Land dataset uncertainty: effect on Romanian National Greenhouse Gas Inventory

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Abstract. The availability of long-term land datasets is fundamental to ensure consistent and accurate national greenhouse gas inventories for land use and land use changes. Estimation of Romania's CO_2 removals and emissions over 1970-2010 was assessed comparatively by using National Statistics (as reference dataset), Corine Land Cover data, as well as four additional datasets produced from the reference dataset and assuming some forest data changes according to other available partial datasets (NFI,LUCAS or expert judgment). A spreadsheet, implementing a model of UNFCCC national greenhouse gas inventory, allowed estimation of both net CO_2 removals and emissions and gross CO_2 fluxes from all carbon pools, for all land subcategories over 1970-2010. The model was run for each dataset. The reference dataset resulted in an average annual gross flux of CO_2, twice as large as the corresponding annual net removals of 13 Tg CO_2, while annual estimates were more than double in post-1990 compared to pre-1990. Uncertainty of net annual CO_2 removals by reference dataset was estimated around 31%, slightly lower than for gross estimate, and just around 55% when based on CLC dataset. Overall, the contribution of 12 broad land sub-categories to CO_2 inventory was similar in the national net and gross estimates, for both pre- and post-1990 periods. Land under conversion represented 9% of the country's area in pre- and only 2% in post-1990, corresponding to an annual average of 28% of gross and 6% of net annual CO_2 estimates. Among the choices of datasets tested, the reference dataset provided the most conservative estimates of the CO_2 inventory. Other datasets generally overestimated annual LULUCF sink and its main contributor forestland, as well as the emissions or removals from land conversion. Compared to pre-1990, when annual sink was rather low, land abandonment and moderating management in the post-1990 period has led to an increase of C stock in all pools, showing the relevance of political changes on land's CO_2 emissions/removals. Inconsistency within available land datasets impairs more accurate estimation of national GHG inventory. The development of an improved land use assessment system around National Forest Inventory is therefore suggested as a solution to implement consistent land definitions and to accurately estimate their areas in time.
Keywords CO_2, datasets, national inventory, land category, pre/post 1990 period.

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Introduction

While land use activities have significant economic contribution at the global level, they also matter because of their high contribution to greenhouse gas (GHG) emissions and CO_2 removals, mainly from land use change, which is the second-largest anthropogenic source of CO_2 (e.g. Houghton et Hackler 2001, Foley et al. 2005, Le Quéré et al. 2011). Estimating emissions and reporting a national GHG inventory constitutes an ongoing obligation for 44 developed country-parties listed in the Annex I of the United Nations Framework Convention for Climate Change (UNFCCC). National GHG inventory for land use, land use change and forestry (LULUCF) is a relatively recent policy requirement, which has critical links to economic development at both the national and regional scale: concerning food and energy security, climate change adaptation and low carbon economy (e.g. Goulet et Morlat 2011, Van der Krabben & Jacobs. 2013, Ostle et al. 2009, Rounsevell & Reay 2009, USDA 2008, Exnerova & Cienciala 2009, Brown et al. 2012, Lewis 2010). Thus, national GHG inventory can be a powerful tool to support policy and decision making regarding the control of anthropogenic emissions on land at macroscale, in complement to subject oriented life cycle analysis considered as more adequate for understanding the atmospheric impact (Ostle et al. 2009). On the other hand, although GHG estimation and reporting are standardized via IPCC guidelines (e.g. IPCC 2003), it is largely acknowledged that a national inventory may not truly account for direct human effects or accurately reflect where and when emissions

occur (Stinson et al. 2011).

Reporting national GHG inventories needs to follow key principles: transparency, consistency, comparability, completeness, accuracy (UNFCCC 2011). Data type and quality contribute to reach all of them, while ignoring related uncertainty results in unreliable inventory estimates. The accepted rule is that the best available data should always be used for a land-related commitment, and attempts should be made to quantify uncertainties that arise from the dataset choice (Dendoncker 2008, IPCC 2003). Furthermore, in order to comply with their emissions reduction targets, developed countries committed to account GHG emissions and CO_2 removals from eligible activities of land use, under specific common accounting rules GHG. In fact, reporting requirements differ for the inventory (which needs, as a minimum, historical statistical data on land categories) and compliance with emissions reduction targets (e.g. spatial identification and tracking in time) which are obviously not met by ordinary land statistics (UNFCCC 2005).

For Eastern European countries, while more is known on local or national driving factors causing land use change, i.e. the collapse of the socialist regime (Ioras & Abrudan 2006, Hostert et al. 2011), less is known about the status and trends of sinks and sources and their associated climatic impact, especially at regional level (Kuemmerle et al. 2011). Furthermore, the capacity of these countries to accurately estimate and report national GHG inventories to UNFCCC has been under scrutiny and, as consequence, their eligibility for emissions reduction transaction under the Kyoto Protocol was recently temporarily suspended (i.e. Bul-

garia, Croatia, Lithuania, Romania, Slovakia and Ukraine). Such estimating, reporting and accounting issues have occurred despite their good forestry databases, while it is generally recognized that the uncertainty due to incomplete coverage of forest-related estimates occurs even in countries with the most sophisticated forest inventories - largely developed nations in Europe and North America (Reich, 2011). Another common major problem is that reporting GHG inventory for non-forest lands is less documented compared to forest-related lands, which undermines the reliability of the overall LULUCF inventory.

Romania, the third largest country in Eastern Europe, reports a national GHG inventory and has also committed under Kyoto Protocol to account GHG emissions and CO_2 removals from forest management and revegetation activities, in addition to mandatory ones, the afforestation/reforestation and deforestation. Current official estimation of the Romanian GHG inventory relies on land statistics, which is the only official data source available historically. Nevertheless, over the last two decades several integral or sectorial land datasets have been developed and the obvious question rises on which one to use, or, how to combine information to meet the inventory and emission reduction compliance reporting requirements, and reduce estimates uncertainties.

Thus, the purpose of this work was to quantitatively analyze how the LULUCF's national inventory of CO_2 removals and emissions estimates are affected when using various land datasets as compared to the reference one provided by the official national statistics. We also try to assess the uncertainty introduced by land data into GHG inventory and which might be the data needs for consistent and complete estimation and reporting of the CO_2 emissions and removals from land. Implicitly, the GHG effect of land use policy in pre- and post-1990 and contribution of land conversions to national GHG inventory over 1970-2010 are assessed.

Material and methods

This assessment consisted in the estimation of the Romania's national inventory of anthropogenic CO_2 emissions and removals from carbon pools associated to LULUCF over 1970-2010 comparatively for several land use datasets. Overall, the estimation follows UNFCCC national GHG inventory 'gain-loss' method, which consists in multiplication of area of certain land category with the corresponding annual value of C stock change factor for that land, assuming consistent land representation criteria are met by both data required. A key assumption in this analysis was that any nationally available data would have an equal chance to be used for the estimation of the national GHG inventory. Currently official land data are described in Table 1. The datasets considered differ with regard to their purpose, underlying definitions (e.g. use or cover) or measurement methods used.

Further on, we derived six datasets for the CO_2 inventory estimates comparison: two independent datasets (i.e. $D_{reference}$, D_{CLC}) as provided by original standing alone sources mentioned in Table 1 and four variations of the reference dataset (i.e. $MD_{non-LUC}$, $MD_{hayfield}$, MD_{arable}, $MD_{combined}$), as described in Table 2. Variations mainly took into account the results of unique, by now, estimates of newest land assessment instruments (Eurostat's Land Use/Cover Area frame Statistical Survey; LUCAS, 2012) and Romania's National Forest Inventory; NFI 2010) and expert guess. For realistic estimates, annual area of conversions to/from national forest fund was applied to all datasets, except for CLC (for which we only verified if it reports larger areas of conversions than by Forestry Operational Report).

Each of the six datasets was then considered as input in a Land Use and change Matrix (LUM), which is a MS Excel spreadsheet underlying CO_2 inventory estimation, i.e. LUM was run for each of six datasets, and results were compared. LUM implemented the key

Table 1 Land use and cover data available for Romania

Dataset and temporal availability	Main feature of dataset	Forest & forestland	Cropland	Grassland	Other land categories
National Institute of Statistics (annual official report since 1970)	Land use data from land registry or cadastral data (heterogeneous across country territory, occasionally geo-referenced and updated). Annual report with full country coverage	Annual area of 5.96-6.33 Mha (national forest fund) & 0.41-0.45 Mha (forest vegetation outside the national forest fund or woodland)	Annual area ranging between 9.33-9.92 Mha for arable and 0.37-0.70 Mha for permanent woody crops	Annual area between 2.70-3.42 Mha for pasture and 1.36-1.71 Mha for hayfields	Water/ponds cover between 0.71-0.91 Mha. Artificial areas (e.g. urban, infrastructure) cover between 1.0-1.61 Mha
Corine Land Cover (European Environmental Agency's 'coordination of information on the environment')	Land cover data and maps for 1990, 2000 and 2006. Spatially explicit and country coverage	Total forest and semi-natural areas (8.021/8.019/8.013)	Annual area of 8.96/8.95/9.04 Mha, including 0.8/0.78/0.74 Mha of orchards and vineyards	Annul area of 4.55/4.56/4.52 Mha, out of which 2.02/2.03/1.94 Mha of hayfield	Water/ponds cover between 0.71/0.71/0.74 Mha. Artificial areas cover 1.45/1.46/1.47 Mha
Forestry operational reports (annual forest Authority reports)	Annual area of conversions to/ from forest within national territory is measured on the ground, mapped (not geo-referenced) and national statistics adjusted	Annual average afforestation areas 12/1.28 kha and revegetation of 4.3/0.5 kha in pre/post-1990	ND/NI	ND/NI	Annual data on deforestation of 14.5/0.5 kha in pre/post-1990

Note. 1 Mha = 1million hectares. Parenthesis shows min and max of area over 1970-2010, whenever available. ND/NI –data not available/no information.

rule that any land within national territory is classified under a unique land use category (i.e. area of activity data) which has associated a specific annual C-stock change in each carbon pool (i.e. CO_2 emissions or removals factor), following UNFCCC reporting requirements (IPCC, 2003; IPCC, 2006). Similar models are used by other countries to report national GHG inventories (e.g. in the USA, see Wood-bury et al. 2007, or UK, see UK 2012). Inputs in LUM were disaggregated as available in the original dataset, but finally aggregated according to six broad land categories defined by

Good Practice Guidelines for Land Use, Land Use Change and Forestry (IPCC 2003): FL-forestland; CL-cropland; GL-grassland; WL-wetland; SL-settlements and OL-other land. According to possible change of land use from one year to next, each category is composed from two subcategories: "remaining" and "in conversion to". For the year when a conversion initiates, the spreadsheet subtracts the area starting the conversion from the 'remaining' of the original land category and moves it under "conversion to" of the target land category where it is maintained for 20 years and

Table 2 Land area datasets input and description, as standing alone datasets (D) and reference dataset variations (MD). Relative values (%) and ± signs denote percentage larger or smaller inputs compared to reference dataset values.

Datasets	Description/range for input data	Justifications/assumption
$D_{reference}$	Reference dataset	Official land data from National Institute of Statistics (www.insse.ro) and area of conversions to/from national forest fund. Currently used in Romania's submission to UNFCCC (U Government of Romania, 2011)
D_{CLC}	Inputs size compared to reference (roughly): -13% arable, -10% pasture, +20% hayfields, +50% vineyards and orchards,+137% woodland and +12% forestland	Net areas for years 1990, 2000 and 2006 from CLC. Areas in conversions are interpolated in-between and extrapolated backward to 1970 with an annual rate as for 1990-2000 and upward from 2006 with a rate as of 2000-2006
$MD_{non-LUC}$	No land use change since 1970	Constant land use as reported by reference dataset for the year 1970 applied throughout the time series 1970-2010
$MD_{hayfield}$	No woodland	Woodland area reported by reference dataset was assumed as hayfields. Reason is that there is no strict implementation of forest definition in current official reporting process by relevant owners, and no enforceable legal provision for their administration as forests, thus under risk of being maintained as forest for short period of time before reconversion to hayfields. As well, there is no information on tree vegetation characteristics.
MD_{arable}	Less arable land	Assess the CO2 effect of the change of largest land category. 10 % less arable land applied to reference data for entire time series, in favor of pasture (because of overstating cultivated area by reporting marginal arable land as productive land in pre-1990 and abandonment in post-1990)
$MD_{combined}$	Reference data in 1970; progressive increase to +100% woodland on hayfield in 2010 and decrease to -10% arable converted to pasture	Likely most realistic scenario based on expert judgment applied to reference data as supported by NFI and LUCAS results (taking into account abandonment of marginal agricultural lands of various uses and progressive expansion of forest vegetation coupled with enforcement of their long term management)

only afterwards it is added to the "remaining" of that new category. This approach follows GPG for LULUCF (IPCC, 2003) ensuring that "actual" rather than "potential" CO_2 emissions and removals are estimated for slow changing pools (i.e. soil organic matter). Inputs into the LUM were "net area at the end of year" for each land subcategory or division as nationally aggregated areas reported by dataset. LUM assumes that the net area of land 'remaining' in the same category is the minimum between current and previous year, whichever was the smallest, while the difference was considered as starting or ending some conversion. Further-

more, because faith of areas starting conversion was not known, conversions to in LUM were modulated by a "conversions allocation factor", i.e. the most probable ratio of transfers (%) from one category to all others in a year, applied to all datasets. These factors were derived based on documented data like forest authority statistics, i.e. 80% of annual conversions from forest occurred to settlements (i.e. road infrastructure) and 20% to other land (e.g. because of active riverbank erosion along more than 1000 km of Danube). For non-forest conversions, the main target categories and allocation factors were set according to expert

judgment: orchards converted to arable (10%), pasture (60%) and woodlands (25%); arable to wetlands (23%) and grassland (60% to either "pasture" or "hayfield"); grasslands to arable (40%), woodland (20%) and wetlands (20%); settlements (i.e. mining and industrial dumps) to forestland (10%) and other land (80%). For improbable conversions factors values were set to 1%, thus not totally excluded (adding 100% for each conversion). Allocation factors were assumed constant for the entire time series 1970-2010. Rules incorporated within LUM have been designed to minimize transition to other land (non classified under other well defined categories, as barren, rocks, etc) and to minimize its buffering role (e.g. share of the area under conversion to/from other land was an adequate indicator of LUM functioning, i.e. negligible areas of some 0.2% of total country area proves its reasonable allocation ability). LUM robustness was also ensured by checking that sum of areas of all land categories at country level to be constant.

The spreadsheet model derived both 'net' annual CO_2 removals or emissions and 'gross' fluxes of CO_2 as absolute annual amounts for each land category and pool. To meaningfully compare the effect of the six land datasets, identical values of C-stock change factors were used for inventory estimates (Table 1). Ecology and management specificities implemented on each land category were accounted for in the spreadsheet by further disaggregation (i.e. on forest type, woody/non-woody crops), down to levels for which C stock change values were available (following the approach of the national GHG inventory currently reported to UNFCCC; Government of Romania, 2012). In order to easily deal with inter-annual variability and capture pre- and post-1990 land management changes, net and gross estimates were reported as the sum over inventory intervals (i.e. 1970-2010 or broken down for pre- and post-1990).

For estimating the contribution of land datasets uncertainty to the overall uncertainty

of the CO_2 emissions and removals, a Monte Carlo simulation (RISK 6, Palisade Corporation, USA) was applied to the inputs for year 2010 within the LUM spreadsheet, following IPCC Tier 2 (IPCC, 2000; IPCC, 2003). An uncertain input was defined as the mean value and its relative standard deviation of the mean (see Table 1). Where data was available, standard error of the mean was used (e.g. C stock change in litter or biomass on lands in conversion to forests), otherwise a probability range of the mean as defined by the reference or based on expert guess (assuming mean is normally distributed). Analysis focused on a comparison of uncertainty of CO_2 estimates given by two complete country coverage datasets (i.e. reference and CLC), cumulated with the uncertainty of the conversions allocation factors. Because of lacking of the variance of the area estimates of CLC, we assumed an uncertainty of 20% of the national total areas for any land category, as a compromise value knowing its underlying broad land classification based on remote sensing procedures of old datasets or mid-resolution imagery (Grassi et. al., 2008; Caetano et al., 2009) and good reported nominal accuracy of CLC products of 85 % (Büttner et. al, 2002; EEA, 2006). Secondly, expert guess uncertainty of annual 'conversion allocation factors' was attached to non-forest conversions (± 20% for from/to cropland, grassland, wetlands and ±50% from/to woodlands) and 5% from/to conversions of orchards, vineyards and settlements (subject to cadastre type measurements and updating frequency of databases). Simulations resulted in the estimation of relative uncertainty of CO_2 emissions and removals estimates for individual land categories and inventory aggregated estimates, further complemented by a sensitivity assessment toward ranking of the inputs based on changes induced in the output (also performed by RISK6).

Table 3 Annual C stock change values and uncertainty associated to reference dataset. Positive value indicate carbon gains in the pool, negative value indicate a carbon loss. Carbon (C) pools which were not shown in table were assumed as not changing in time at the national scale (e.g. soil organic matter in mineral soils on forestland, following Tier 1 assumption of IPCC GPG for LULUCF (2003). Values of C stock change in mineral soils may be overestimated for all conversions, but there is no better data available at this time

C stock /removals or emissions source category (unit)	Annual C stock change factor values/ range (tC/yr/ha)	Relative uncertainty estimate (as ±2 stdev of mean, %)	References for data and uncertainty source or assumptions
Forest Land remaining Forest Land			
Land area of national forest fund/ woodlands	-	±5/± 20	Reference dataset as from forest cadastre/ agricultural cadastre & cadastre specifications/expert guess
Living biomass (for national forest fund) (tC yr^{-1} ha^{-1})	Average annual increment between 1.58 - 2.10, and decrease of 0.24 – 0.38	±20	National scale aggregated values of annual increment on species and groups of species, according to the "Inventarul Fondului Forestier National al Romaniei" published in 1985 by the Ministry of Silviculture of Romania (Government of Romania 2014), official annual harvest statistics and Giurgiu et al. (2004)
Living biomass (for woodlands) (tC yr^{-1} ha^{-1})	Average annual increment of 1.8 and decrease of 0.3	±50	National scale average aggregated values of annual increment according Synthesis of sylvo-pastoral plans published in 1990 by the Ministry of Silviculture of Romania (Government of Romania 2014), and annual harvest statistics and expert guess
Land converted to Forest Land			
Land area of conversions to national forest fund/woodlands	-	±5/± 20	Cadastral type data by forestry statistics and cadastre specifications/expert guess
Living biomass (tC yr^{-1} ha^{-1})	0.16÷2.61	±10	Age-dependent growth of biomass from Romania's joint Implementation project of Afforestation (Government of Romania, 2014) and uncertainty of project estimate as standard
Dead organic matter (tC yr^{-1} ha^{-1})	0.15÷0.32	±25	As above
Mineral soils (SOMmin) (tC yr^{-1} ha^{-1})	+1.85 from CL; +1.75 from GL,WL; +2.65 from SL; +2.2 from OL	±75	Difference between the national scale average values of the C stocks associated to each land use from "Monitoring of soil quality in Romania" implemented by National Research and Development Institute for Soil Science, Agrochemistry and Environment (Government of Romania 2014)

Table 3 (continuation)

C stock /removals or emissions source category (unit)	Annual C stock change factor values/range (tC/ yr/ha)	Relative uncertainty estimate (as ±2 stdev of mean, %)	References for data and uncertainty source or assumptions
Forest Land converted to other lands			
Land area of conversions from national forest fund/ woodlands		±5/± 20	Cadastral type data by forestry statistics and cadastre specifications/expert guess
Living biomass (tC ha^{-1})	-66.88	±10	Average standing C stock for national forest fund estimated by Forest Inventory (Government of Romania 2014)
Dead organic matter (tC ha^{-1})	-7.42 for litter pool; -0.75 for dead wood pool	±10	National average C stock in litter pool from ICP Forest database (Government of Romania 2014), and lying dead wood pool from NFI (IFN 2014)
SOMmin (tC yr^{-1} ha^{-1})	-1.85 to CL; -1.75 to GL,WL; -2.65 to SL; -2.2 to OL	±50	As for land converted to forests
Cropland			
Land area and areas in conversions to cropland		±5/±50	Cadastral data and expert guess
Living biomass (re-vegetation with forest tree species) (tC yr^{-1} ha^{-1})	0.16-2.61	±10	As for land converted to forests
C stock in living biomass (non-forest woody vegetation) (tC/ha)	63	±75	From IPCC (2003)
Living biomass (net annual change) (tC yr^{-1} ha^{-1})	2.1	±50	From IPCC (2003)
SOMmin under arable land (tC yr^{-1} ha^{-1})	-0.05	±50	Simple average of net C stock changes reported by all 27 member states of the European Union in their national GHG inventories submitted to UNFCCC in 2012 (Mandl et al. 2012)
SOMmin under permanent croplands (e.g. orchards) (tC yr^{-1} ha^{-1})	0.01	±50	As above
SOMmin in conversions to any cropland (tC yr^{-1} ha^{-1})	-0.1 tC yr^{-1} ha^{-1} from GL,WL; +0.8 from SL; +0.35 from OL	±50	As for land converted to forests
Grassland			
Land area and areas in conversions to grassland	-	±20/±50	Cadastral data and expert guess

Table 3 (continuation)

C stock /removals or emissions source category (unit)	Annual C stock change factor values/range (tC/yr/ha)	Relative uncertainty estimate (as ±2 stdev of mean, %)	References for data and uncertainty source or assumptions
C stock in living biomass (tC ha⁻¹)	0.85	±75	From IPCC (2003)
Living biomass (net annual change) (tC yr⁻¹ ha⁻¹)	0.01	±75	As for SOMmin under Cropland
Net change in SOMmin under permanent grassland (tC yr⁻¹ ha⁻¹)	0.01	±50	As for SOMmin under Cropland
SOMmin in conversions to grassland (tC yr⁻¹ ha⁻¹)	+0.1 from CL; 0 from WL; +0.9 from SL; -0.45 from OL	±50	As for land converted to Forestland
Settlements			
Land area	-	±5	Cadastral data/expert guess
SOMmin in conversions to settlements (tC yr⁻¹ ha⁻¹)	-0.8 from CL; -0.9 from GL,WL; -0.45 from OL	±50	As for land converted to Forestland

Results

Quantitative results from the 'reference' dataset

Areas of land categories have experienced little changes from 1970 to 2010. The largest cumulated increase of forestland and grassland areas by some 5% was balanced by a strong decrease of settlements and other land, by 24% and 34%, respectively. Across time, other land category remained constant to some 0.2% of the total country area (i.e. less than 0.5 Mha). Overall, some 9% of the country area was involved in conversions in 1989 and only 2% in 2010 (first one capturing pre-1990 and the second post-1990 pictures, as long as the total area reported as 'conversion to' represents the cumulated areas starting conversion over previous 20 years). Conversions from forestland and grassland, that hold the highest C-stock pools, decreased to roughly half during the post-1990 period, under lower economic pressure on land. Conver-

sions from settlements also decreased after 1990, because of a lesser ecological restoration of the industrial and mining dumps, while the area of conversions to settlements decreased because of much reduced need of land for new industrial activities, not yet compensated by residential expansion in post-90.

Over 1970-2010, LULUCF was a sink amounting net CO_2 removals of 538 Tg CO2 resulting from gross fluxes totaling 1,219 Tg CO_2. Meanwhile, both net and gross annual estimates varied ±100% compared to the average for the 40 years span, i.e. an annual net removals of 13 Tg CO_2 or gross flux of 30 $TgCO_2$. Annual average gross estimate was 25% larger in post-1990 compared to pre-1990, while net one increased some six times (Table 4).

Major land categories were consistently sinks while land conversions were either small sources or sinks. The highest contribution to GHG inventory was from forestland (removals from 'remaining' contributed some 53% in gross or 118% in net estimate over entire 1970-2010), 'conversion to' forest 15%

Table 4 Annual average net CO_2 emissions or removals on land subcategories for pre- and post-1990 for reference scenario. *r* denotes land "remaining" in the same category and *c* denotes "converted to". By UNFCCC convention negative sign (-) shows CO2 removals from atmosphere, while positive one (+) emissions to atmosphere

Land category	Pre-1990 ($GgCO_2$ yr^{-1})	Post-1990 ($GgCO_2$ yr^{-1})	Change post-1990 to pre-1990 (%)
FL*r*FL	-9417	-21358	127
Conversions from FL	2383	777	-68
cFL	-3899	-5262	35
CL*r*CL	432	716	66
GL*r*GL	-300	-321	7
cCL	741	142	-81
cGL	937	217	-77
*c*WL	230	-29	-113
*c*SL	6447	1590	-75
*c*OL	1747	1661	-5
Total	-3083	-22645	635

in gross or 35% in net and 'conversions to settlements' (with 30% in gross or 13% in net LULUCF estimate). Although revegetated areas (e.g. tree plantations on arable land) are a small sink, cropland remaining cropland, which hosts them, was a small source because of emissions from changes in woody crops area (e.g. orchards, vineyards). On the other hand, emissions and removals from land conversions contributed 8% of total net removals, as driven by lands in conversion to forestland and settlements, being smaller in post- compared to pre-1990. Emissions associated to conversion from forest (i.e. deforestation) were larger in pre-1990, offsetting 77% of the annual net LULUCF sink (or 25% from forestland removals), compared to only 3% in post-1990 (or 3% from forestland removals), associated to an absolute change of annually deforested area which dropped from some 15kha in pre-1990 to some 0.5kha in post-1990. Overall, halving conversions to forest in post-1990 and much less conversions for non-forest lands resulted in large increase in CO_2 removals.

Comparisons of net and gross CO2 fluxes by various land datasets

The estimates for 1970-2010 derived by two standing alone datasets, reference and CLC (Figure 1) have the same general pattern, both also captured the effect of land use changes between pre- and post-1990 (e.g. peaks on all graphs) and wood harvesting level change in post- compared to pre-1990.

Compared to D_{CLC} which smoothed the time series by annualization of land use changes, reference dataset strongly reflected the interannual variability (e.g. drop of areas of vineyards and orchards reported in 1977 and 1979). This way, reference dataset allowed more inclusive reporting of annual CO_2 emissions and removals from LULUCF sector: D_{CLC} resulted in -28% of the gross and +19% of the net CO_2 inventory estimates compared to reference. Assuming no change of the land categories areas over 1970-2010 ($MD_{non-LUC}$), resulted in -28% of the gross and +16% of the net CO_2 estimates compared to reference.

Variations by partial modifications of the reference dataset resulted in negligible changes in gross and slight overestimation of total net LULUCF
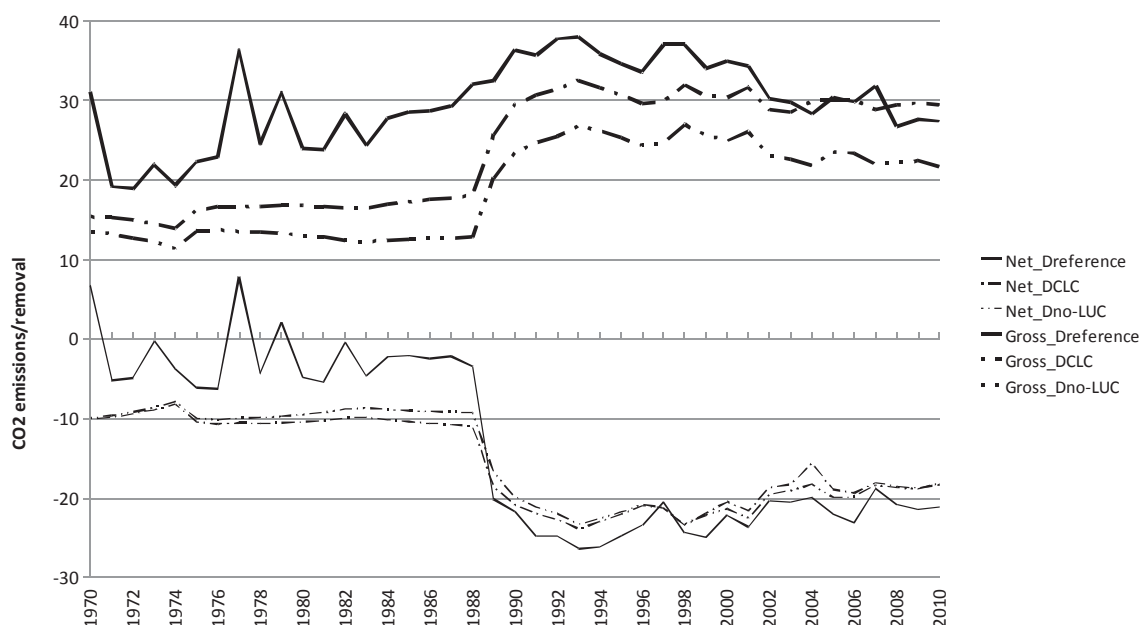
Figure 1 Annual gross and net CO_2 inventory estimates according to various land datasets

estimates. The general pattern of the reference dataset maintained, since no better data was available to modify the inputs with strong general effect (e.g. peaks of permanent woody crops - vineyards and orchards). The order of magnitude of emissions/removals was not significantly different amongst datasets. Under any of the modified datasets, net and gross estimates were generally larger for land remaining in the same category and smaller for lands under conversions, compared to reference (Table 5).

Overall, for modified datasets net LULUCF estimates were larger because of larger sinks estimated for all major land uses. Noteworthy, $MD_{combined}$ dataset, which can be assumed as the most realistic land dynamic structure (capturing both hayfield conversion to woodland

Table 5 Deviation from reference based estimates of total net and gross CO_2 fluxes over 1970-2010 on land subcategories

Land subcategory	Gross estimate					Net estimate				
	$MD_{non-LUC}$ (%)	MD_{CLC} (%)	$MD_{hayfield}$ (%)	MD_{arable} (%)	$MD_{combined}$ (%)	$MD_{non-LUC}$ (%)	MD_{CLC} (%)	$MD_{hayfield}$ (%)	MD_{arable} (%)	$MD_{combined}$ (%)
5A1	5	11	2	0	- 1	5	11	2	0	- 1
5B1	0	0	0	- 8	- 3	127	122	- 1	-30	- 16
5C1	4	14	9	23	3	4	14	9	23	3
5A2	16	14	0	0	0	16	14	0	0	0
5B2	*na*	*- 66*	*- 6*	*0*	*36*	*na*	*- 66*	*- 6*	*0*	*37*
5C2	*na*	*- 84*	*0*	*- 4*	*-39*	*na*	*- 83*	*- 3*	*- 9*	*-52*
5D2	*na*	*- 76*	*-17*	*3*	*-20*	*na*	*- 71*	*-44*	*9*	*-59*
5E2	*na*	*-100*	*- 3*	*3*	*1*	*na*	*-100*	*- 9*	*- 6*	*-18*
5F2	*na*	*- 64*	*- 2*	*0*	*- 5*	*na*	*- 64*	*- 2*	*0*	*- 5*
Total	*na*	*- 65*	*-11*	*- 3*	*15*	*na*	*- 64*	*-10*	*- 3*	*15*
	-28	- 20	- 1	4	0	*16*	*19*	*5*	*16*	*2*

Note. Rows in *italics* denote sources, the others are sinks. Negative signs mean smaller CO_2 removals or emissions estimates compared to value estimated by reference dataset.

and conversion of arable to pasture over last decades) has shown negligible effect for both gross (+2%) and net estimates (+0%) compared to reference. Assuming no woodlands by $MD_{hayfield}$ resulted in +5% higher total net estimates because of much smaller emissions when hayfields were needed for conversions to other uses. The scenario associated to dataset involving less arable land (MD_{arable}) also resulted in larger gross and net estimates due to availability of arable land to satisfy the need for conversions to higher C stocks land categories.

Datasets affect significantly the estimates of the main contributor to land CO_2 inventory, the forestland sink. Generally across the datasets, both remaining forest and conversions to forest were larger sinks compared to reference, e.g. CLC estimates +11% and $MD_{non-LUC}$ estimates +5% larger forest sink than reference. Estimation showed strong annual variability caused by annual harvest change in post- compared to pre-1990.

All modified datasets resulted in non-negligible inventory contribution of conversions compared to the reference. In average, according to reference dataset, conversions contributed by 7% in net and 28% in gross CO2 inventory estimate. D_{CLC} resulted in largest effect caused by land conversions, i.e. +14% larger sink for conversions to forestland compared to reference dataset. Regarding deforestation, D_{CLC} heavily underestimated emissions from deforestation for pre-1990, but not for post-1990. Other conversions turned to relatively smaller or larger emissions whenever woodlands and grassland were converted to any other land. The emissions from conversions to cropland have decreased compared to the reference because of less conversions occurring in wetlands converted to arable (i.e. as under MD_{arable}).

Contribution of the change in C pools

CO_2 land inventory was dominated by the

change in the living biomass. On average, it represented 83% of LULUCF's gross flux, ranging from 100% on forestland and wetlands to 37% in conversions to settlements, depending on how, and if, change in soils organic matter was considered in calculations. Annual flux varied widely in time especially under sudden land use change affecting living biomass in conversions from high to low C-stock lands (e.g. pasture conversion to arable), which can also explain often inter-annual variability. On other hand, the flux resulting from changes of litter, dead wood and soil organic matter pools, taken together, represented in average 17% of gross estimate. Actually, soil pool related emissions were more relevant for non-forest subcategories and for any land conversions.

Uncertainty and sensitivity analysis of the reference dataset

Attaching a stochastic process to the reference dataset resulted in 31% uncertainty of the annual CO_2 net removals for year 2010, slightly higher than 27% for the corresponding gross estimate. The lowest relative uncertainty was obtained for the net estimate related to forest land: 21% for 'remaining' and 10% for 'conversions to forest'. The relative uncertainty for CO_2 removals or emissions from non-forest land categories was more than 50% for stable lands and more than 100% for conversions. Attaching further uncertainty to 'conversions allocation factors' also resulted in some 10 percentage points larger uncertainty for all conversions related estimate (although complex correlations among them were not accounted by our model). With D_{CLC}, the uncertainty reached 55% for total net LULUCF and 40% for forestland.

Further on, the sensitivity analysis showed that the area of "woodlands" plays a very significant role in defining the uncertainty of estimates of both forest sink and total LULUCF estimates. Also, LULUCF estimate were more

affected by the uncertainty of the change in C pools than land area.

Discussion

The right question to ask when an environmental commitment related to land has to be made is whether the data qualitatively, quantitatively and temporally allow reporting according to the requirements, or at least how available data can be combined or improved to serve that purpose. This involves an exercise of screening of all available datasets available in the country.

Intense land reorganization occurred in Romania in pre-1990 because of land confiscation and industrialization and socio-economic transition in post-1990. Overall, across Eastern Europe underlying political shift has generated a change in land use system affecting one sixth of the planet's land surface (Hostert et al., 2011). Local and regional impacts on cultural landscape and biodiversity are expected major as well (Taff et al., 2010; Kuemmerle et. al, 2011). Under such complex socio-economic environment, consistency within land use statistics may be challenged because of inertial practices related to data collection and processing, and also due to recent major changes in statistical systems (i.e. towards EU harmonization). The risk for lower quality of the national land statistics increased in post-1990, because of institutional and land structural changes, actually occurring in all East European countries, cited for Hungary (Laczka and Soós, 2003; Government of Hungary, 2012), Bulgaria (Government of Bulgaria, 2012), Estonia (Government of Estonia, 2012), Poland (Government of Poland, 2012) and Slovenia (Petek, 2008). As a consequence statistical reports are likely not updated, generating mismatches between recorded and actual land use, and time series affected by occasional true-ups sometimes only for some land sub-categories or activities. For Romania, additional to all these, the fact that underlying database of reference dataset is not spatially explicit, raises

doubt on our result of little land use change over 1970-2010. For example reference dataset (INSSE, 2010) shows a shift across all land categories from 1987 to 1988 as a consequence of a post-1990 retroactive clear up. Also, outliers noticed for "orchards" and "woodland" in 1988-1989 and over 1998-2004 were most likely caused by external factors like political pressure to report more forestland (without any factual modification of the concerned area) or because of methodological inertia or financial/institutional difficulties in updating changes. Interestingly, the change of forest definition, first set in 1962 (Law 3/1962) changed in 1996 (Law 26/1996), 2005 (Government Ordinance 95/2005) and 2008 (Law 46/2008) did not result in any significant variation of forest area reported by reference dataset. Relevant for GHG inventory is also the fact that reference dataset seemed much less able to provide detailed data on actual spatial composition of landscape microstructure (Lipsky, 2010), further complicated because of high land abandonment when pattern variation within landscape can be greater than among landscape (Dendoncker et al., 2008). From this perspective, D_{CLC} may actually provide a more realistic area of forests and grassland under a "land cover" definition, and notable, it estimates, for both, some 10% more areas than reported by the national statistics. More forest is also confirmed by 1st NFI cycle which rigorously implements thresholds based forest definition (http://roifn.ro/site/). The reference dataset implements a strict "land use" definition with forestland composed from 'national forest fund, so called NFF' and 'forest vegetation outside national forest fund' (or woodlands). NFF represents 95% of country's forest accurately mapped as being subject to forest management planning and administration. Woodlands, which resulted by the spontaneous forest expansion, have not been subject of forest management planning, so related information is extremely poor; such lands are likely reported by national statistics inconsistently in time either as woodland or pasture, while recorded as forest vegetation under any

'land cover' assessment (i.e. National Forest Inventory - NFI or remote sensing mapping in scientific papers or CLC). Overall, this looks like an underestimation of forest area as long as land cover can be used as an adequate proxy for forestland area, instead of land use one. In any case, the main advantage in using national statistics lays in its apparent full time consistency and complete country coverage, thus not requesting a challenging harmonization of different data sources (Woodbury et al., 2007).

The reference dataset is actually a combination of heterogeneous underlying sources offering indirect guarantee for complete and consistent land use capturing in time and space. Land registry is a major source of data, usually locally implemented cadastral database as ownership information, complemented by operational data in forestry, both backed by ground measurements. Additional information is provided by sectorial statistics in agriculture mostly based on municipality or owners/farmers' declarations. Notably, for the agricultural lands reported under agricultural statistics, errors can be particularly high when "activity area" is taken as a proxy for "land use", or when subjective methods are involved (e.g. non-rigorous implementation of land definition on owner declaration) or lack of rigorous checks and quality assurance/control procedures. Using such data for emissions reduction commitments on land is further strongly limited by non-spatially explicit nature of information and impossibility to be processed as a unique national database. Arguably, land under national forest fund and its conversions are part of a slightly better defined survey system, still technologically obsolete and dominated by bureaucratic and subjective data manipulation instead of a modern geo-referenced digital database. The most significant weakness of reference dataset related to forest land is that it implements an exclusive forest definition, which is 'land administration oriented' thus focusing on national forest fund, instead

of one based on quantitative thresholds which would be able to capture all forests and change no matter of their cadastral status.

Current GHG inventory methods involve land area in a multiplicative operation, thus any dataset inconsistency has a quantitative consequence on CO_2 inventory accuracy and uncertainty. Under current forestry planning approach, the reference dataset should provide unbiased annual estimates of land area for national forest land and its conversions (completely based on ground measurements), although deforestation data is not publicly transparent. The lowest confidence is attached to estimate related to woodlands area, which are erratically reported either as woodlands or hayfields and can be only classified as stable forestland after development of a management plan. Compared to reference dataset, D_{CLC} underestimates by 34 % annual areas of conversions to/from forestland, especially conversions from forests in pre-1990. While it provides convenient countrywide and spatially explicit data also for 1990, reliability of D_{CLC} remains low because of relatively coarse scale mapping less appropriate for measuring conversions. Uncertainty of CLC area estimates was never derived and any agreement of areas to other datasets at aggregated level are assumed to occur by chance (Gallego and Bamps, 2008, Hazeu and de Wit, 2004; Cruickshank and Tomlinson, 1996). Since the strongest non-land influence on the GHG inventory is hold by the changes in living biomass pool from forestland and organic matter soil pool for lands under conversions, using CLC dataset would introduce the risk of overestimation of annual sink because of larger forest area without adjusting accordingly the wood harvest. Although sensitivity analysis did not show harvest as an important input, it remains an issue for Romanian LULUCF inventory to be checked and confirmed by independent sources (e.g. from second cycle of the NFI), since national statistics reports a halving of annual wood har-

vest in post-1990 compared to pre-1990, thus national statistics coverage of all wood harvest is questionable. Overall, structure of LULUCF estimate is similar to other national GHG inventory estimates, e.g. in Germany's inventory living biomass pool change is responsible for 76%, dead wood 15% , litter 5% and soil 4% of their net annual removals (UBA, 2012).

Datasets introducing partial modifications only affect forestland and show negligible changes of overall inventory estimates compared to reference dataset. Non-annual land assessments introduce smoothness of time series between start-end moments, e.g. D_{CLC} annualizes the short term effects of major sudden changes. Because of different concepts behind land assessment and definitions implemented by various datasets, datasets modifying information used here would serve better for verification purpose than for adjusting the reference data, while triggering national discussion on the need to improve the consistency of land data.

Emissions and removals from land conversions have rather small contributions to inventory in Romania. Areas in conversions represent a very small share in any land category, smaller for forest (<4%) and larger for cropland and grassland (< 8%), unlike in other countries economically more developed, e.g. France and the UK report by 30% of cropland area as being in cropland-grassland conversion (CITEPA 2012, Brown et al. 2012). Globally, land conversions are a major source of emissions, i.e. in the EU's member states there were some 28 mil. ha of land under conversions in 2010, of which 6% were conversions from forestland and 22% to forestland, 80% were conversions from grassland and cropland together, which corresponded to 3% of the net and 14% of the gross annual GHG inventory estimates (Mandl et al. 2012). Land use pattern and trends are somehow similar across Europe, with expanding of settlements and forests over the last 20 years mainly on grassland and cropland as dominant trend (Rounsevell &

Reay, 2009, EEA 2013) indicating an increasingly diffuse urbanization process and continuing landscape fragmentation (EEA 2006). In any case, current ability of land assessment system to capture land use changes is very limited, as long as LUM implements the rule that area in certain conversion equals the difference between net areas at the end of consecutive years. This mostly affects estimates for nonforest land conversions, since LUM ensures that the area of conversions to/from forest is fully accounted annually as reported by operational forestry.

Uncertainty of inventory annual estimate is dominated by forest sink, and apparently influenced by uncertainties of C pool changes. Our sensitivity analysis did not reveal uncertainty of land areas as a significant input, nor for stable land uses and for conversions. Generally, the uncertainty is known as larger for areas of conversions and smaller for stable land use (Canadell et al. 2007). In Romania, the area of national forest fund and conversions to/from national forest fund are accurately recorded by ground measurements, but large uncertainties remain for areas and emissions/removals estimated for conversions of woodlands, grassland and wetlands to/from cropland, as well as on regrowth of cut forests (e.g. private owned forests are reportedly subject of degradation). According to the error propagation method applied, the contributions of highly uncertain CO_2 emissions and removals estimates associated to non-forest lands have very small contribution to LULUCF inventory under the dominance of less uncertain forest sink. On the other hand, although the annual C stock change factors in all pools are taken as certain values in this study, their often large uncertainty was often highlighted, especially for soils of any land use (Bellamy et al. 2005, Dinca et al. 2012) under the long-term effect of historical changes and difficulty in attributing them to recent changes (Kirk & Bellamy 2010). Noteworthy, assuming linear dynamic of C loss from soils is contrary

to evidences showing a nonlinear and asymmetric change of the C stock in relation to reverse land use conversions (e.g. Ragot and Schubert 2008), but approach is accepted for the sake of GHG inventory reporting comparability. Following the UNFCCC requirement that uncertainty analysis should be a mean to improve GHG inventories (so not an indicator of inventory's accuracy), deep concern remains for forest land data provided by reference dataset. Nevertheless, the sink currently reported by GHG inventory based on reference data can be assumed as most conservative (in the sense that forest sink is not overestimated; UNFCCC 2011, Grassi et al. 2008). Romania's latest official submission to UNFCCC estimated average annual CO2 removals between 17-19 Tg CO2 over 1990-2010 (Government of Romania, 2012), while independent research estimated higher annual forestland sink of some 50 Tg CO2 for the same period (Olofsson et al. 2009, Olofsson et al. 2011) based on a forest area very close to the results of 1st NFI (IFN, 2014). Compared to pre-1990, when annual sink was rather low, land abandonment and management extensivization in post-1990 have led to increases of C stock in all pools, which again supports conservative estimates by current version of national GHG inventory.

Conclusions

Because of the long-term nature of the changes in C pools, time consistency of land data, especially on conversions, is crucial for an accurate inventory of CO_2 emissions and removals on lands. Among several alternative land datasets tested for Romania, the reference dataset prepared from the national statistics, allows reporting a conservative LULUCF estimate in the national GHG inventory for the entire time series. Nevertheless, one should notice that reference data is qualitatively heterogeneous: national forest fund area and its conversions are accurate as updated and based on ground

measurements, unlike non-forest lands and their conversions. Underestimation of emissions from deforestation and uncertainty of the GHG inventory estimates calculated here discourages using remote sensing based D_{CLC}, especially because of underestimation of areas under conversions from forests, overestimation of forest sink by larger forest areas and unavailability of better harvest data. In fact this is valid when all other datasets are tested; the largest greenhouse effect is related to emissions and removals from conversions and wood harvesting level (pre-and post-1990 inventories, as well as likely partial coverage of true harvesting). Additional available data from sectoral statistics on various conversions do not improve the inventory estimate but can be rather helpful for verification purpose.

Apparently, the uncertainty of national inventory depends more on changes in C pools than on land data.

Meeting reporting requirements of commitments on climate change, emissions reduction accounting and adaptation actions accurate LULUCF estimates has to be achieved by combining all spatially explicit resources available around NFI grid, in line with most modern systems of land use assessments.

Acknowledgements

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