lazdiņš *et al.*, 2013d). Initial carbon stock at 0-30 cm depth in grassland is considered 77 ± 6.9 tonnes ha^{-1}. The carbon stock in forest land converted to cropland after transition period of 20 years according to the Equation 2.25 is 57 tonnes C ha^{-1} at 0-30 cm depth; respectively, reduction of carbon stock in mineral soils is 25.6 tonnes ha^{-1} or 1.3 tonnes C ha^{-1} annually. The carbon stock in grassland converted to cropland after transition period of 20 years according to the Equation 2.25 is 52.7 tonnes C ha^{-1} at 0-30 cm depth; respectively, increase of carbon stock in mineral soils is 23.7 tonnes ha^{-1} or 1.2 tonnes C ha^{-1} annually.

In organic soil of forest land and grassland converted to cropland the factor for cropland remaining cropland (7.9 tonnes C ha^{-1} annually) is used to estimate carbon stock changes.

Grassland

Woody biomass increment figures for 2004-2013 are taken from the NFI, but for the historical data results of recalculation of increment of living biomass in grassland are considered

[5] *Section 5.2.3.1 Choice of Method, Tier 1.*

(Jansons, 2007). Mortality factors are taken from forest land assuming that mortality in grassland is equal to average mortality in forest land in a particular year. Decay period for dead wood is considered 20 years according to IPCC 2006.

The emission factor of drained organic soils is considered to be 6.1 tonnes C ha^{-1} yearly according to IPCC 2013.

Combined impact factor for carbon stock changes in mineral soil is 1 equal to (land use – all, management – non-degraded, input – medium); respectively, no carbon stock changes are accounted in mineral soils.

N_2O and CH_4 emissions from biomass burning are calculated according to the Tier 1 methodology in IPCC 2006 using country specific activity data.

Carbon stock changes in mineral soils in cropland converted to grassland are reported as net removals because carbon stock in grasslands in average at 0-30 cm depth is significantly higher than in cropland(Lazdiņš *et al.*, 2013a) and the difference is 23.7 tonnes C ha^{-1}.

Methane emissions from ditches on organic soils have been included in estimates also for lands converted to grasslands and it is calculated with the same approach as grassland remaining grassland.

Settlements

The CO_2 removals are accounted for living and dead biomass categories in settlements remaining settlements based on the NFI data. Removals are accounted based on weighted gross increment, mortality factors, BEFs, carbon content and wood density in a particular year in forest land. For emissions from dead wood pool in settlements remaining settlements 20 years transition period is considered.

Emissions from soils in settlements remaining settlements are calculated according IPCC 2006 Tier 1 method. It is assumed that inputs equal outputs so that settlement mineral soil C stocks do not change in settlements remaining settlements. Emissions from organic soils in settlements remaining settlements are calculated using equation 2.26 in IPCC 2006 (equation No. 15).Emissions from organic soils are calculated using emission factors for cultivated organic soils. Annual emission factor (EF) for cultivated organic soils in cool temperate climatic temperature regime is 7.9 tonnes C ha^{-1} yr^{-1}.

$$L_{Organic} = \sum_{c} (A \cdot EF)_c , where$$

$$L_{Organic} = annual carbon loss from drained organic soils, tonnes C yr^{-1};$$
$$A = land area of drained organic soils in climate type c, ha;$$
$$EF = emission factor for climate type c, tonnes C ha^{-1} yr^{-1}. \quad (1)$$

The emissions (losses in carbon pools) are reported under category forest land converted to settlements. Carbon stock changes associated with commercial felling, including removal of woody vegetation on forest infrastructure (roadsides, ditches etc.) are accounted considering that losses in living biomass are equal to average growing stock in forest land remaining forest in a particular year. Similarly, dead wood stock in forest land remaining forest in a particular year is considered as carbon losses from dead wood due to conversion of forest land to settlements. Instant oxidation method is considered for living and dead wood carbon pools.

Carbon stock changes in dead biomass are accounted using instant oxidation method considering that all dead biomass converts to emissions in the year of the land use change. Average carbon stock in dead biomass (12.14 tonnes C ha^{-1} in litter and 6.0 tonnes C ha^{-1} in dead wood) is used in calculations. Carbon stock in dead wood in converted land is considered to be equal to average carbon stock in dead biomass in forest land in a year of the conversion.

The change in soil C stocks for land converted to settlements is computed using equation 2.24 in IPCC 2006, which combines the change in soil organic C stocks for mineral soils and organic soils. Change in soil organic C stocks in mineral soils is estimated using Equation 2.25 in IPCC 2006 (equation No. 16 in this document). Emission from mineral soil is accounted assuming that carbon accumulated in upper 30 cm (82.6 tonnes C ha^{-1}) partially turns into emissions within 20 years (0.8 tonnes C h^{-1} annually). The impact factor (F_{LU} x F_{MG} x F_I) is 0.8.

$$\Delta C_{Mineral} = \frac{\left(SOC_0 - SOC_{(0\text{-}T)}\right)}{D}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REFc,s,i} \cdot F_{\mathrm{LUc,s,i}} \cdot F_{\mathrm{MGc,s,i}} \cdot F_{\mathrm{Ic,s,i}} \cdot A_{\mathrm{c,s,i}}\right), where$$

$\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils, tonnes C yr^{-1};
SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C;
$SOC_{(0\text{-}T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C;
D = time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr;
c = represents the climate zones;
s = the soil types;
i = the set of management systems that are present in a country;
SOC_{REF} = the reference carbon stock, tonnes C ha^{-1};
F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless;
F_{MG} = stock change factor for management regime, dimensionless;
F_I = stock change factor for input of organic matter, dimensionless;
A = land area of the stratum being estimated, ha. (1)

Wetlands

Latvia reports CO_2 emissions associated only with industrial peat extraction in this category. The rest of the area of wetlands is not managed and CO_2 emissions are not calculated, exception is area with woody vegetation located adjacent to water courses, water body or swamps and which does not fit to definition of forest land category.

Emission factor for carbon stock changes (2.8 tonnes C ha^{-1} yr^{-1}) due to drainage is taken from IPCC 2014a[6].

Aggregated emissions from industrial peat-lands are equal for the whole time series due to lack of data about status of industrial peat-lands prepared for extraction 20-40 years ago.

Carbon content in air dry peat (0.45 tonnes C per tonne of peat) is considered according to Table 7.5 of IPCC 2006[7]. Moisture of peat reported in national statistics is considered 40 %.

Off-site CO_2-C emissions associated to the horticultural (non-energy) use of peat extracted and removed are reported using instant oxidation method.

Relevant policies

The Cabinet of Ministers of the Republic of Latvia adopted the Forest Policy on the April 28, 1998. The main goal defined in the policy is to ensure a sustainable management of Latvian forests and it is being accomplished by documents of policy planning and regulations: the Forest Law, Forest-based Sector Development Guidelines and other forest related regulations.

The Forest Policy underlines that forest is an important part of Latvian environment and economics. The goals of the policy are:

- to ensure that the area of forest is not decreasing by setting limits to the forest land transformation;
- to ensure maintenance and increase of productivity of forest lands;
- to encourage afforestation of agriculturally non-effective land.

By following these goals the increase of forest area and input in the national economy will be reached.

The Forest Law (Latvijas Republikas Saeima, 2000) is the central law of the forest sector of Latvia, stating the following goals:

---

6 *Emission factors for CO_2–C and associated uncertainty for lands managed for peat extraction, by climate zone*

7 *Conversion factors for CO_2–C for volume and weight production data*

- to promote economically, ecologically and socially sustainable management and utilization of forests by ensuring equal rights to all owners and legal possessors of forest, ownership privacy, independence in economic actions and equal duties;
- to regulate terms of management.
- The Cabinet of Ministers defines terms of evaluation of a sustainable forest management by meeting criteria and indicators of Pan-Europe.
- Following the definitions of this Law, the responsibility of a forest owner or legal possessor is to regenerate forest stand after felling or effect from other factors as well as to ensure tending of forest stand.

The Regulation on Determination Criteria of Compensation and Calculation of Deforestation (Latvijas Republikas Ministru Kabinets, 2012) defines a procedure of calculation and compensation and criteria for negative effect caused by deforestation. It defines that the compensation to the government should be paid if the land that is registered with National Real Estate Cadaster information system as the forest area deforested. The compensation should be paid for:

- decrease of carbon dioxide attraction potential;
- reduction of biological diversity;
- decrease of quality of the environmental and natural resource protection zones and sanitary protection zone functions.

Forest-based Sector Development Guidelines (Zemkopības ministrija, 2006) is a medium-term policy planning document. Guidelines consist of the forest-based sector development medium-term (2014-2020) strategic goals, guidelines of policy development, directions of actions to achieve these goals, problems hindering achievement of these goals, and results in policies. Forest-based Sector Development Guidelines are the main document of growth and development of Latvian forestry sector. The development solutions included in this document give fundamental investment in achieving goals of other planning documents.

In Guidelines of Land Policies 2008-2014 (Reģionālās attīstības un pašvaldību lietu ministrija, 2008) the goal is to ensure sustainable use of land as unique natural resource. By following this goal it is foreseen that by 2030 the indicators of land use will be:

- agricultural lands – 35%;
- forest lands – 56%;
- lands for construction purposes – 7%;

- other lands (shrubs, swamps, under water) – 12%;
- agricultural lands that are not used – 1%.

Rural Development Programme 2014-2020 (Zemkopības ministrija, 2014) sets three long-term strategic rural development policy goals:

- competitiveness of agriculture;
- sustainable management of natural resources and climate policies;
- balanced territorial development in rural areas.

Rural Development Programme 2014-2020 is the most important tool contributing to the climate change mitigation in LULUCF sector. More detailed description of the activities in this program is provided in chapter's Error: Reference source not found sub-chapter Error: Reference source not found.

Climate change mitigation actions in LULUCF sector

The climate change mitigation measures in LULUCF sector, which are planned to be implemented in Latvia, are designated on the base of consultations with non-governmental organizations and taking into account national circumstances, in order to pursue the mitigation potential and contribute to implementation of other policies and ecosystem services, like biological diversity and water protection.

The existing policies aimed to climate change mitigation are approved in the Rural Development Programme 2014-2020, no additional measures are considered in other legal documents; therefore, the WEM scenario is equal to WAM scenario.

Existing policies (WEM scenario)

The measures proposed in the LULUCF sector action plan (529/2013/EU art 10) have been subordinated to medium term planning document: **National Development Plan of Latvia for 2014-2020** (hereinafter referred to as – NAP 2020)[8]. The listing of policies is based on the final version of the Rural Development Programme 2014-2020 (Zemkopībasministrija, 2014).

Measures in cropland

Development and adaptation of drainage systems in cropland

The activity is aimed on reconstruction and improvement of existing drainage systems in cropland to maintain and increase economic value of land and productivity of crops on drained lands. The measure has direct and indirect impact on GHG emissions in short and in long term. Impact on CH_4 and N_2O cannot be evaluated with reasonable level of uncertainty due to lack of reliable research data; therefore, only soil carbon stock changes are evaluated.

Drainage systems in cropland in Latvia are usually established not for continuous operation, but to get rid of exceeding water in spring, so that the mechanical processing of soil can be started earlier, and to avoid floods during heavy rain and snow melting.

The direct impact in cropland is associated with accumulation of CO_2 in soil carbon pool due to higher productivity of the drained fields and application of more advanced management practices. The evaluation of impact of the measure considers that it will be implemented in extensively managed cropland where poor conditions of drainage systems shorten active vegetation season or production of agricultural crops is not possible at all.

One of indirect impacts of the measure is concentration of production – more fertile cropland will be available without land use changes, so the need and willingness to convert grassland or forest land to cropland to increase production will be reduced by economic drivers.

[8] *http://www.nap.lv/*

Tier 1 method of the IPCC 2006 is applied to compare carbon stock changes in soil in case of maintenance of the drainage systems in the cropland in good conditions and current situation. Initial carbon stock in soil is considered to be equal to the value characteristic for high activity clays (HAC soils) in temperate region – 95 tonnes ha^{-1} at 0-30 cm deep soil layer. Basic scenario (current situation) considers continuous tillage in long term cultivated cropland with moderate input of organic material in soil (carbon stock change factor for land use 0.69, for tillage 1.0 and for input of organic material 1.0). The resulting carbon stock in soil before implementation of the proposed scenarios is 65.6 tonnes C ha^{-1}.

Implementation of the measure considers a higher input of organic material (soil carbon stock change factor due to the organics input 1.1) after the drainage due to higher productivity and application of more fertilizers considering 20 years transition period. Implementation of the measure will contribute to the net CO_2 removals in soil – **1.32 tonnes CO_2 ha^{-1} annually** (26.4 tonnes CO_2 ha^{-1} in total) during 20 years' period after implementation of the measure. Summary of the impact of the measure is provided in Table 1.

Table 1: Summary of impact of the measure

Parameter	Measurement unit	Value
Total affected area	kha	4.6
Total GHG reduction potential	tonnes CO_2eq	122024
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	6101
	tonnes CO_2eq $year^{-1}$ ha^{-1}	1.32

Support to introduction and promotion of integrated horticulture

The measure applies to the establishment of new orchards on existing cropland and extracted peat quarries. Implementation of the measure will affect carbon stock in living biomass and soil. Change of the land management system, particularly, establishment of continuous ground vegetation, will affect N_2O and CH_4 emissions; however, existing methods are not sufficient to predict these emissions in diverse growth conditions. The impact of the measure is projected for the 20 years' period for soil and 30 years – for living biomass carbon pools.

The quantitative estimation of impact of the measure is done according to the tier 1 method of the Penman, 2003. Carbon stock in living biomass after the transition period is calculated according to the Table 3.3.2 of the guidelines "Default coefficients for aboveground woody biomass and harvest cycles in cropping systems containing perennial species" – 63 tonnes C ha^{-1} in above-ground biomass with the average accumulation rate of 2.1 tonnes C ha^{-1} annually. Initial carbon stock in soil is considered 95 tonnes ha^{-1} (HAC soils in temperate region). Soil carbon stock change factors for land use, tillage and input are adopted from the recent guidelines (cropland – 0.69, regular tillage – 1.0 and moderate input –

1.00, IPCC 2006); respectively, before the implementation carbon stock in soil is 65.6 tonnes C ha^{-1}.

Implementation of the measure will contribute to the net CO_2 removals in soil – **8.9 tonnes CO_2 ha^{-1} annually** (267 tonnes CO_2 ha^{-1} in total) during 30 years' period (Table 1).

Table 1: Summary of impact of establishment of new orchards

Parameter	Measurement unit	Value
Total affected area	kha	0.5
Total GHG reduction potential	tonnes CO_2eq	133526
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	4451
	tonnes CO_2eq $year^{-1}$ ha^{-1}	8.9

Certain reduction of the GHG emissions can be reached by establishment of the cranberries plantations on abandoned peat-lands with nutrients poor surface layer, if compared to management of these lands for crop production or grassland management. According to the IPCC 2014a peatlands on sphagnum peat produces 36 114 kg CO_2 eq. ha^{-1}, if managed as cropland, 22 575 kg CO_2 eq. ha^{-1} – if managed as grassland and 6363 kg CO_2 eq. ha^{-1} – if managed for cranberries production or set aside after closure of drainage systems. Reduction of the GHG emissions can be considered in the case, if the area is continuously saturated with water. Periodic saturation with water may even increase the GHG emissions from soil according to the studies in Nordic countries (Salm, 2012).

<u>Support to stubble field in winter period</u>

The measure considers more extensive crop rotation in cropland, including application of green manure, to secure higher inputs of organic material into soil. It will be implemented in intensively managed cropland with medium input of organic material (the carbon stock change factor for input equals to 1.0, IPCC 2006). After implementation of the measure, the management system in the affected fields will be changed to "High, without manure" according to the IPCC 2006; respectively the carbon stock change factor for input will increase to 1.11. No GHG emissions are considered due to land use changes after implementation of the measure, because the negative impact of the activity on crop production will be compensated by intensification of production on extensively managed cropland.

Implementation of the measure will contribute to the net CO_2 removals in soil – **1.32 tonnes CO_2 ha^{-1} annually** (26.4 tonnes CO_2 ha^{-1} in total) during 20 years' period (Table 1).

Table 1: Summary of cost and impact of the measure

Parameter	Measurement unit	Value

Total affected area	kha	25
Total GHG reduction potential	tonnes CO_2eq	660963
Average annual GHG reduction potential per area unit	tonnes CO_2eq year^{-1}	33048
	tonnes CO_2eq year^{-1} ha^{-1}	1.32

Growing of papilionaceous plants (legumes)

The measure is similar to the previous and considers use of legumes in mixture with other crops in cropland, considering higher inputs of organic material into soil and partial replacement of mineral fertilizers with nitrogen fixing plants. It will be implemented in the intensively managed cropland with medium input of organic material (the carbon stock change factor for input equals to 1.0, IPCC 2006). After application of the measure the management system in the affected fields, will be changed to “High, without manure” according to the IPCC 2006 and the carbon stock change factor for input will increase to 1.11.

Implementation of the measure according to the tier 1 method will contribute to the net CO_2 removals in soil – **1.32 tonnes CO_2 ha^{-1} annually** (26.4 tonnes CO_2 ha^{-1} in total) during 20 years’ period after implementation of the measure (Table 1).

Table 1: Summary of impact of the production of legumes

Parameter	Measurement unit	Value
Total affected area	kha	50
Total GHG reduction potential	tonnes CO_2eq	1321925
Average annual GHG reduction potential per area unit	tonnes CO_2eq year^{-1}	66096
	tonnes CO_2eq year^{-1} ha^{-1}	1.32

Greening of cropland

Leaving a certain area of cropland out of conventional cropping system, if the area is not afforested or used for perennial crop production, in general will not lead to reduction of the GHG emissions or increase of CO_2 removals, because reduction of the field size in one place should be compensated by increase of a field area in other place to maintain production, if no other productivity measures are applied. However, there is an option to reduce GHG emissions by reduction of management activities on organic soil. No additional support is considered for conversion of organic soil; therefore, in the impact calculation it is assumed, that share of cropland on organic soil left for greening purposes will be equal to share of organic soils in cropland.

Conversion of cropland on organic soil to grassland will reduce CO_2 and N_2O emissions. According to the IPCC 2014a CO_2 emissions from cropland on organic soil in temperate climatic zone equals to 28.97 tonnes CO_2 ha^{-1} annually, the emissions from grassland on organic soil in temperate climatic zone equals to 22.37 tonnes CO_2 ha^{-1} annually, respectively, the land use changes from cropland to grassland on organic soil reduce the CO_2 emissions by 6.6 tonnes CO_2 ha^{-1} annually. Conversion of 1 ha of cropland to grassland considering 5.18% share of organic soils would reduce CO_2 emissions by **0.3 tonnes CO_2 ha^{-1} annually**. Reduction of N_2O emissions are covered by the agriculture sector.

Duration of the impact of the activity depends from carbon stock in organic soil in transformed cropland on organic soil. In calculations the impact is considered equal to 20 years; however, it continues as long as the field is not returned to crop production. Summary of the impact of the measure is provided in Table 1.

Table 1: Summary of impact of the greening activities

Parameter	Measurement unit	Value
Total affected area	kha	-
Total GHG reduction potential	tonnes CO_2eq	273 504[9]
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	13 675
	tonnes CO_2eq $year^{-1}$ ha^{-1}	0.3

Measures in forest land

Development and adaptation of forestry infrastructure

The measure is aimed on reconstruction and improvement of existing drainage systems in forest land to maintain and increase economic value of land and productivity on drained lands. The measure has a direct and indirect impact on GHG emissions in short and in long term. Living and dead biomass carbon pool is highly affected in forest land. Impact on the non-CO_2 GHG (CH_4 and N_2O) cannot be evaluated with reasonable level on uncertainty due to lack of reliable research data. Therefore only impact on CO_2 emissions is evaluated.

Forest drainage is one of the most efficient solutions to increase CO_2 removals in living biomass and other carbon pools in forest lands. The research data on impact of drainage of organic soils demonstrates controversial results; for instance, 51 years long monitoring of impact of drainage and afforestation of a transitional bog in central part of Latvia demonstrates a significant increase of carbon stock in all carbon pools, including soil. However, during the first 15 years after drainage, the study area is the source of emissions (Lazdiņš *et al.*, 2014a; b; Lazdiņš &Lupiķis, 2014; Lupiķis*et al.*, 2014). The IPCC 2014a considers that soil is the source of CO_2 emissions in all forests on organic soils, the factor of CO_2 emissions according to the guidelines is 2.6 tonnes C ha^{-1} annually. According to the IPCC 2014a, the CO_2 emissions from soil in rich rewetted organic soil in temperate climatic zone are 0.5 tonnes C ha^{-1} annually; respectively, difference between soil carbon stock changes in the forest area with maintained drainage system and rewetted area on organic soil in theory is 2.2 tonnes C ha^{-1} annually. However, this is not approved by studies in

[9] *Considering 20 years impact period.*

neighbouring countries (Salm*et al.*, 2009, 2012; Salm, 2012). Due to contradictious estimates in the guidelines and the research results impact of reconstruction of drainage systems on soil is not considered here.

The most of the forest drainage systems in forest land in Latvia are established before 1990. Proposed lifetime of a drainage system is 30 years; consequently, the most of the drainage systems are now outdated. However, in spite of declining of technical conditions of the drainage systems, the drained generation of trees usually continues to grow following increment curves, characteristic for naturally dry forest or even better due self-regulating of water regime. The growth rate can be disturbed by natural ageing of the forest stands, regenerative felling or intensive thinning, as well as due to severe changes in growth conditions like flooding of an area by beavers. The most common reason for "switching off" self-regulation of water regime in Latvia is regenerative felling. Therefore, it is important to prioritize reconstruction of drainage systems in mature stands before regenerative felling and young stands to secure that growth of the second generation of trees on drained lands follows the growth curves characteristic for naturally dry and drained forests.

An example of two scenarios – drained and wet organic soil is shown in Figure 1. It is considered, that in case of reconstruction of the forest drainage systems in pine stands, the development of the second rotation of trees will follow the blue columns and in case of rewetting – red columns in Figure 1.

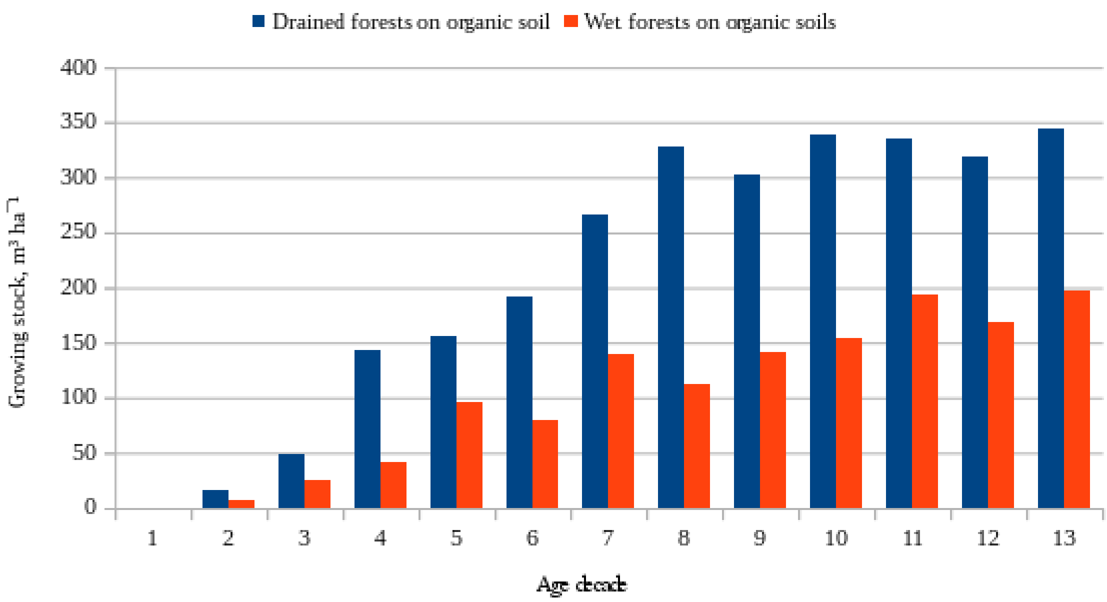

Figure 1: Growing stock in drained and naturally wet pine stands on organic soils

The carbon stock change in dead wood and litter carbon pools is not considered in the calculation due to high uncertainty of the research data.

The average annual impact of the measure on CO_2 removals is 1.3 tonnes CO_2 ha^{-1} and the average impact during the rotation period is 99 tonnes CO_2 ha^{-1} (Table 1).

Table 1: Summary of impact of the measure

Parameter	Measurement unit	Value
Total affected area	kha	12
Total GHG reduction potential	tonnes CO_2eq	1181825
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	15612
	tonnes CO_2eq $year^{-1}$ ha^{-1}	1.3

Afforestation and improvement of stand quality in naturally afforested areas

The scope of afforestation is economically and environmentally efficient utilization of former farmlands, which are not any more used for food of fodder production. This is the most efficient climate change mitigation measure in the Rural development plan 2014-2020.

The afforestation secures accumulation of CO_2 in living and dead biomass, litter and soil (only in less fertile and depleted soils). The growth conditions in afforested lands usually are similar to fertile forest stand types on drained or naturally dry mineral soils. Carbon stock changes in litter are 0.37 tonnes CO_2 ha^{-1} annually during 150 years period, according to the calculation method applied in the GHG inventory. In average, afforestation of 1 ha will contribute to removal of 596 tonnes of CO_2 during the rotation or 7.4 tonnes of CO_2 annually. Total impact of the measure will be nearly 4 million tonnes of CO_2 or 0.05 million tonnes of CO_2 in average annually (Table 1).

Table 1: Summary of impact of the measure

Parameter	Measurement unit	Value
Total affected area	kha	6.6
Total GHG reduction potential	tonnes CO_2eq	3 935 472
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	48 666
	tonnes CO_2eq $year^{-1}$ ha^{-1}	7.4

Regeneration of forest stands after natural disturbances and preventive measures in forests

Two measures are considered under this activity – regeneration of forest stands after forest fires and other natural disasters, and maintenance and improvement of preventive system of the forest fires.

Regeneration of forest stands after natural disasters considers support to regeneration of forests after natural disasters, like forest fires and strong storms, as well as to reconstruction of diseasing valueless forest stands. The measure will affect carbon stock in living biomass, dead wood, litter and soils carbon pools. In evaluation of carbon stock changes in living biomass 2 scenarios are compared – natural regeneration and planting of trees, considering that planted trees will grow faster. The breeding effect is considered according to the recent research results (Jansons &Baumanis, 2008; Lazdiņš, 2010, 2012; Lazdiņš *et al.*, 2013d).

The average additional increment of stem wood per rotation due to utilization of the improved planting material in the forest regeneration according to the given assumptions is 43 m^3 ha^{-1} (0.47 m^3 ha^{-1} annually) or 60 tonnes CO_2 ha^{-1} (0.59 tonnes CO_2 ha^{-1} annually, Table 1).

Table 1: Summary of impact of the measure

Parameter	Measurement unit	Value
Total affected area	kha	31
Total GHG reduction potential	tonnes CO_2eq	1862524
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	18195
	tonnes CO_2eq $year^{-1}$ ha^{-1}	0.59

Preventive measures of forest damages is aimed to maintenance and improvement of forest fire prevention system, including reconstruction of existing and building of new fire observation towers. The potential impact of the measure on the GHG emissions is not evaluated yet; however, it is well known that the towers are very efficient in early identification and localization of the forest fires, hence the area of the forest fires is considerably smaller than it would be if the fire prevention system did not exist. Due to lack of data this activity is not considered in projections of the climate change mitigation measures; however, it should be done as soon as reliable research data are available.

Improvement of ecological value and sustainability of forest ecosystems

The scope of the measure is to support pre-commercial thinning of young stands in private forests to secure implementation of sustainable forest management practices (Jansons & Zālītis, 1998; Zālītis, 2004; Zālītis & Lībiete, 2008; AS" Latvijas valsts meži", 2012) aimed to increase economic and ecological value of forests in long term.

Pre-commercial thinning has short and long term impact. The short impact is a transfer of certain portion of the carbon from living biomass to the dead biomass pool with following conversion into CO_2 during 20 years according to Tier 1 approach according to IPCC 2006. The long term impact is increase of growing rate (by 15 % annually in average, according to an expert judgement used in some growth models).

The climate change mitigation effect of the pre-commercial thinning is calculated as the difference between growing stock at the end of the rotation period and the difference in timber stock extracted in the commercial thinning. The growth models are derived from recent research data (Zālītis, 2006; Zālītis& Jansons, 2009; Zālītis *et al.*, 2014).

The average impact of the measure is additional increment of 1.4 m^3 ha^{-1} stem wood or additional removals of 1.9 tonnes CO_2 ha^{-1} annually resulting in net additional removals of 146 tonnes CO_2 ha^{-1} per rotation (Table 1). Duration of the impact of the activity is 100 years; however, the most of the contribution will be reached during the first 50 years.

Table 1: Summary of cost and impact of the measure

Parameter	Measurement unit	Value
Total affected area	kha	15
Total GHG reduction potential	tonnes CO_2eq	2196836
Average annual GHG reduction potential per area unit	tonnes CO_2eq $year^{-1}$	28056
	tonnes CO_2eq $year^{-1}$ ha^{-1}	1.9

Additional measures

No additional measures are considered in existing policies and strategies. However, additional measures are evaluated at scientific level to propose improvements of existing policies and climate change mitigation targeted financial instruments.

The scientifically verified climate measures are separated in this document into the forest land and cropland or grazing land management related activities. Measures with direct positive impact on CO_2 removals in forest land are:

1. afforestation and establishment of short rotation plantation forests;
2. purposeful forest regeneration including remedial drainage of wet areas;
3. forest thinning, particularly pre-commercial thinning;
4. fertilization of forest and recycling of wood ash in forest;
5. establishment of new forest drainage systems, especially on mineral soils;
6. regenerative felling of ageing forests (long term impact in conjunction with regeneration and remedial drainage);
7. reconstruction of low valued naturally regenerated stands of deciduous trees.

The measures No.1, 2 and 7 are included into the WAM scenario to some extend; however, the climate change mitigation potential of these measures is considerably larger than the implementation plans.

Considerable area of farmlands became available for afforestation and establishment of short rotation plantation forests after reduction of husbandry production in 90^{ths}, which lead to abandonment or extensive use of the most of pastures and considerable area of cropland. It is not estimated in Latvia, what is the total area available for afforestation and short rotation forests, because economic conditions are rapidly changing and use of cropland and grassland is closely related accessibility of certain types of subsidies in agriculture. In spite of being the most valuable climate change mitigation measure, afforestation is not economically beneficial in short term in the current economic situation and considerable changes are necessary in agriculture policy to boost implementation of this measure on a commercial base.

Establishment of 200 kha of poplar plantations would increase harvesting stock by 5 million m^3 during 20 years, providing additional CO_2 removals of 3.7 million tonnes annually. Afforestation has an important side impact, if the afforested area is on organic soil, which is the biggest source of emissions in cropland and grassland. According to IPCC 2014b afforestation of 1 ha of cropland on organic soil reduces CO_2 emissions by 19.4 tonnes ha^{-1}, but total reduction of GHG emissions including DOC, N_2O and CH_4 is 25 tonnes CO_2 eq ha^{-1} annually. Afforestation of all organic soils in cropland theoretically would reduce GHG emissions by 2.2 million tonnes CO_2 eq, besides removals in living and dead biomass. Alternative solution – conversion of cropland on organic soil to grassland would reduce GHG emissions by 0.75 million tonnes CO_2 eq if all organic soils are converted (8.5 tonnes CO_2 eq ha^{-1} annually). Afforestation of grassland on organic soil would reduce emissions by 16.5 tonnes CO_2 eq ha^{-1} annually (0.48 million tonnes CO_2 eq annually if all grasslands on organic soils are afforested). Therefore, the maximum potential of the afforestation of organic soils in Latvia, beside CO_2 removals in living and dead biomass, is 2.68 million tonnes CO_2 eq annually according to default emission factors (IPCC 2014a), if all organic soils are afforested.

Drainage of forest stands suffering of exceeding water is proved to be the most efficient climate change mitigation measure in Latvia contributing to CO_2 removals in living and dead biomass, but having also some short term negative impact on soil carbon stock. Additional CO_2 removal on drained mineral soil is 3.3 tonnes ha^{-1} annually, on organic soils – 2.7 tonnes ha^{-1} annually. The potential of forest drainage in Latvia – additional removals of 1483 Gg CO_2 annually.

Forest regeneration considering scarification and planting or sowing improved genetic material secures additional CO_2 removals in living biomass due to breeding effect (50 tonnes ha^{-1} per forest management cycle); if applied in all forest stands regenerated by spruce, pine or birch breeding effect contributes to additional removals of 103948 Gg CO_2 in 75 years or 138 Gg CO_2 annually. Breeding has additional poorly investigated impact on carbon stock in dead biomass (due to better growth and larger dimensions of trees), litter and soil carbon stock.

Forest thinning secures continuous CO_2 removals in forest stands, improves health of forest stand and reduces risk of natural disturbances, increase carbon stock in HWP (10-15 % of total removals in HWP), contributes to replacement of fossil fuel (15-20 % of the total) and contributes to additional CO_2 removals in living biomass. Impact of thinning in "business as usual" conditions is sufficiently quantified in spruce and pine stands, according to these estimates thinning can contribute to additional removals of 110 Gg CO_2 annually in coniferous stands.

Forest fertilization and ash recycling in Latvia can contribute to additional removals of 1.2 million tonnes of CO_2 in living biomass annually. Additional effect of fertilization is increase of carbon stock in dead wood and soil carbon pools; however, these changes are not quantified in production conditions.

The most valuable measure on reduction of GHG emissions in cropland and grassland is already described previously. This measure is afforestation of organic soils, which are the biggest source of CO_2 and N_2O emissions and wet mineral soils, which is considerable source of CH_4 emissions. Conversion of cropland on organic soil to grassland (pasture) would also contribute to considerable reduction of CO_2 and N_2O emissions.

Another measure with the largest climate change mitigation effect in cropland is agro-forestry – establishment of short rotation woody crops as buffer zones around water streams and drainage ditches or on abandoned farmlands not used for crop production. Short rotation crops in the fields (not buffer zones) can be used for utilization of wood ash, wastewater sludge and other organic residues, which cannot be safely applied to fields used in food production. Poplar or willow plantation in 80 years replace 960 tonnes ha^{-1} of CO2 emissions (44 Gg CO_2 annually in 30000 ha). The area limit of 30000 ha is determined by availability of organic fertilizers necessary for efficient growth. Area and potential of production of buffer zones around drainage ditches and water streams is not evaluated yet.

It is necessary also contribute more to implementation of agricultural practices increasing soil carbon stock, like use of organic amendments (treated husbandry residues, peat, torrefied biomass and others) and crop rotations considering plants with large residual biomass. It is necessary also to support liming of soils in farmlands to avoid acidification and depletion of soils and to secure success of other measures depending from fertility of soil. The input of organic materials into soil in the intensively cultivated croplands decreased during last decades, if compared to situation before 1990; therefore, the potential of CO_2 removals in mineral soils in cropland can be really huge. According to Tier 1 method of the IPCC 2006 improved agricultural practices can contribute to sequestration of 11.2 million tonnes of CO_2 in soil in cropland (7.3 tonnes ha^{-1} in 20 years period or 0.4 tonnes CO_2 ha^{-1} annually). However, this positive impact will be partially compensated by expanding of croplands to have the same annual area for the traditional crop production. Another, less favourable alternative, is reduction of agricultural production due to shortage of cropland area.

Different alternatives of implementation of the climate change mitigation measures in forest land, cropland and grassland, including their direct and indirect, as well as combined impact related to efficiency of production, productivity, environmental and social issues should evaluated further to provide scientifically based and economically viable solutions for additional climate change mitigation measures to reach the GHG mitigation targets in 2020 and afterwards.

Projection of results of implementation of measures

The net impact of the existing measures (WEM scenario) during the whole impact period is 12 136 kilotonnes CO_2; the total affected area – 185 kha; the average annual impact is 1.4 tonnes CO_2 ha^{-1} (256 kilotons CO_2 eq. $year^{-1}$ in all affected areas, Table 1). The most efficient measure is afforestation (486 kilotons tonnes CO_2 eq. $year^{-1}$); however, the total impact of this measure still has to be evaluated. According to Tier 1 based methodology, duration of the impact of the measures in cropland is 20-30 years; according to Tier 1 and Tier 2 based methodology, duration of impact of the measures in forest land is 76-102 years.

The most of the impact (66 %) is expected after 2030 due to long lasting effect of the measures in affected forest lands. The mean annual impact is calculated as an average – the total impact divided by duration of the measure.

Significant changes in the projection may arise from estimation of impact of the fire prevention system, which seems to be the most valuable climate change mitigation measure from those proposed in the Rural development plan 2014-2020.

Table 1: Summary of impact of the existing measures

Measure	**Impact period, years**	**Total affected area, ha**	**Total GHG reduction potential, tonnes CO_2eq**	**Annual GHG reduction potential per area unit, tonnes CO_2eq $year^{-1}$**	**Annual GHG reduction potential per area unit, tonnes CO_2eq year-1 ha^{-1}**	**GHG reduction potential until 2020, tonnes CO_2eq**	**GHG reduction potential in 2021-2030, tonnes CO_2eq**	**GHG reduction potential after 2030, tonnes CO_2eq**
Measures in cropland								
Cropland drainage	20	4 615	122 024	6 101	1,3	36 607	61 012	24 405
Establishment of orchards	30	500	133 526	4 451	8,9	26 705	44 509	62 312
Greening activities	20	40 000	273 504	13 675	0,3	82 051	136 752	54 701
Production of legumes	20	50 000	1 321 925	66 096	1,3	396 578	660 963	264 385
Extensive crop rotation	20	25 000	660 963	33 048	1,3	198 289	330 481	132 193
Measures in forestland								
Drainage in forest	76	11 971	1 181 825	15 612	1,3	93 670	156 117	932 038
Afforestation	81	6 600	3 935 472	48 666	7,4	291 995	486 658	3 156 820
Forest thinning	78	15 000	2 196 836	28 056	1,9	168 337	280 562	1 747 937
Forest regeneration	102	31 000	1 862 524	18 195	0,6	109 169	181 949	1 571 406
Total impact	-	184686	11 688 599	233 900	1,27	1 403 401	2 339 002	7 946 196

Projections of the GHG emissions

The impact of the existing measures (WEM scenario) on CO_2 emissions and removals is considered in the projection of the LULUCF sector. According to the land use estimates the net CO_2 emissions in scenario without measures will increase from 1.1 million tonnes CO_2 in 2015 to 7.2 million tonnes CO_2 in 2035 (Figure 1). The main drivers for increase of the CO_2 emissions will be ageing of forest and projected decrease of increment, deforestation to settlements due to growth of economic activity in rural regions and increase of peat production for use in horticulture. Notably, that the biggest sources of future CO_2 emissions are estimated using Tier 1 method according to the IPCC 2006. Implementation of the Tier 2 methods and application of the country specific emission factors might change the estimates dramatically, like it happened due to implementation of the soil emissions factors according to IPCC 2014a.

Implementation of existing measures will reduce CO_2 emissions by 199 Gg CO_2 annually, in average, reaching maximum at 2020 and starting to reduce after 2029 (Figure 1).

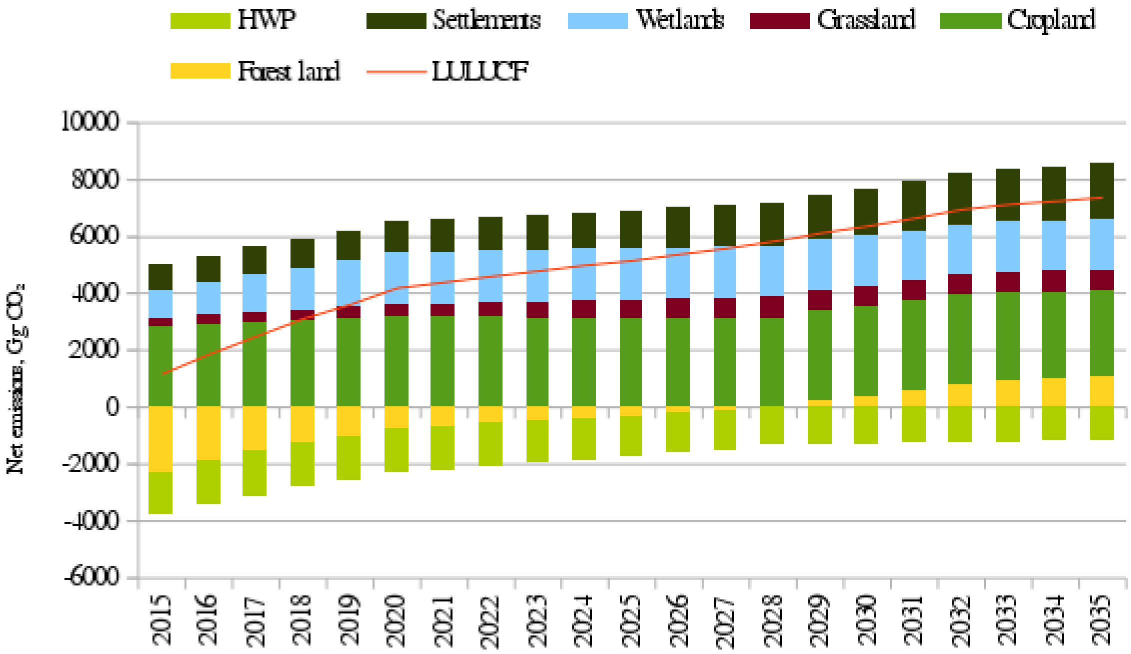

Figure 1: Projections of CO_2 emissions from LULUCF sector without measures

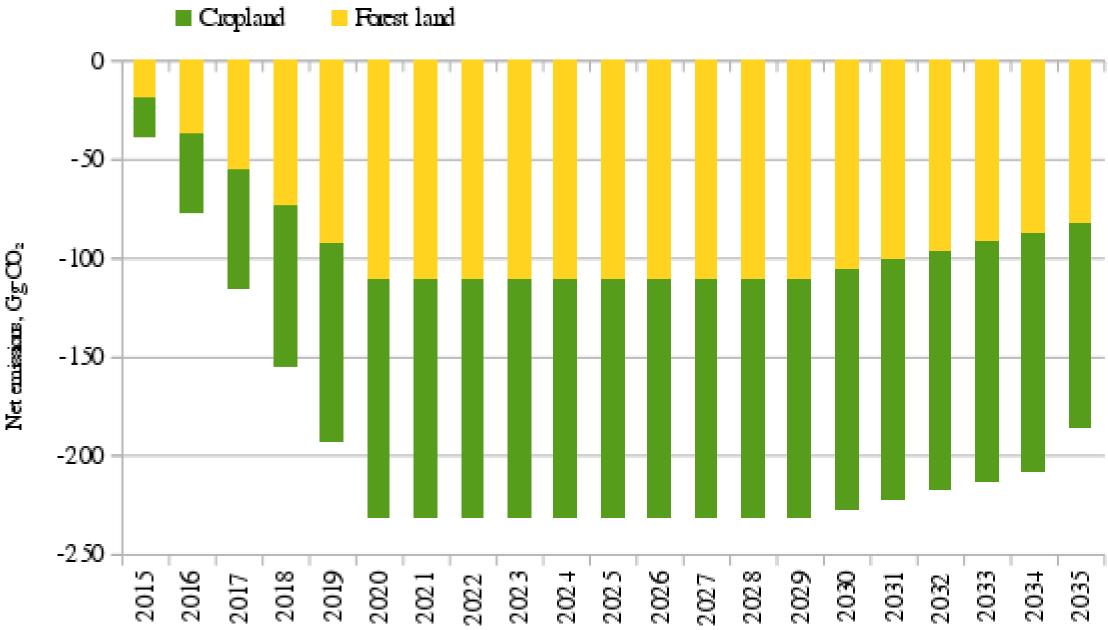

Figure 1: Impact of existing measures on projections of CO_2 emissions from LULUCF sector

N_2O emissions are much more stable in the projections – 2.17 Gg N_2O annually in average (647 Gg CO_2eq) in WOM scenario (Figure 1). The most of the N_2O emissions are associated with organic soil in forest lands. N_2O emissions from organic soil in cropland and grassland not being subject of land use changes are accounted under Agriculture sector. Implementation of the existing measures have no impact on N_2O emissions; however, availability of more accurate estimates on changes of GHG emissions due to a change of land use and management regime will provide opportunity to calculate impact of the existing measures on N_2O emissions.

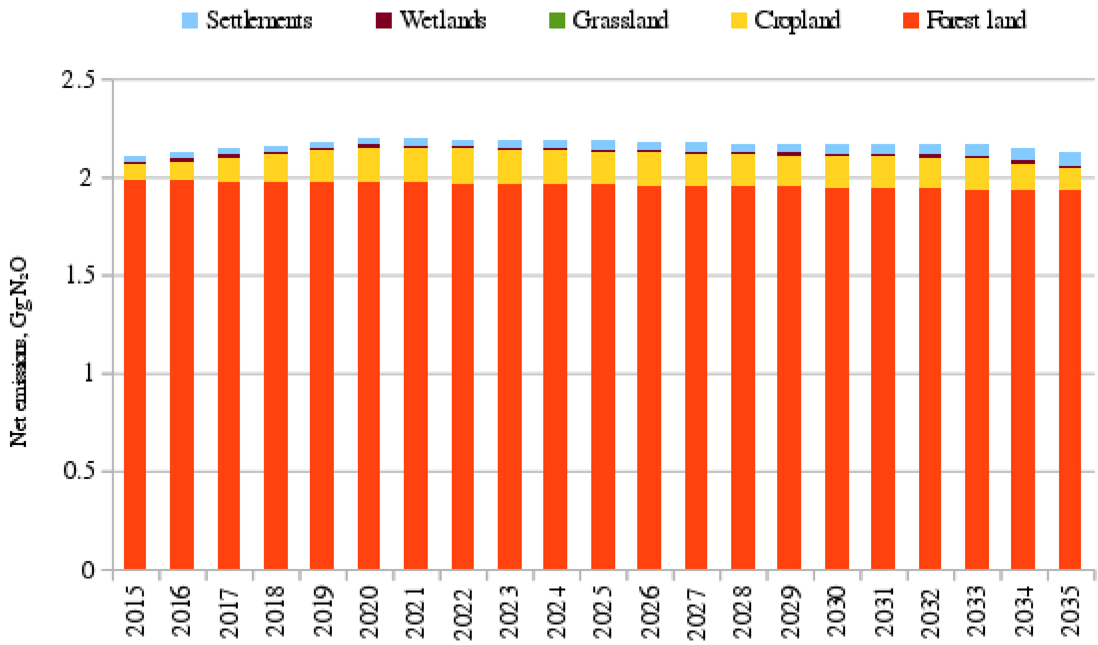

Figure 1: Projections of N_2O emissions from LULUCF sector without measures

The average CH_4 emissions in WOM scenario in 2015-2035 is 12.95 Gg CH_4 (324 Gg CO_2eq), they are increasing from 11.49 Gg CH_4 in 2015 to 14.26 Gg CH_4 in 2035 (Figure 1). The main driving force for increase of CH_4 emissions are rewetting of forest lands.

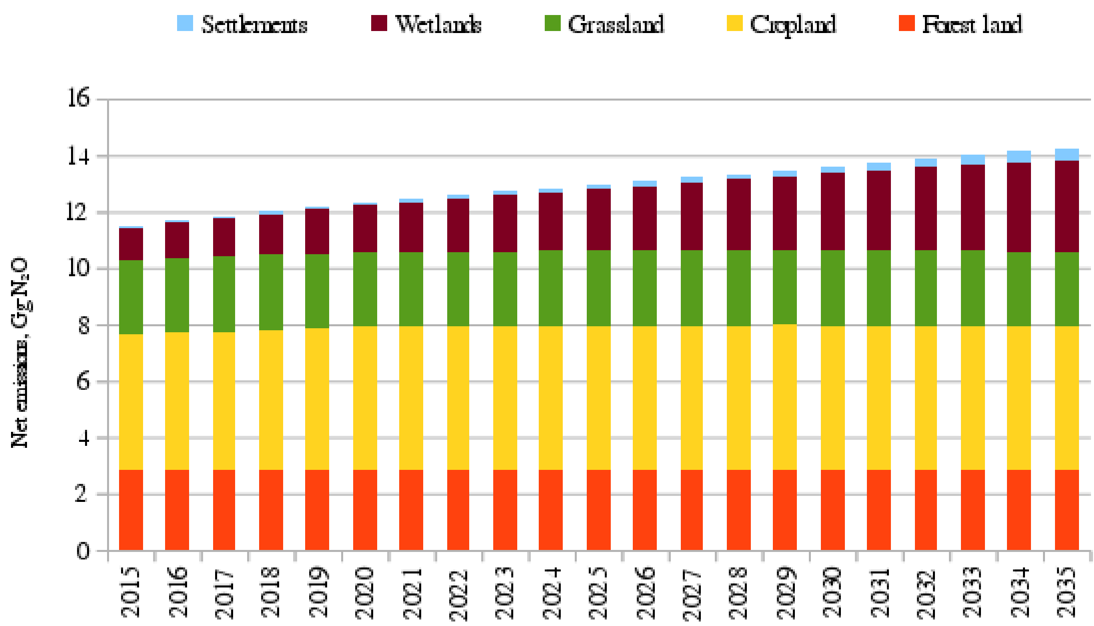

Figure 1: Projections of CH_4 emissions from LULUCF sector without measures

The net GHG emissions from LULCF sector according to the projections of WOM scenario will increase from 2069 Gg CO_2eq in 2015 to 8371 Gg CO_2 eq in 2035 (Figure 1). The increase of emissions is determined by several reasons, but the most important are increase of economic activity (conversion of land use to settlements and cropland), ageing and reduction of increment in forest lands and increase of peat production for agriculture. Peat production suppose to have opposite impact – increase of carbon stock in soil, but it is mostly exported therefore this impact is not accounted in Latvia.

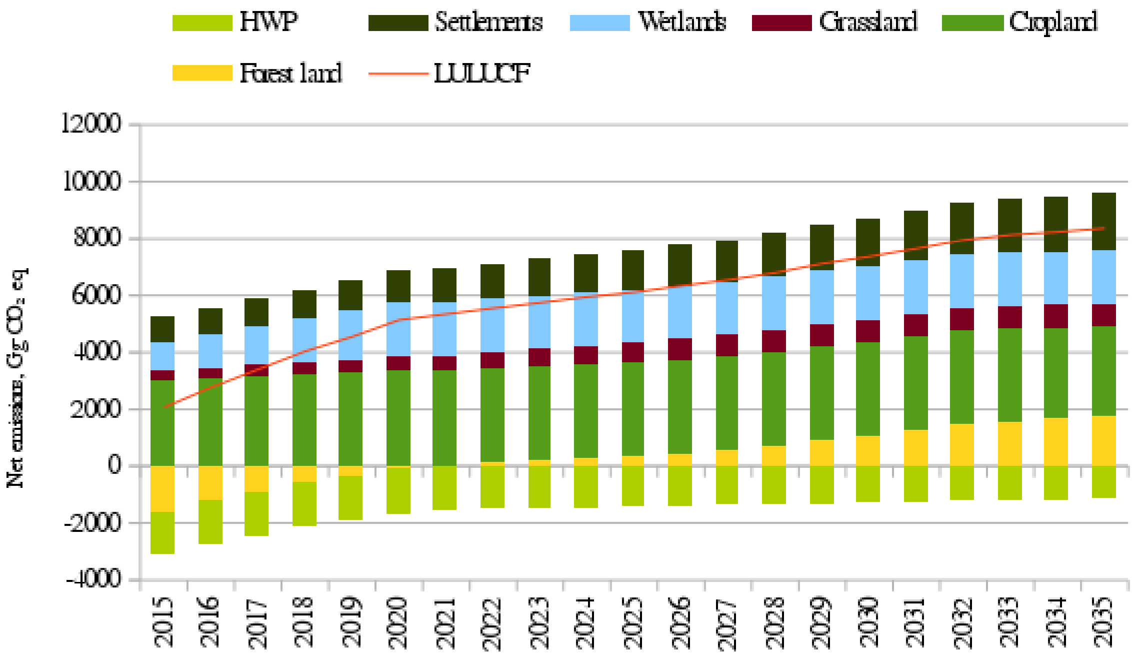

Figure 1: Projections of GHG emissions from LULUCF sector without measures

Comparing different GHG, the most significant and continuously growing source of emissions is CO_2. Emissions on N_2O and CH_4 are minor part of the GHG emissions (Figure 1).

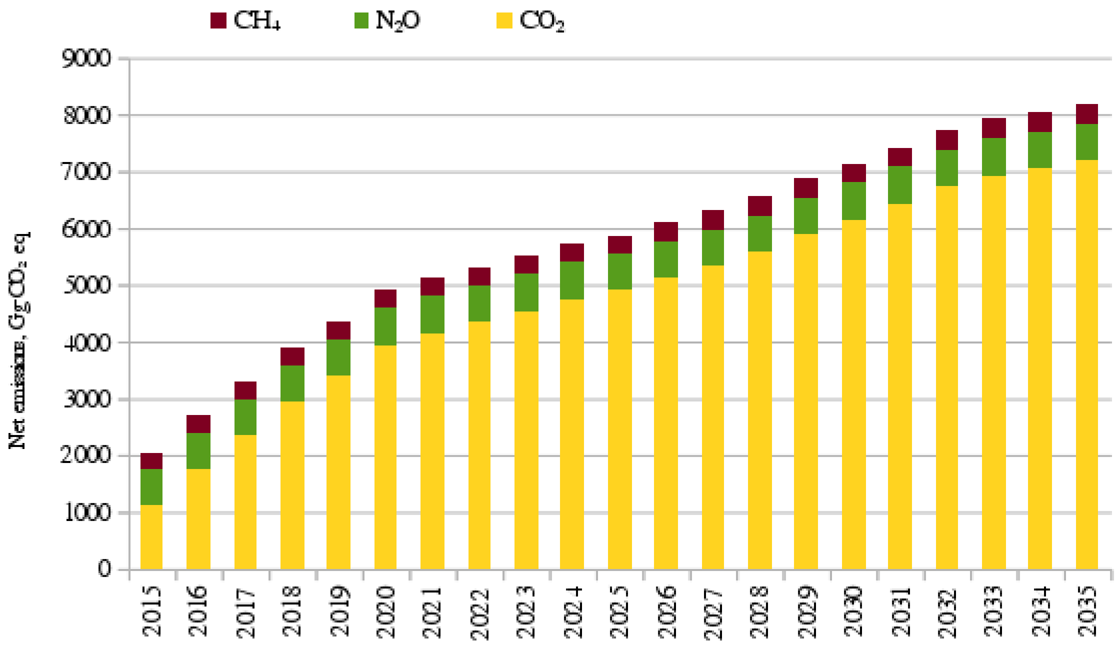

Figure 1: Projections of GHG emissions from LULUCF sector with existing measures

The relative impact of the climate change mitigation measures in WEM scenario ranges from 1.8 % to 4.5 % of the emissions in WOM scenario. The most significant impact the measures have in forest lands, where in some years the impact is 40 times higher than the projected emissions; however, the total impact is not fluctuating significantly (Figure 1).

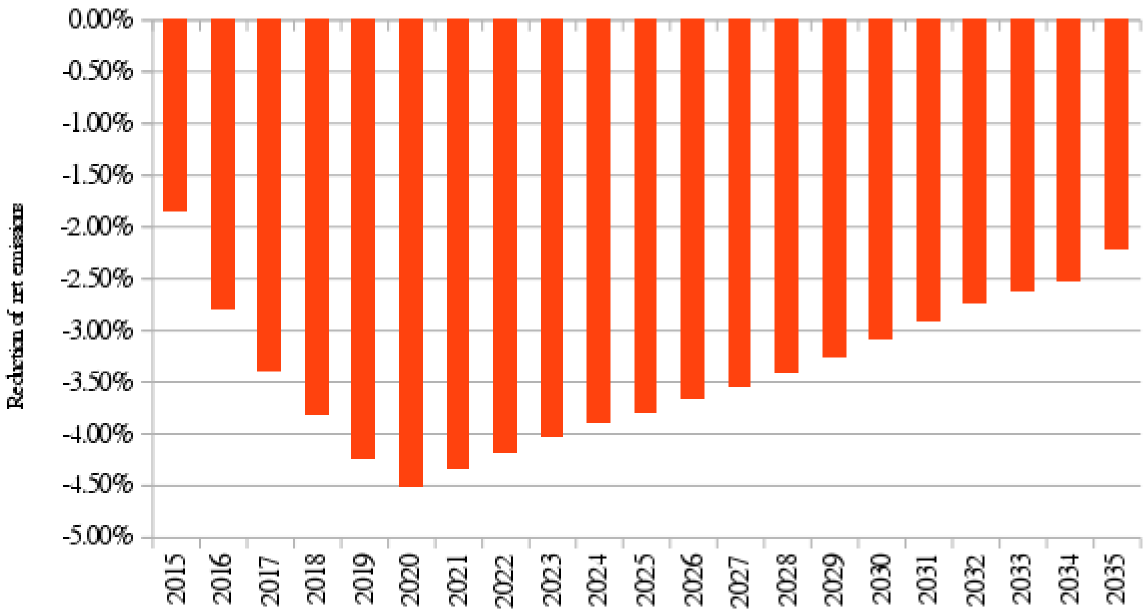

Figure 1: Relative impact of the existing measures on GHG emissions from LULUCF sector

Sources of information

1. AS ”Latvijas valsts meži” (2012). Kvalitātes prasības jaunaudžu kopšanas ciršu izpildei (Apstiprināts ar AS „Latvijas valsts meži” 20.04.2012. rīkojumu Nr. 3.1-2.1_001a_200_12_12). AS ”Latvijas valsts meži”. Available from: http://www.lvm.lv/files/text/Jaunaudzu%20kopsanas%20kvalitates%20prasibas.doc.
2. IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).Published: IGES, Japan.
3. IPCC 2014a, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland.
4. IPCC 2014b, 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds) Published: IPCC, Switzerland.
5. Jansons, Ā. & Baumanis, I. (2008). Parastās priedes (Pinus sylvestris L.) klonu atlase Kurzemes zonas 2. kārtas sēklu plantācijas izveidei un sagaidāmais ģenētiskais ieguvums. *Mežzinātne | Forest Science* 17(50), 88–116.
6. Jansons, J. (2007). *Methods utilized to recalculate historical forest increment data* [online]. Salaspils.
7. Jansons, J. & Zālītis, P. (1998). Dabiski atjaunojamo lapu koku apmežojumu struktūra un kopšanas iespējas. *Meža dzīve* Nr.4, 12–15.
8. Latvian Environment, Geology and Meteorology Centre (2014). *Latvia's National Inventory Report Submitted under United Nations Convention on Climate Change and the Kyoto Protocol Common Reporting Formats (CRF) 1990 – 2012* [online]. Rīga.
9. Latvijas Republikas Ministru Kabinets (2012). Noteikumi par atmežošanas kompensācijas noteikšanas kritērijiem, aprēķināšanas un atlīdzināšanas kārtību (Ministru kabineta noteikumi Nr. 889). Latvijas Vēstnesis, 201 (4804). Available from: http://likumi.lv/doc.php?id=253624.
10. Latvijas Republikas Saeima (2000). Meža likums (ar labojumiem līdz 13.10.2011.). VSIA Latvijas Vēstnesis.
11. Lazdiņš, A. (2010). *LAP 2007-2013 pasākumu ietekmes apraksts saistībā ar klimata izmaiņu novērtēšanas metodiku un CO_2 piesaistes aprēķins par 223. un 226. pasākumiem par 2007.-2009. gadiem*. Salaspils. (UBE-2010-0063-B).
12. Lazdiņš, A. (2012). *Atbalsts klimata pētījumu programmai (starpziņojums par 2012. gada darba uzdevumu izpildi)* [online]. Salaspils. (020512/S68).
13. Lazdiņš, A., Bārdule, A. & Stola, J. (2013a). Preliminary results of evaluation of carbon stock in historical cropland and grassland. *Proceedings of Interdisciplinary Research for Higher Socioeconomic Value of Forests*, Riga, 2013. pp 56–57. Riga: LSFRI Silava.
14. Lazdiņš, A., Bārdule, A., Stola, J. & Krišāns, O. (2013b). Temporary carbon stock changes in forest soil in Latvia. *Proceedings of Interdisciplinary Research for Higher Socioeconomic Value of Forests*, Riga, 2013. pp 51–52. Riga: LSFRI Silava.
15. Lazdiņš, A., Butlers, A. & Lupiķis, A. (2014a). Case study of soil carbon stock changes in drained and afforested transitional bog. *Proceedings of 9th Baltic theriological conference*, Ilgas, 2014. Ilgas: Latvian State Forest Research Institute ”Silava”.
16. Lazdiņš, A. & Čugunovs, M. (2013). *Oglekļa dioksīda (CO_2) piesaistes un siltumnīcefekta gāzu (SEG) emisiju un zemes lietojuma veida ietekmes novērtējums intensīvi un ekstensīvi kultivētās aramzemēs, daudzgadīgos zālājos un bioloģiski vērtīgos zālājos*. Salaspils.
17. Lazdiņš, A., Čugunovs, M., Zariņš, J. & Lūkins, M. (2013c). *Atbalsts klimata pētījumu programmai (Pārksats par projekta 2013. gada darba uzdevumu izpildi)*. Salaspils.

18. Lazdiņš, A., Donis, J. & Strūve, L. (2012a). Latvia's national methodology for reference level of forest management activities (English summary). LSFRI Silava.
19. Lazdiņš, A., Donis, J. & Strūve, L. (2012b). *Latvijas meža apsaimniekošanas radītās ogļskābās gāzes (CO_2) piesaistes un siltumnīcefekta gāzu (SEG) emisiju references līmeņa aprēķina modeļa izstrāde*. Salaspils. (5.5-9.1-0070-101-12-91).
20. Lazdiņš, A., Liepiņš, K., Lazdiņa, D., Jansons, Ā., Bārdule, A. & Lupiķis, A. (2013d). *Mežsaimniecisko darbību ietekmes uz siltumnīcefekta gāzu emisijām un CO_2 piesaisti novērtējums (pārskats par 2013. gada darba uzdevumu izpildi)*. Salaspils. (5.5-5.1/001Y/110/08/8).
21. Lazdiņš, A. & Lupiķis, A. (2014). *Hidrotehniskās meliorācijas ietekme uz CO_2 emisijām mežaudzēs uz susinātām augsnēm*. Salaspils. (290514/S138).
22. Lazdiņš, A., Lupiķis, A. & Okmanis, M. (2014b). Soil carbon stock change due to drainage of a forest stand growing on a transitional bog. In: Finér, L., Karvinen, L., &Stupak, I. (Eds) *Proceedings of Environmental Services provided by the Nordic-Baltic Forests*, Vantaa, Finland, 2014. pp 48–50. Vantaa, Finland: Finnish Forest Research Institute. ISBN ISBN 978-951-40-2513-6.
23. Lazdiņš, A. & Zariņš, J. (2012). *Vēsturiskās (1990. gada) apsaimniekoto aramzemju platības noteikšana un līdz 2009. gadam notikušo aramzemju platības izmaiņu novērtēšana*. Salaspils. (2/27.01).
24. Lazdiņš, A. & Zariņš, J. (2013). Meža ugunsgrēku un mežizstrādes atlieku dedzināšanas radītās siltumnīcefekta gāzu emisijas Latvijā. *Proceedings of Latvijas Universitātes 71. zinātniskā konference "Ģeogrāfija, ģeoloģija, vides zinātne",* Rīga, 2013. pp 133–137. Rīga: Latvijas Universitāte.
25. Līpiņš, L. (2004). Assessment of wood resources and efficiency of wood utilization (Koksnes izejvielu resersu un to izmantošanas efektivitātes novērtējums). LLU. Available from: http://www.zm.gov.lv/index.php?sadala=258&id=803.
26. L.U. Consulting (2010). Augšņu un reljefa izejas datu sagatavošana un eiropas komisijas izstrādāto augsnes un reljefa kritēriju mazā labvēlīgo apvidu noteikšanai piemērošanas simulācija (Projekta kopsavilkuma ziņojums). Latvijas Republikas Zemkopības Ministrija.
27. Lupiķis, A., Mūrniece, S. & Lazdiņš, A. (2014). Impact of reconstruction of forest drainage systems on increase of living woody biomass in thinned middle-age coniferous stands. *Proceedings of 9th Baltic theriological conference*, Ilgas, 2014. Ilgas: Latvian State Forest Research Institute "Silava".
28. Ministru kabineta noteikumi Nr. 238 Nacionālā meža monitoringa noteikumi (2012). Ministru kabinets. Available from: http://likumi.lv/doc.php?id=246285.
29. Ministru Kabinets (2012). MK noteikumi Nr. 308 "Meža atjaunošanas, meža ieaudzēšanas un plantāciju meža noteikumi". Latvijas vēstnesis. Available from: http://www.likumi.lv/doc.php?id=247349.
30. Penman, J. (Ed.) (2003). *Good Practice Guidancefor Land Use, Land-Use Change and Forestry* [online]. 2108 -11, Kamiyamaguchi, Hayama, Kanagawa, Japan: Institute for Global Environmental Strategies (IGES). Available from: http://www.ipcc-nggip.iges.or.jp.
31. Reģionālās attīstības un pašvaldību lietu ministrija (2008). Zemes politikas pamatnostādnes 2008. – 2014. gadam (Informatīvā daļa). LR Ministru Kabinets. Available from: http://www.zm.gov.lv/doc_upl/pamatnostadnes.pdf.
32. Rüter, S. (2011). *Projection of Net-Emissions from Harvested Wood Products in European Countries*. Hamburg. (Work Report No. 2011/x of the Institute of Wood Technology and Wood Biology).
33. Salm, J. O. (2012). *Emission of greenhouse gases CO2, CH4, and N2O from Estonian transitional fens and ombrotrophic bogs: the impact of different land-use practice*. Diss. Tartu: Tartu Ülikooli Kirjastus. Available from: http://dspace.utlib.ee/dspace/bitstream/handle/10062/25471/salm_jyri_ott.pdf?sequence=1.

34. Salm, J.-O., Kimmel, K., Uri, V. & Mander, Ü. (2009). Global Warming Potential of Drained and Undrained Peatlands in Estonia: A Synthesis. *Wetlands* 29(4), 1081–1092.
35. Salm, J.-O., Maddison, M., Tammik, S., Soosaar, K., Truu, J. & Mander, Ü. (2012). Emissions of CO2, CH4 and N2O from undisturbed, drained and mined peatlands in Estonia. *Hydrobiologia* 692(1), 41–55.
36. United Nations (1998). Kyoto protocol to the United Nations framework convention on climate change. United Nations.
37. Zālītis, P. (2004). *Sastāva kopšanas cirtes*. LVMI Silava.
38. Zālītis, P. (2006). *Mežkopības priekšnosacījumi*. Salaspils: et cetera. ISBN 9984-19-976-2.
39. Zālītis, P., Donis, J., Ruņģis, D., Gaitnieks, T. & Jansons, J. (2014). *Četri mežzinātņu motīvi*. Salaspils: Daugavpils Universitātes Akadēmiskais apgāds "Saule". ISBN 978-9984-14-679-9.
40. Zālītis, P. & Jansons, J. (2009). *Mērķtiecīgi izveidoto kokaudžu struktūra*. Salaspils: LVMI Silava. ISBN 978-9934-8016-6-2.
41. Zālītis, P. & Lībiete, Z. (2008). Kopšanas ciršu režīms egļu jaunaudzēs. *LLU Raksti* 20 (315), 38–45.
42. Zemkopības ministrija (2006). Meža un saistīto nozaru attīstības pamatnostādnes. Valsts Kanceleja. Available from: http://polsis.mk.gov.lv/view.do?id=1917.
43. Zemkopības ministrija (2014). Latvia - Rural Development Programme (National). Zemkopības ministrija. Available from: https://www.zm.gov.lv/lauku-attistiba/statiskas-lapas/lauku-attistibas-programma-2014-2020?nid=966#jump.