GEOGRAPHICAL REPORTS
OF TOKYO METROPOLITAN UNIVERSITY 57 (2022) 71–78

ESTIMATION METHODS OF MINERAL SOIL CARBON STOCKS IN SETTLEMENTS: A REVIEW OF NATIONAL GREENHOUSE GAS INVENTORY REPORTS

Kimihiro KIDA*

Abstract The United Nations Framework Convention on Climate Change is a treaty that addresses global climate changes, such as global warming. Under this framework, the Kyoto Protocol was established to reduce anthropogenic CO_2 emission. Together, these international treaties require countries to provide the National Greenhouse Gas Inventory Report every year, in which their estimated greenhouse gas emissions comprising six sectors are described. In the present study, the estimation methods used for assessing mineral carbon stocks for settlements reported in the sector of "Land Use, Land-Use Change, and Forestry" were reviewed. Although this report aimed to conduct time series comparisons of greenhouse gas emissions in a country against the starting year, lack of standardized estimation methods made this a challenge. Therefore, quantitative comparison of the estimation results of mineral soil carbon stocks in settlements among countries is difficult. Since scientific data about carbon stock and its dynamics in settlement soils as compared with forest, cropland, and grasslands is scarce, countries tend to adopt primary assumptions and estimation methods presented in the estimation guideline published by the Intergovernmental Panel on Climate Change. However, the basic concept of primary assumptions established in 2006 has several uncertainties. Therefore, to improve estimation quality of mineral soil carbon stock in settlements, more scientific studies about long term carbon dynamics of soils in settlement environment and carbon dynamics in removed surface soil by land conversion process to settlements are warranted. The next National Greenhouse Gas Inventory Report will be the final report under the Kyoto Protocol, after which greenhouse gas emission reports are ongoing to be conducted under the Paris Agreement. Hence, new concepts and data contributing for enhanced estimation of greenhouse gas emission are expected to be published in the next few years to prepare for the following reports under the Paris Agreement.

Keywords: Land use change, National Greenhouse Gas Inventory Report, Remaining settlements, Soil carbon

1. Introduction

Greenhouse gas emission is a recognized factor that contributes to climate change inducing

*Department of Forest Soils, Forestry and Forest Products Research Institute.

global warming. The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty against global climate change, including global warming. Under UNFCCC, the international Kyoto Protocol (KP) treaty commits participating countries to reduce anthropogenic CO_2 emission. Therefore, according to these treaties, contracting countries are required to submit the National Green House Gas Inventory Report (NIR) every year. Then, preparation time for NIR submission of certain year is two years. For example, the NIR submitted in 2021 was a report about greenhouse gas emission of 2019. The commitment period of KP terminated in 2020, and then Paris Agreement began as the successor. However, final NIR under KP have not been released yet. Since the next NIR is a final report under the KP, the next several years may be the turning point to estimate greenhouse gas emission and removal. Hence, a better understanding on the methods for estimation of CO_2 emission used in the submitted NIRs is now relevant. Although the NIR is extensive and comprises many topics, the present study will focus on a very limited topic about mineral soil carbon in settlements, which is reported in the sector of Land Use, Land-Use Change, and Forestry (LULUCF).

In the NIR, greenhouse gas emission is reported separately in six sectors: Energy, Industrial Processes and Product Use, Agriculture, LULUCF, Waste, and Other. Moreover, main carbon pools reported in the LULUCF are living biomass, dead wood, litter, mineral soil, and organic soil, with soil being recognized as the largest carbon reservoir in terrestrial area (Ciais *et al.* 2013). "Settlements" is one of the six main land use types defined in the LULUCF chapter along with Forest, Cropland, Grassland, Wetlands, and Other Land. Carbon amount in wood products produced by forestry was also reported as Harvest Wood Product in this sector. This paper is a brief review of the latest NIRs in English submitted by 37 countries (reviewed countries are shown in Table 1 and all of NIRs are available in the UNFCCC website) about estimation methods of mineral soil carbon stock in settlements. Additional details of the estimation methods for the LULUCF sector can be found in the 4th volume of the Intergovernmental Panel on Climate Change (IPCC) 2006 guideline (IPCC 2006).

2. Definition and Area estimation of Settlements

Definition of settlements

The principal definition of settlements was established in 2006 by the IPCC (IPCC 2006). For identification and calculation of land use area and areas converted to settlement, some countries established their own specific definitions for all land use types including settlements. Especially for settlements, some countries established specific sub-categories to separate various land cover types, such as paved and vegetated settlements. Thus, the term 'Settlements' in the NIRs is not always comparable among countries based on the same definition. Moreover, existence and quality of data, especially historical land use data, is also different depending on the historical background of each country and the configuration of the transition period, which is the time required to achieve a stable carbon balance (as same as under remaining land use area) after land use conversion (default value is 20 years, according to the 2006 IPCC guideline).

Area estimation of the settlements

Some countries analyzed satellite and aerial photo imaging data to estimate existing and previous land use areas using different definitions for land use identification, whereas other countries estimate previous and present land use areas based on statistical data, which is the case of

Japan. Since definitions of land use subcategories and calculation methods of the land use area are different among countries, quantitative comparison of carbon stock and change reported in the LULUCF sector, especially related settlements, among countries is very difficult. An example is the area of the "road," which is a major subcategory of settlements. The term of "road" in Japanese statistics includes not only paved area for vehicles and walkers but also open (unpaved) area such as embankments and greeneries. On the other hand, Germany, which is a county using imaginary analysis, separately estimated transport area of road and roadside greeneries.

Table 1 Data sources of Land use area, Soil thickness to estimate, and carbon stock change by land conversion to settlement

Country name	Source type of land use area	Soil thickness to estimate (cm)	Mineral soil carbon stock change by land conversion to settlement	References
Australia	images	30	DE	Australian GDISER 2021
Austria	statistics	30	DE	EA Austria 2021
Belgium	images	30	DE	Belgian IEA 2021
Bulgaria	images, statistics	30	DE	EA at MEW 2021
Canada	images, statistics	ND in NIR	ND	ECC Canada 2021
Croatia	images	30	IC in open area, DE in paved area, totally DE	MESD 2021
Cyprus	images	30	DE	DE of MARDE 2021
Czechia	images, statistics	30	DE	Czech HI 2021
Denmark	images	100	NC in open area, DE in paved area	Nielsen *et al.* 2021
Estonia	point monitoring	18-29	DE	ME Estonia 2021
Finland	images	100	DE	Statistics Finland 2021
Germany	images	30	NC in open area, DE in paved area	FEA 2021
Greece	images	ND in NIR	DE	MEE 2021
Hungary	images	30	DE	UNEI, Hungarian MS 2021
Iceland	images	30	DE	EA Iceland 2021
Ireland	images, statistics	30	DE	EPA 2021
Italy	images	30	DE	IEPR 2021
Japan	statistics	30	IC in newly established greenery area	GGO Japan and ME Japan 2021
Latvia	images	30	DE	MEPRD 2021
Liechtenstein	statistics	30	DE	Office of Environment 2021
Lithuania	statistics	30	DE	ME Lithuania 2021
Luxembourg	images	30	DE	EA 2021
Malta	images, statistics	50	DE	Malta RA 2021
Netherlands	images, statistics	30	DE	NIPHE 2021
New Zealand	images	30	IC (same as grassland)	ME New Zealand 2021
Norway	images	100	DE	Norwegian EA 2021
Poland	images, statistics	100	DE	NCEM 2021
Portugal	images	40	DE	Portuguese EA 2021.
Romania	images, statistics	30	DE	NEPA 2021
Slovakia	statistics	30	DE	SHIME Slovak Republic 2021
Slovenia	images	30	DE	MESP Slovenian EA 2021
Sweden	point monitoring	50	DE	Swedish EPA 2021
Switzerland	images, statistics	30	DE	FOEN 2021
Turkey	images	30	DE	Turkish Statistical Institute 2021
Ukraine	images, statistics	30	DE	MEPNR Ukraine 2021.
United Kingdom	images	100	DE	Brown *et al.* 2021
United States	images, statistics	100	DE	United States EPA 2021

images: estimation of area by imaginary analysis, statistics: summary of areas in the statics, point monitoring: estimation by five-year cycle monitoring data at intersection points of 5 km x 5 km grid, DE: decrease, IC: increase, NC: no change, ND: no data. All references were downloaded from UNFCCC (2021).

3. Estimation of Mineral Soil Carbon Stocks in Settlements

Definition and calculation of the thickness of mineral soil

According to the 2006 IPCC guideline, mineral soil is defined as soils containing lower than 20 wt% of soil organic carbon. Although 30 cm depth from the top of mineral soil is the default value mentioned in IPCC guideline, actual depth for estimation is defined by the utility and continuity of the country specific soil data set. Therefore, the default thickness (30 cm) was adopted by 25 countries, including Japan, whereas other countries applied 40, 50, or 100 cm of thickness to proceed the carbon stock estimation (Table 1). This difference makes it difficult to quantitatively compare mineral soil carbon stock among the countries.

Settlements remaining settlements (Settlements older than conversion period)

In the LULUCF sector, carbon stocks and carbon stock change in remaining land use (same land use for more than 20 years in default) and in converted to a land use (settlement for less than 20 years in default) was separately calculated.

Since there are not enough scientific data about chrono-sequential mineral soil carbon and its dynamics in remaining settlements, all countries report this information according to the primary assumption (Default method in 2006 IPCC guideline), which described that mineral soil carbon stock is stable due to carbon equilibrium between inputs and outputs in remaining settlements. According to this assumption, some countries established country specific carbon stock values calculated by field survey or approximation by land cover vegetation and land paving ratio; in turn, other countries established this calculation by multiplication between the default coefficients by IPCC or specific coefficients of the country and mineral soil carbon stocks in previous land uses. Since mineral soil carbon stock is stable, according to the primary assumption, carbon pool of mineral soil is excluded from estimation for net greenhouse gas emission and removal in remaining settlements. Notably, no country adopted the country specific mineral soil carbon dynamics in remaining settlements.

Land management in settlements is complicated owing to their geographical and historical background, and also diverse purpose and function, along with the insufficient chrono-sequential data, finally leading all countries to adopt the default assumption released by IPCC. However, since remaining settlements is a future stage of 'settlements converted to settlements,' it is reasonable to consider that mineral soil carbon dynamics in remaining settlements can contribute to establish the practical transition period for estimation of greenhouse gas emission and removal in settlements converted to settlements.

Settlements converted to settlements

The number of countries that adopted specific data for estimating mineral soil carbon stock change caused by conversion to settlements is larger than the number of countries that adopted specific data for remaining settlements. Nonetheless, this difference does not indicate that the estimation of settlements converted to settlements is more advanced than that of remaining settlements. Most of the country specific data and land use change coefficients are derived from advanced estimations (using country specific data or carbon dynamics models) for forest, cropland, and grassland carbon stocks. The IPCC 2006 guideline presented two basic concepts to estimate mineral soil carbon stock change: (1) a subtraction of mineral soil carbon stock in previous land use from settlement converted to settlements, and (2) a multiplication of land use change coefficient to mineral soil carbon stocks in previous land use. These approaches are expected to

enhance the method of estimation.

Thirty four countries reported that land use conversion to settlement from forest, cropland, and grassland resulted in a reduction of the mineral soil carbon stocks (Table 1), mainly caused by surface soil removal by earthworks. Most countries mentioned surface soil removal by conversion to settlement, especially to paved area, and established country specific decrease coefficients or adopted default decreasing coefficients for land conversion effect. Moreover, some unpaved land in countries that applied the law for the preservation of surface soils regarded surface soil removal as a no carbon stock change event from previous land use. For example, Germany established no surface soil carbon stock change from previous land use as it assumed that surface soils excavated in the construction process of gray-infrastructures, such as building and roads, was relocated to neighboring open areas. Then, reduction of mineral soil organic carbon stocks in settlements was derived by the reduction of mineral soil organic carbon stocks in paved area in Germany. Moreover, lack of chrono-sequential data in settlements converted to settlements has contributed for the countries to adopt conservative estimations without mineral soil carbon accumulation in vegetated area of settlements. Therefore, studies about long term carbon dynamics in mineral soils and discussion about estimation concept of surface soil removal are important to establish the estimation of mineral soil carbon stock change by conversion to settlement and to reflect the decomposition processes of mineral soil carbon.

4. Conclusion

NIRs under the KP period will be terminated in 2022, with data for the greenhouse gas emissions then being reported under the Paris Agreement, which is a similar objective international treaty. Since the base year for estimation and defining the reduction goal of greenhouse gas emission is different among countries, direct comparison of estimated greenhouse gas emission and removal under the Paris Agreement is going to face the same challenges as the reports under KP. Therefore, a new estimation concept and advanced methods of estimation should be established in the next several years to reflect the overall outcome of the reports during the KP period and also represent the foundations for the preparation of the first reports under the Paris Agreement in 2025. The estimation of mineral soil carbon stocks in settlements has several uncertainties and insufficiencies about carbon dynamics and existing carbon stock data due to the lack of scientific studies. Long term carbon dynamics by analysis of soils under the settlements and data of greenhouse gas emission from removed surface soil and removal processes should be clarified to make more realistic estimations reflecting the decomposition process of organic matter in mineral soils. Although several reports addressing related topics have been published, more studies about soils in settlements are warranted to advance and prepare for the next reports under the Paris Agreement.

Acknowledgment

This paper is dedicated to Professor Makiko Watanabe on the occasion of her retirement from Tokyo Metropolitan University.

References

Australian GDISER (Australian Government Department of Industry, Science, Energy and Resources) 2021. *National Inventory Report 2019: The Australian Government Submission to the United Nations Framework Convention on Climate Change.* Canberra: Australian Government Department of Industry, Science, Energy and Resources.

Belgian IEA (Belgian interregional Environment Agency) 2021. *Belgium's greenhouse gas inventory (1990-2019).* Brussels: Belgian interregional Environment Agency.

Brown, P., Cardenas, L., Choudrie, S., Del Vento, S., Karagianni, E., MacCarthy, J., Mullen, P., Passant, N., Richmond, B., Smith, H., Thistlethwaite, G., Thomson, A., Turtle, L. and Wakeling, D. 2021. *UK Greenhouse Gas Inventory, 1990 to 2019.* Oxfordshire: Ricardo Energy & Environment.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., DeFries, R., Galloway, J., Heimann, M., Jones, C., Le Quéré, C., Myneni, R. B., Piao, S. and Thornton, P. 2013. Carbon and Other Biogeochemical Cycles. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* ed. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley., Cambridge and New York: Cambridge University Press.

Czech HI (Czech Hydrometeorological Institute) 2021. *National Greenhouse Gas Inventory Report of the Czech Republic.* Komorany: Czech Hydrometeorological Institute.

DE of MARDE (Department of Environment Ministry of Agriculture, Rural Development and Environment) 2021. *Cyprus National Greenhouse Gas Inventory 2021.* Nicosia: Department of Environment Ministry of Agriculture, Rural Development and Environment.

EA (Environment Agency) 2021. *Luxembourg's National Inventory Report 1990-2019.* Esch-sur-Alzette: Environment Agency.

EA Austria (Environment Agency Austria) 2021. *Austria's National Inventory Report 2021.* Vienna: Environment Agency Austria.

EA Iceland (The Environment Agency of Iceland) 2021. *National Inventory Report Emissions of greenhouse gases in Iceland from 1990 to 2019.* Reykjavik: The Environment Agency of Iceland 2021.

EA at MEW (Environment Agency at the Ministry of Environment and Water) 2021. *National Inventory Report 2021 Greenhouse Gas Emissions in Bulgaria 1988-2019.* Sofia: Environment Agency at the Ministry of Environment and Water.

ECC Canada (Environment and Climate Change Canada) 2021. *National Inventory Report 1990–2019: Greenhouse Gas Sources and Sinks in Canada.* Gatineau: Environment and Climate Change Canada.

EPA (Environmental Protection Agency) 2021. *Ireland's National Inventory Report 2021 Greenhouse Gas Emissions 1990-2019.* Wexford: Environmental Protection Agency.

FEA (Federal Environment Agency) 2021. *National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2019.* Dessau-Roßlau: Federal Environment Agency.

FOEN (Federal Office for the Environment) 2021. *Switzerland's Greenhouse Gas Inventory 1990–2019: National Inventory Report and reporting tables (CRF). Submission of April 2021 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol.* Bern: Federal Office for the Environment. http://www.climatereporting.ch

GGO Japan (Greenhouse Gas Inventory Office of Japan) and ME Japan (Ministry of the

Environment, Japan) (eds.) 2021. *National Greenhouse Gas Inventory Report of JAPAN 2021.* Ibaraki: Center for Global Environmental Research, Earth System Division, National Institute for Environmental Studies.

IEPR (Institute for Environmental Protection and Research) 2021. *Italian Greenhouse Gas Inventory 1990-2019.* National Inventory Report 2021. Roma: Institute for Environmental Protection and Research.

IPCC 2006. IPCC Guidelines for National Greenhouse Gas Inventories, 2006.

ME Estonia (Ministry of the Environment) 2021. *Greenhouse Gas Emissions in Estonia 1990-2019 National Inventory Report.* Tallinn: Ministry of the Environment.

ME Lithuania (Ministry of Environment of the Republic of Lithuania) 2021. *Lithuania's Greenhouse Gas Inventory Report 2021.* Vilnius: Ministry of Environment of the Republic of Lithuania.

ME New Zealand (Ministry for the Environment) 2021. *New Zealand's Greenhouse Gas Inventory 1990–2019.* Wellington: Ministry for the Environment.

MEE (Ministry of Environment and Energy) 2021. *National Inventory Report of Greece for Greenhouse And Other Gases for The Years 1990-2019.* Athens: Ministry of Environment and Energy.

MEPNR Ukraine (Ministry of Environmental Protection and Natural Resources of Ukraine) 2021. *Ukraine's Greenhouse Gas Inventory 1990-2019.* Kyiv: Ministry of Environmental Protection and Natural Resources of Ukraine.

MEPRD (Ministry of Environmental Protection and Regional Development) 2021. *Latvia's National Inventory Report.* Riga: Ministry of Environmental Protection and Regional Development.

MESD (Ministry of Economy and Sustainable Development) 2021. *Croatian greenhouse gas inventory for the period 1990 - 2019.* Zagreb: Ministry of Economy and Sustainable Development.

MESP Slovenian EA (Ministry of the Environment and Spatial Planning Slovenian Environment Agency) 2021. *Slovenia's National Inventory Report 2021 GHG emissions inventories 1986 - 2019.* Ljubljana: Ministry of the Environment and Spatial Planning.

Malta RA (Malta Resources Authority) 2021. *Malta's National Inventory of Greenhouse Gas Emissions and Removals, 2021.* Malsa: Malta Resources Authority.

NCEM (National Centre for Emission Management) 2021. *Poland's National Inventory Report 2021.* Warszawa: National Centre for Emission Management.

NEPA (National Environmental Protection Agency) 2021. *Romania's Greenhouse Gas Inventory 1989-2019.* Dolj: National Environmental Protection Agency.

NIPHE (National Institute for Public Health and the Environment) 2021. *Greenhouse gas emissions in the Netherlands 1990–2019 National Inventory Report 2021.* Bilthoven: National Institute for Public Health and the Environment.

Nielsen, O.-K., Plejdrup, M. S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M. H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V. K., Nord-Larsen, T., Vesterdal, L., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S. B., Olsen, T. M. and Hansen, M. G. 2021. *Denmark's National Inventory Report 2021. Emission Inventories 1990-2019 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol.* Aarhus University, DCE – Danish Centre for Environment and Energy, 944 pp. Scientific Report No. 437 http://dce2.au.dk/pub/SR437.pdf

Norwegian EA (The Norwegian Environment Agency) 2021. *Greenhouse Gas Emissions*

1990-2019, National Inventory Report. Oslo: The Norwegian Environment Agency.
Office of Environment 2021. *Liechtenstein's Greenhouse Gas Inventory 1990-2019 National Inventory Report 2021.* Vaduz: Office of Environment.
Portuguese EA (Portuguese Portuguese Environment Agency) 2021. *Portuguese National Inventory Report on Greenhouse Gases, 1990 - 2019.* Amadora: Portuguese Environment Agency.
SHIME Slovak Republic (Slovak Hydrometeorological Institute Ministry of Environment of the Slovak Republic) 2021. *National Greenhouse Gas Inventory Report 1990 – 2019.* Bratislava: Ministry of Environment of the Slovak Republic.
Statistics Finland 2021. *Greenhouse Gas Emissions in Finland 1990 to 2019.* Helsinki: Statistics Finland.
Swedish EPA (Swedish Environmental Protection Agency) 2021. *National Inventory Report Sweden. 2021 Greenhouse Gas Emission Inventories 1990-2019.* Stockholm: Swedish Environmental Protection Agency.
Turkish Statistical Institute 2021. *Turkish Greenhouse Gas Inventory 1990 - 2019.* Ankara: Turkish Statistical Institute.
UNEI, Hungarian MS (Unit of National Emissions Inventories, Hungarian Meteorological Service) 2021. *National Inventory Report 1985-2019.* Budapest: Hungarian Meteorological Service.
UNFCCC 2021. *National Inventory Submissions 2021*.
https://unfccc.int/ghg-inventories-annex-i-parties/2021 (January 9th, 2022)
United States EPA (United States Environmental Protection Agency) 2021. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019.* Washington, DC: U.S. Environmental Protection Agency.