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Development of Latvian land use and land use change matrix using geospatial data of National forest inventory

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Abstract. Land use and land use change calculation matrix is one of the most important parts of the national greenhouse gas (GHG) inventory in land use, land use change and forestry (LULUCF) sector providing information of an overall summary and changes in land use at a national level over a specified period of time. Information on land use and land use changes are further used to calculate other parameters important for determination of GHG emissions and carbon stock changes in living and dead biomass, soil and litter, as well as basic information on the impact of applied climate change mitigation measures. Calculations of land use change can be carried out in a partly automated process using GIS tools, which makes calculations easier to perform, reduces time consumption for this task and occasional mistakes due to manual operations. The aim of this study is to improve the methodology for development of land use and land use change matrix in the national GHG inventory system using geospatial data of National forest inventory (NFI) and auxiliary data sources. The developed system uses geospatial NFI data and auxiliary information provided by the land parcel information system (LPIS) and stand-wise forest inventory, and it improves accuracy and consistency of the land use and land use change matrix, providing the ability to apply the same land use accounting method for the whole reporting period since 1990 without a significant increase of uncertainty. The developed method determines land use changes in a 5-year period by comparing three successive NFI cycles. To determine the actual land use category in a particular year, we adjusted weights for different land use categories. Interpolation is used to determine year-by-year transitions.

Key words: Land use and land use changes, land use matrix, national forest inventory, greenhouse gas inventory.

INTRODUCTION

Land use and land use change as an interdisciplinary scientific topic has emerged only recently and the importance of it is also acknowledged by national and international research organizations. For instance, the United States of America National Research Council has identified it as a one of the seven grand challenges in environmental science (Brown et al., 2019). In land use, land use change, and forestry (LULUCF) land use values and results of the GHG emission estimates are the aftermath of a complicated intercommunication between social and ecological factors (Desta et al., 2000). Land use information provides knowledge on how society uses land resources, which is one of the key elements for accounting a projection of GHG emissions. Humans have modified land for their benefit and well-being, throughout history they have performed activities like cropping, grazing, logging, mining and urbanization and these processes are still in action at present time (Sleeter et al., 2012; Holman et al., 2017; Wulder et al., 2018). Human material, social, and cultural needs have been and still are provided by the land and its resources (Mekkonen et al., 2018; Birhane et al., 2019). However, nature still plays a role in land use changes, which can cause either a positive or a negative impact (Gomes et al., 2019).

The main reason why land use and cover have caught global academic and political attention is its standpoint as a primary factor characterizing direct influence to ecosystems and the factor that responds in different ways, depending from land use, on global climate change (Cegielska et al., 2018; Hersperger et al., 2018). One of the monitoring tools used for land use and land use change is National forest inventory. It is an important tool to construct historical and long term monitoring system, which can provide data about land use and land use changes (Soulard & Wilson, 2013). In LULUCF sector land use is divided into 6 main categories – forest land, cropland, grassland, wetlands, settlements and other lands. These land use categories according to Intergovernmental Panel on Climate Change (IPCC) guidelines are split into 2 groups – areas, where land use change took place 20 years ago or more recent and other lands, where land use changed more than 20 years ago or no land use change took place during the accounting period (Eggleston et al., 2006).

National forest inventory (NFI) has been introduced in most of the European countries because of the need for a national and regional sample based multi-resource forest inventories (Traub et al., 2017). Perpetual monitoring programs, like national forest inventories, are a significant source of information for ecological and environmental research and decision making (Lindenmayer & Likens, 2010). NFI is a part of Latvia's forest monitoring program and it produces estimates of numerous parameters describing the current status and changes of forest resources – information needed for policy and decision making at national and subnational levels, as well as for international reporting (Pulkkinen et al., 2018). National forest inventory in Latvia is implemented since 2004 by Latvian State Forest Research Institute Silava (LSFRI Silava), which is appointed by the national responsible authority – the Ministry of Agriculture. Each year before April 1st LSFRI Silava submits the information obtained during the previous year's NFI to the Ministry of Agriculture.

Since 2008 LSFRI Silava is responsible for data collection necessary for reporting of carbon stock changes and GHG emissions, and NFI data is the main source of activity data, which is used in the national GHG inventory (Jansons & Licite, 2010). The methodology currently used for accounting of carbon stock changes is listed as the most comprehensive approach – the utilized methods can be applied in a similar way for any type of land use (i.e., generic methods for Forest Lands, Croplands, Grasslands, Wetlands, Settlements and Other land) (Eggleston et al., 2006).

The main goal of this study is to develop and improve land use and land use change matrix in the national GHG inventory system using geospatial data from NFI and auxiliary data. Geographical information systems (GIS) are used in this study because the IPCC guidelines require accounting of land use and land use changes in a spatially explicit way, therefore GIS tools is the only reliable tool to process land use and land use change data. GIS tools can relatively easy store, capture and analyze geospatial data without intermediate solutions, which is important when implementing study results into practice (Clarke et al., 2019). Automatization of this process using GIS tools is aimed at improving the speed of data processing because the new calculation method will considerably reduce the probability of mistakes, demand for expert judgements and time consuming manual data sorting that was necessary prior to this study to develop the land use and land use change matrix.

MATERIALS AND METHODS

Study area

NFI plots are scattered through the whole territory of Latvia, in total there are 16,156 permanent plots (Fig. 1). Every plot represents an area of 400 ha and each plot is measured once during the 5-year period. Sample plots can be divided into smaller units called sectors, which are created, if the plot is situated on a boundary of different land use categories or vegetation types (Jansons & Licite, 2010). Each compartment, also called sector, contains information about land use category and stand inventory information, if there are trees in the specified sector (Fig. 5).

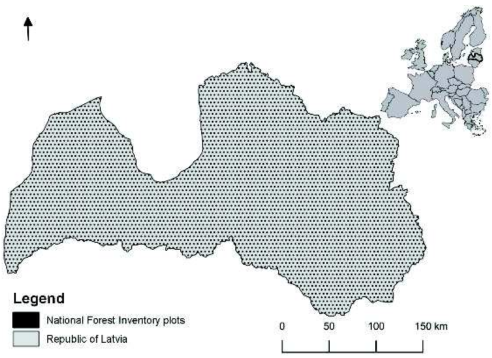

Figure 1. Study area.

Geospatial data processing

One of the goals of the study is to create a calculation method that takes into account possible land use category changes through 3 NFI cycles (15 years) and permanent land use change categories (properties of these land use change categories have permanent or long-lasting possibility, such as forest roads, railway tracks, water bodies, etc.).

Three 5-year periods are intersected with each other, starting with the oldest one using GIS tools. In order to calculate final land use categories in a way that takes into account short time changes between NFI cycles, weights are added to the subsequent cycles as well as to categories that are unlikely to change easily (roads, water bodies, settlements, etc.). All land use and land use change categories with constant and non-changing properties are supplemented with weight value 1. Categories of three subsequent NFI cycles are supplemented with weighted values, which differ from their age. The oldest is supplemented with weight 20, the middle one - with weight 30, and the youngest one - with weight 50. Fields that meet the constant, non-changing properties will always be one value higher than those, who don't have it. Example: the oldest one will weigh 21, middle one 31, but oldest one 51. Weighted values then are used to calculate the land use in a particular period or year (Fig. 2). This process is repeated to all subsequent NFI cycles and previously obtained data, starting from the year 1985. For all previously mentioned processes we use GIS software and file format that supports curved line shape.

Fig. 2. shows the same NFI permanent plot through 3 cycles or 15 years. In spite of cycle 3 land use changes to grassland, the final category is defined as cropland. The reason for this estimate is the specific properties of calculation formula which indicate that the third cycle is not 'heavier' than the two previous cycles together, if the transition is not marked as non-reversible (construction, drainage ditch, etc.). Although the cycle 3 is closer to the present times and more relevant to the possible present-day situation, in this case, it is possible that grassland is only a temporal land use in this plot and in the future, it will turn back into cropland. If grassland in this plot will be detected also in the fourth cycle, the final land use category will be changed to grassland according to the logic of the calculation, and previously reported land use data will be recalculated, assuming that the land use change took place in the time between site visits in cycle 2 and 3.

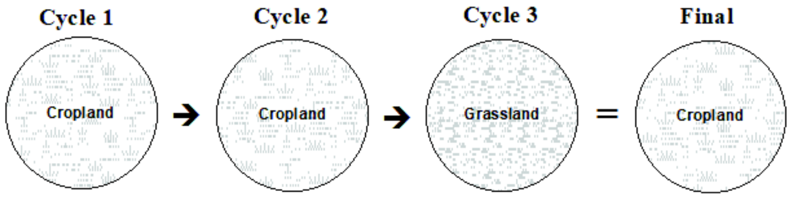

Figure 2. Example of evaluation of land use and land use change.

Fig. 3 shows a scenario, where cropland in the cycle 2 changes into cropland but because land use category in cycle 1 and cycle 3 is grassland, the final land use category remains grassland. This scenario represents situations, when calculation method takes into account that land use category can change periodically for a short period of time. In some cases, land owners change their land use to cropland for a period of one year to meet personal land management needs, thus influencing land use change information for the specific information gathering cycle and immensely impacting information on land use and land use change in the long run. This occurs because of the specific field data gathering method, which dictates that each individual plot is monitored only once in a 5-year period also called cycle and the gathered information will represent land use in the specific plot for the whole cycle.

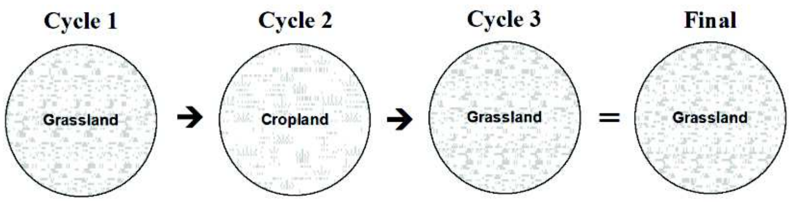

Figure 3. Example of evaluation of land use and land use change.

Fig. 4. represents a scenario, when land use type in the two older cycles is forest land but in the newest cycle the settlement category appears across the plot, which indicates that forest road construction has taken place recently, thus changing the land use category to settlement in cycle 3 and also influences calculated final land use category, which adjusts accordingly to the new changes, because forest roads have non-

reversible land use property. Non-reversible land use property indicates that it cannot change easily in a long period of time. Buildings, roads, drainage ditches and other structures of anthropogenic origin, which are components of the settlement category, leave a long lasting impact on land use change process because their longevity comparing to different land use category ingredients is far greater, the only exceptions are lakes and rivers which fall into the wetland category and also have non-reversible land use property. Non-reversible land use property also protects from possible mistakes in land use category classification during field works in future, because if by any chance non-reversible ingredients are not detected in future cycle field works it will be represented in calculated final land use category, thus making it one of the data processing safety mechanisms.

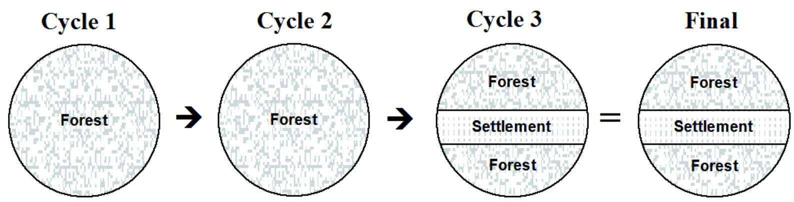

Figure 4. Example of evaluation of land use and land use change.

Fig. 5 illustrates how differently weighted categories interact with each other to transfer to the final land use category. If the interaction is between categories with different weights (regarding land use category), the final land use category will be the same as the category that has the 'heaviest' value (for example, orchard).

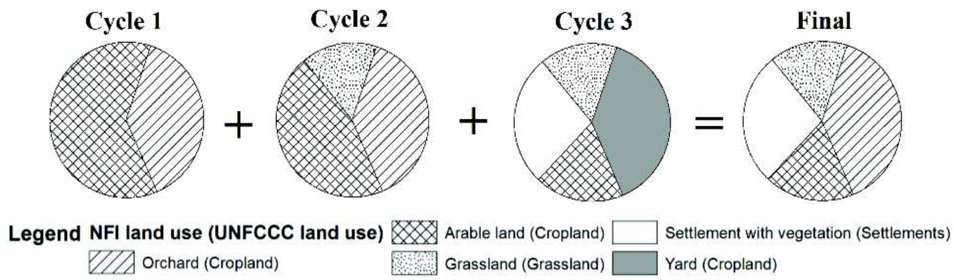

Figure 5. Illustration of land use and land use change.

If interaction between the three cycles is between categories with the same weight of land use categories, then the final land use category will be the category that is repeated at least 2 times, or in case, if the land use category is different in each cycle, the latest category will be applied as the final land use category. The reason for this is the fairly rapid changes of land use in the particular NFI plots, which can be caused by human error. To avoid previously mentioned problems in reporting of the land use and land use changes, we propose a method that considers the previous three NFI cycles for deciding the final land use category.

Land use and land use change matrix

Land use and land use change matrix is calculated using the final land use category, which is estimated by combining 3 subsequent NFI cycles. NFI plot areas are calculated in such a way so that altogether they represent the total area of Latvia. The first step is to calculate the proportion between the area of all the NFI plots and the area of Latvia,

$$\text{Unit coefficient} = \frac{\sum \textit{of all plot shape area}}{\textit{Country area}} \quad (1)$$

and the next step – to calculate the representative area of each part of the NFI plot,

$$\text{NFI plot area in ha} = \frac{\sum \textit{of all the plot shape area}}{\textit{Unit coefficient}} \quad (2)$$

The layer, which represents the final land use category, is then intersected with a polygon layer, which represents areas of permanent grasslands, which are obtained from the LPIS, maintained by the Rural Support Service. This step is necessary because of the complexity of evaluation of the situation in the field during the site visit by the NFI teams. When data collection is conducted by the specialists in the field, it cannot be precisely determined if grassland is natural or it is manually sown and if it is periodically plowed. Data provided by the Rural Support Service helps to eliminate potential errors during the field works. If the land use category in the final land use category layer is representing grassland and plot overlaps with cultivated grassland polygon, the land use category is changed to cropland.

While the Latvian NFI in total has 49 land use categories, the UNFCCC has only 6 land use categories. Land use and land use change categories that are consolidated from the NFI database are specially made for the NFI purposes, but they are easily transformable to the UNFCCC categories - there is already a table available for conversion purposes. The result is the land use and land use change matrix that gives the values of area change between two different NFI cycles.

In total six land use change matrices were generated, each covering a 5-year cycle (Fig. 6). For the period of time before the NFI was started in Latvia in 2004, Landsat data was used. The first trials of Landsat data use for LULUCF needs in Latvia started in 2011 (Lazdins, 2011). Combined matrix, covering a time span from 1990 was also created at this time, however, it was also concluded that unguided classification of land use may lead to considerable uncertainty, particularly, considering the small size of the NFI plots in comparison to the spatial resolution of the Landsat data.

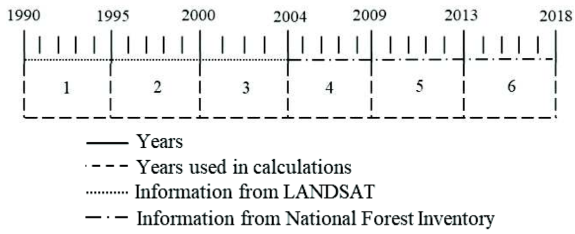

Figure 6. Years with information on land use and land use change used in elaboration of the land use change matrix.

Land use and land use change matrix - comparison between cycles by years

Comparison between matrices of different years is made by creating a template for all years of the reporting period, in this case, 1990–1995. Each land use category is compared with the other five land use categories to determine the area that has transferred from other land use categories each year. Constant values are obtained from previously calculated data matrices, which serve as 'anchor' values that are real and reliable. Other values that are between the 'anchor' values are calculated using linear interpolation.

$$\text{Last year area} = \frac{youngest\ cycle\ area - oldest\ cycle\ area}{\sum of\ years\ between\ youngest\ and\ oldest\ cycle} \quad (3)$$

Modifications for calculations of land use and land use change matrices in future

NFI field specialists monitor around 1/5 of all plots every year and only a partial land use category update is available. The necessity for yearly land use and land use change updates led to development of a modified calculation method that provides reliable data about land use changes for the last 10 years, which can be used further to calculate GHG emissions in the LULUCF sector. Every year we can add partial information to the database, where the newest accessible data replaces the oldest data (Fig. 7).

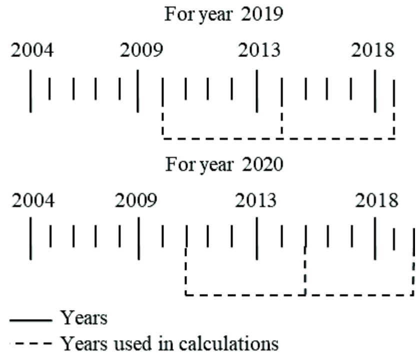

Figure 7. Yearly update of NFI database with partial information.

RESULTS AND DISCUSSION

Matrices can be created between each cycle or through all cycles. Table 1 shows land use and land use changes through all the cycles from 1990 to 2018 and describes, which land use category has gained area from other land use categories. Since 1990 the most noticeable change in land use in Latvia is the transformation of cropland to grassland and transformation of grassland to forest land (Table 1). It was caused by widespread abandonment of rural areas in Latvia and other post-soviet countries in the early nineties after the collapse of the Soviet Union (Prishchepov et al., 2012; Alcantara et al., 2013). That led to active afforestation and natural succession in the Baltic States and has resulted in an increase of forest land area (Lazdiņš et al., 2010), which is also observed in the Nordic region (Gundersen et al., 2014). A need for land use and land use change data have led to other studies, which have been conducted in Latvia to estimate land use and land use change data and trends. These studies have shown a decreasing trend for agricultural land and grassland and an increasing trend for forest land after the collapse of the Soviet Union in 1990 and these trends were the result of agricultural land abandonment, which led to increase in grassland and forest land areas resulting from ecological succession (Baders et al., 2018).

The graph in Fig. 8 represents all land use categories and land use changes each year since 1990. It needs to be taken into account that the wetland category also includes active and abandoned peat extractions fields, which were determined earlier using wall to wall approach. In 2016, when the total area of wetlands was around 404 kha, active and abandoned peat extraction fields constituted 34.2 kha (Butlers & Ivanovs, 2018). The only constant value that has not changed since 1990 is other lands. Other lands have not changed because the only land use category in NFI that can be reclassified to other lands is sandy dunes, which are located in the NFI plots nearby the Baltic sea. Values shown in Table 1 are the same as the ones in Fig. 8. The difference between Fig. 8 and Table 1 is that the Fig. 8 represents land use changes for each year separately, but Table 1 represents land use changes through the whole calculation period from 1990 to 2018.

Table 1. Land use and land use change matrix between the years 1990–2018 (all the matrices mentioned in this article and the complete in-depth set of matrices are available digitally at https://goo.gl/EgVHcx)

Land use change		Land use Land use at the end of the period						Sum before
		Settlement	Cropland	Other land	Forest land	Wetland	Grassland	
Land use at the start of the period	Settlements	263,115	3,072		19,807	1,131	5,352	292,476
	Cropland	16,346	1,399,117		56,150	10,780	578,809	2,061,201
	Other lands			5,437				5,437
	Forest land	21,507	3,559		3,091,588	22,505	38,161	3,177,319
	Wetlands	1,079	1,364		9,445	357,976	5,345	375,209
	Grassland	5,958	62,768		65,266	11,698	401,617	547,308
Sum after		308,004	1,469,880	5,437	3,242,255	404,090	1,029,284	6,458,950

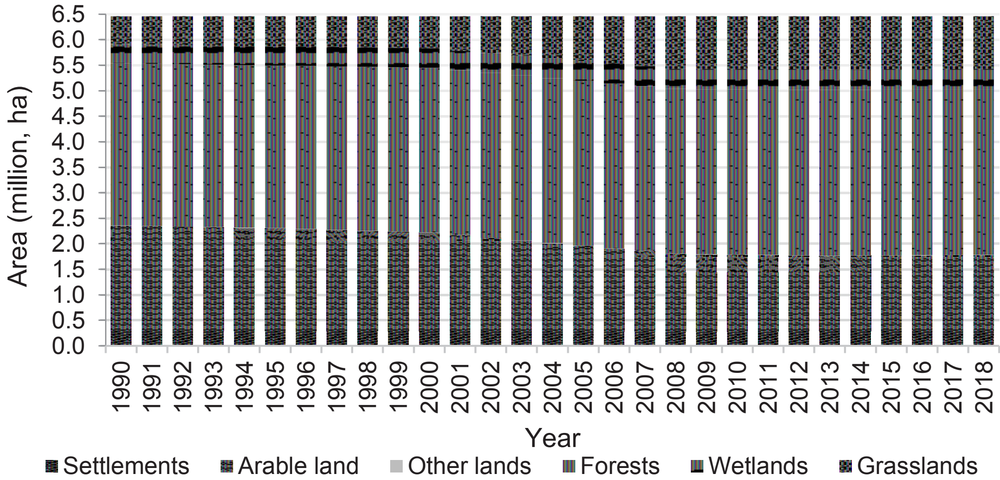

Figure 8. Land use and land use changes since 1990.

According to the study done by Baders et al. (2018), the proportions of land use categories in Latvia in the year 1990 was the following – 49.2% - forest lands, 26.3% - grasslands and 11.5% - croplands. Comparing with the results obtained in our study there are similarities in forest land category, but differences in cropland and grassland land use categories. Our study show that forest lands occupy 49.2% of the territory of Latvia, but grasslands occupy 8.5% and croplands 31.9%, indicating that the results of our study differ from the previously mentioned study accordingly: -17.8% for grasslands and +20.4% for croplands. The same study indicates that proportions of land use categories in 2011 in Latvia was: forest lands - 50.3%, grasslands - 23.7% and croplands - 12.7%, which is similar to results obtained in our study that shows the following proportions of land use categories in 2011: 50.2% - forest lands, 16% - grasslands and 23.1% - croplands. Difference from our studies in forest land is -0.1%, in grasslands -7.7% and in croplands

+10.4%. These differences indicate that the results of our study are impacted by the new calculation system, which takes into account probable land use changes throughout years, like periodical yearly changes in grassland and cropland categories, where one land use category can change into another by owners adapting the land use of their private property to their management needs and plans. Examples are shown in Fig. 2 and Fig. 3.

Individual land use change matrices for each land use category through the years also have been elaborated. Through the years it is possible to trace land use changes between different land use categories (Table 2). In this case, it is shown how cropland from 2013 to 2018 gains land area from other land use categories. This is only a part of the full size matrix which starts from the year 1990. A complete set of matrices is available digitally at https://goo.gl/EgVHcx. Even though values between the anchor years, which are coloured gray in the table, are calculated using linear interpolation, it gives a representational value to data and gives at least theoretical estimates on how land use has changed during the reporting period. Anchor values have been obtained from land use and land use change matrices, which were calculated previously.

Table 2. Land use change matrix between cropland and other land use categories from 2013 to 2018

Land use after	Land use before	2013	2014	2015	2016	2017	2018
Cropland	Settlements	2,502	2,090	1,678	1,266	854	443
	Cropland	1,437,871	1,441,609	1,445,348	1,449,086	1,452,824	1,456,563
	Other land	0	0	0	0	0	0
	Forest land	2,377	2,284	2,191	2,098	2,005	1,912
	Wetlands	1,364	1,251	1,138	1,025	912	800
	Grassland	27,355	23,917	20,478	17,040	13,601	10,163
	Total (ha)	1,471,469	1,471,151	1,470,833	1,470,515	1,470,198	1,469,880

The stand-wise forest inventory database of the State Forest Register (SFR) has been used to make alterations to previously generated land use and land use change data. It is assumed that the area, which is legally transferred into forest land, respectively, included in the SFR database, should be accounted as land converted to forest land. NFI plots and sectors that are accounted by NFI teams as forests on farmland or overgrown areas (NFI categories 62 and 64), and according to the NFI data are afforested after 1989 and are intersecting with the SFR database layer are transferred to land converted to forest land category. After those alterations additional 70'243 ha have been added to the category of afforested lands, in total accounting for 382'386 ha of land area.

Table 3. Relative differences between land use data according to the National Forest Inventory and land use data previously reported for LULUCF, (%)

	1990	1995	2000	2008	2013	2018
Settlements	+0.8	+0.8	+0.8	+0.6	+0.7	+0.9
Cropland	+3.5	+3.3	+2.1	-4.6	-6.3	-7.3
Other lands	0.0	0.0	0.0	0.0	0.0	0.0
Forest land	+0.8	+0.7	+0.8	+0.8	+0.9	+0.8
Wetlands	-1.1	-1.1	-1.1	-1.0	-0.9	-0.9
Grassland	-4.1	-3.7	-2.6	+4.2	+5.6	+6.5

The calculated land use and land use change data values are compared to the data reported for LULUCF and it shows similarities in land use and land use changes. The biggest observed differences are in cropland and grassland land use, where the calculated data have a 2.1–7.3% shift, comparing with the LULUCF data (Table 3). Those differences have occurred because of the specific calculation method applied in land use and land use change calculations using NFI data, which is explained in Fig. 2 and Fig. 5, and auxiliary data usage like LPIS.

CONCLUSION

The estimated land use and trends in land use changes are similar to previously available land use and land use change data from LULUCF reports ensuring that the developed method is comparable with other data sources and can be used for land use and land use change calculations in future.

The proposed method considerably improves the quality of the activity data for GHG accounting in LULUCF sector by reducing non-existing land use changes like conversion of cropland to grassland and vice versa, by linearization of the trends of land use changes and by the implementation of recently available NFI data.

The elaborated GIS and linked spreadsheet tools have reduced the necessary time for land use calculations and also eliminated possible errors that might have occurred during manual calculations of activity data for land use and land use changes in Latvia.

Even though the obtained results are representable and meet the required demands, the use of auxiliary data like LPIS data is still recommended to eliminate possible impurities in the NFI data in reporting of impact of management activities and rare land use categories, e.g. peat extraction sites.

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