# Stock-Taking Study on Carbon Emissions from Land Use and Management in East and North-East Asia

## August 2022

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# Abbreviations and Acronyms

| | |
|---|---|
| AFOLU | Agriculture, Forest and Other Land Uses |
| APEC | Asia Pacific Economic Cooperation |
| BUR | Biennial Update Report |
| DLD | Desertification and Land Degradation |
| FAO | Food and Agricultural Organization |
| GHG | Green House Gas |
| IPCC | Intergovernmental Panel on Climate Change |
| IPBES | Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services |
| IUCN | International Union for Conservation of Nature |
| KtC | kilotonnes ($10^3$ tonnes) of carbon |
| LULUCF | Land Use Land Use Change and Forestry |
| LDN | Land Degradation Neutrality |
| MtC | megatonnes ($10^6$ tonnes) of carbon |
| NAPA | National Adaptation Program of Action |
| NDCs | Nationally Determined Contributions |
| NEASPEC | North-East Asian Subregional Program for Environmental Cooperation |
| NGHGI | National Green House Gas Inventories |
| TgC | teragrams of carbon (1 TgC = 1 MtC) |
| ToR | Terms of Reference |
| TNC | Third National Communication |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WRI-CIAT | World Resources Institute Climate Analysis Indicators Tool |

# Executive Summary

Every year about 12 million hectares of land are degraded worldwide, mainly through deforestation and conversion to agricultural land.[1] According to the Intergovernmental Panel on Climate Change (IPCC), land use, land use change and forestry (LULUCF), along with agriculture, emitted about 13 per cent of global carbon emissions between 2007 and 2016.

In particular, North-East Asia covers 21 per cent of the world's land surface and more than 25 per cent of the world's forests distribution.[2,3] More than half of the world's forests are found in only five countries (i.e., Brazil, Canada, China, the Russian Federation, and the United States of America), two of which are in North-East Asia. With a high level of emissions from LULUCF (e.g. 2.6 $GtCO_2$ in 2018) coupled with rapid economic development, land in North-East Asia has been rapidly degrading, and nearly 88.7Mha of tree cover has been lost from 2000 to 2021, equivalent to 20 per cent of the world's total loss.[4] The dominance of arid/semi-arid grasslands in the subregion further increases its vulnerability to degradation.

To understand the interlinkages of desertification and land degradation (DLD) and climate change with the aim of developing a subregional approach to creating synergies among actions on addressing DLD and climate change in North-East Asia, this study (a) reviews the existing scientific assessments on carbon emissions from land use change and management in North-East Asia; (b) reviews main assessment results based on different methodologies and identified gaps in the assessments; and (c) discusses policy implications for mitigating carbon emissions and potential areas for collaborative work. The study focuses on five land categories: forests, cropland, grassland, wetlands, and human settlements.

**The carbon emissions from land use and management in North-East Asia steadily decreased to 2016 and then remained steady until 2018**. LULUCF sector was main $CO_2$ emitters of Democratic People's Republic of Korea (DPR Korea) and Mongolia with an average annual emission of 3.13 and 3.3 MtC, respectively. Cropland, wetland and settlements were large emitters of carbon in North-East Asia, while forest land and grassland in China, Japan and the Russian Federation serve as significant carbon pool.

**Forest land has huge potential to be a carbon sink.** In the Russian Federation, the world's largest forest country, forests are important for carbon sink. It has increasingly sequestered carbon from 1990 to 2010; however, the rate of removal declining slowly to 2019. In China, emissions from land use continued to grow from 1990 to 2016 while forests created carbon sinks, which reflected forests emissions from -434 TgC (from 1989 to 1993) to -37,510 TgC (from 2011 to 2015). Japan's

[1] IPBES (2018)
[2] World Development Indicators (2022)
[3] FAO and UNEP (2020)
[4] Global Forest Watch (2022)

forest land has offset all the emissions from other LULUCF sub-categories, making it a net carbon sink sector since 1990, with large-scale plantations carried out during the 1960s. In Mongolia, carbon sequestration by forests has decreased by 5 per cent between 1990 and 2012, mainly driven by forest fires, disease, pests, mining activities, and illegal logging. In the Republic of Korea, afforestation has successfully offset carbon emissions from forests and created a carbon sink, equivalent to -32.5MtC per year between 2001 and 2021.[5] However, according to the National Green House Gas Inventories (NGHGI) report, emissions removal from forests has steadily decreased in the Republic of Korea due to ageing trees, and sequestration could drop further unless replaced with younger trees.

**Croplands present a good opportunity for carbon sequestration with an increase in yield.** Croplands removed 15.3 TgC to 23.98 TgC of carbon per year between 1990 and 2010 in China. In 2020, emissions from Japan's cropland (4,657 $KtCO_2$) fell by 48 per cent compared to 1990 values (8,985 $KtCO_2$) mainly due to improved cropland management, although in 2020, emissions showed an increase of 17 per cent from 2018. In the Russian Federation, the growth of vegetation on abandoned farmlands has boosted carbon sequestration by 42.6 TgC a year. However, in the Republic of Korea, emissions from croplands increased sharply from 0.7 TgC in 1990 to 4 TgC in 2018.

**Grasslands also represent a significant carbon sink.** China has seen increased carbon storage in grasslands, mainly driven by restoration and a ban on grazing in grasslands. As a result, grassland remains a net carbon sink in China. However, it is alarming that the rapid conversion of grassland for settlements and farming purposes contributed to losses in carbon storage in China. Mongolia, with a total area of about 792,000 $km^2$ of grassland, has a significant potential for grassland carbon stock, while this potential has been decreasing mainly due to overgrazing. On the other hand, emissions from grasslands have increased over the years in Japan. An increase in manure application coupled with warmer weather was responsible for the increase in $CO_2$ emissions from grasslands. In the Republic of Korea, grasslands have stored carbon, but studies suggest it could turn into a carbon source soon.

**Settlements are increasingly becoming a major source of carbon emissions.** Rapid urbanization in China demands land conversion to settlements at an ever-increasing scale. Between 1990 and 2010, the expansion of settlements from urbanization in China caused a loss of about 142 TgC from terrestrial ecosystem carbon storage. It is estimated that China will lose about 115.2 TgC carbon storage due to settlement by 2030 under the business-as-usual scenario. However, in Japan, settlements were responsible for emitting about 178 KtC in 2020, an 94 per cent decrease from the 1990 value. Net $CO_2$ emissions due to land conversion to settlements in the Russian Federation was fluctuated. They increased from 18.37 TgC in 1990 to 46.14 TgC in 2015, followed by sharp drops to 12.48 TgC in 2019 and 2.2 TgC in 2020.

[5] Global Forest Watch (2022)

**Wetlands can be either a carbon sink or a carbon source if converted to other land categories.** Wetlands in China became a carbon sink since 2014, with emissions of -44.54 TgC. However, wetlands in Japan, the Republic of Korea, and the Russian Federation emitted 0.02 TgC, 0.3 TgC, and 3.02 TgC in 2014, respectively, while emissions from wetlands in Japan decreased by 74.1 per cent by 2019 compared with the 1990 value.

Noting the data discrepancies across data sources and methods,[6] the study mainly refers to NGHGI and WRI-CAIT datasets and further refers to scientific publications in case that national data reporting is not available. Findings may vary depending on different models and types of data used.

The study identified the following assessment gaps.

- Reporting of carbon emissions from the LULUCF sector is often incomplete, especially for sub-categories other than forests.
- Lack of clarity and consistency in reporting activity data for some sub-categories, such as land under conversion, has constrained the comparability of trends in land use changes and subsequent emissions in North-East Asia.
- Language barriers limited knowledge sharing and coordination amongst countries at technical and policy levels.
- Lack of scientific studies to assess carbon emissions from LULUCF at country and regional levels.
- Varying definitions such as forests, wetlands, and other land.
- High variability in estimates due to varying data sources and methods.
- Lack of an evidence-based accounting framework for carbon debits and credits in the land sector.

## Recommendations for assessing carbon emissions from LULUCF

**The study highlights the need to develop a common integrated assessment model with further research and expert consultations. The model should be flexible, low risk, and adapt to different economic, environmental, and social conditions in North-East Asia.**

**At the technical level,** the study recommends improving (a) completeness of reporting, especially in land use sub-categories other than forest land and including disturbances in forest land; (b) reporting of the soil carbon pool, particularly of organic soils, which represent a large carbon store and thus a significant potential source of GHGs; (c) clarity on methodology, emission factors, and recalculations related to carbon emissions from LULUCF; (d) taking integrated approaches for reducing carbon emissions from land use, land use management, and DLD: for example, standardizing definitions of LULUCF sub-categories for better comparability in the region; and

[6] The data sources include National Greenhouse Gas Inventory (NGHGI) reports, scientific publications, and the World Resources Institute Climate Analysis Indicators Tool (WRI-CAIT).

coordinating a common approach on the number of land cover types and spatial resolution to be used for generating land use maps.

**At the policy level,** it is suggested that countries (a) strengthen policy and technical cooperation, promoting carbon neutrality, especially in the LULUCF sector; (b) form a technical expert group to develop coordinated methods; (c) develop a standardized user guide for estimating emissions and sinks from LULUCF; (d) improve synergy with other programmes such as agriculture, forestry, livestock, urban planning, marine management; (e) adopt policies and programmes that retain carbon in high biomass forests, extend harvest cycles, replant and afforestation, and change forest management to increase the land sink and reduce emissions; and (f) strengthen institutional ties and communication between GHG inventory and resource management agencies to facilitate exchanging data and information and research of new data and methodologies.

It is also recommended for countries to mobilize innovative funding schemes to enhance carbon sink, reduce land degradation, develop more robust methods for assessing carbon emissions, and enhance knowledge sharing and coordination amongst national sectors and regional countries.

# Chapter I. Introduction

## 1.1 Background information

Global land provides the basis and primary resources for human livelihoods and wellbeing. It provides multiple services such as land for agriculture, forestry ecosystems, infrastructure development, water, and carbon storage. However, global land and soils are desertifying and degrading, jeopardizing their ability to support food security, ecosystem services, biodiversity and carbon sequestration.[7]

Two major forces that drive desertification and land degradation (DLD) include:

i) Land use and land management, including deforestation, overgrazing of livestock, over-cultivation of crops, and inappropriate irrigation (also known as land Use, land use change and forestry: LULUCF);[8] and
ii) Climate factors (e.g. variability in climate and global warming).

On average, about 12 million hectares of land are degraded worldwide annually, mainly through deforestation and conversion to agricultural land.[9] For instance, agriculture, forestry, and other land use activities accounted for around 13 per cent of $CO_2$, 44 per cent of methane ($CH_4$), and 82 per cent of $N_2O$ emissions from human activities globally from 2007 to 2016.[10] This sector not only emits but also presents immense opportunities to sequester carbon and thwart global warming.

According to a recent review study in 2021, East Asia and North America were responsible for about 40 per cent of global Green House Gas (GHG) emissions in 2018, dominated by the United States of America (USA) and China.[11] Land use and management were one of the main contributors emitting about 11.6 $GtCO_2$ globally (or about 21 per cent of the global emissions), and East Asia alone emitted about 2.6 $GtCO_2$ (22 per cent) in 2018, which is the highest in the world.[12] Of the total global emissions from land use and management in 2018, 47 per cent (5.4 $GtCO_2$) were from agriculture, forest, and other land uses (AFOLU), almost twice the percentage reported from 2007 to 2016 (i.e. 23 per cent).[13]

Carbon emissions from AFOLU primarily originate from deforestation, transformations between croplands and pasture, peat land drainage and burning, wood harvesting, the regrowth of forest and other natural vegetation after agricultural abandonment and harvest, and soil $CO_2$ flux due to

[7] FAO (2000)
[8] IPCC (2019), FAO (2000), IPBES (2018), Huang, et al. (2019), IUCN (2019)
[9] IPBES (2018)
[10] IPCC (2019)
[11] Lamb, et al. (2021)
[12] Lamb, et al. (2021)
[13] IPCC (2019)

grassland and cropland management.[14] Smaller amounts of carbon are also emitted from managed soils, pasture, rice cultivation, manure management, biomass burning, and synthetic fertilizer application. These emissions are estimated at 1.3 $GtCO_2$ from managed soils and pasture, 1 $GtCO_2$ from rice cultivation, and another 1 $GtCO_2$ from all other combined sources.[15] An increasing trend in $CO_2$ emissions from AFOLU since 2008 is also observed at 0.8 per cent per year.[16] While $CO_2$ emissions from land use and management dominate other sources in many developing countries, the removal and burning of biomass and draining of carbon-rich soils were cited as the main sources of emissions.[17]

Land degradation induced by land use changes is affected by and contributes to climate change through GHG emissions and reduced carbon uptake rates. Desertification exacerbates climate change through changes in vegetation cover, dust aerosols, and GHG fluxes. Meanwhile, climate change creates additional stress on land and vegetation through extreme weather events, exacerbating existing risks to livelihoods, biodiversity, human and ecosystem health, infrastructure, and food systems. Drought and warming exacerbate evaporation of soil moisture while loss of vegetation cover exposes soil to erosion, thereby leading to loss of soil fertility and utility. Forest fires are rapidly increasing globally and are responsible for DLD and associated carbon emissions.[18] Land degradation has contributed over 4.4 billion tons of $CO_2$ from 2000 to 2009, making it a major contributor to climate change, while 24 million hectares (ha) of land are affected by DLD, of which 12 million ha is lost due to DLD.[19]

The North-East Asian region is vulnerable to DLD due to arid and semi-arid land with high exposure to global environmental changes (Figure 1). Vegetation greenness and land use change studies have indicated a net loss of vegetation cover and associated desertification and land degradation in the region.[20] In China, severe and intense soil erosion has increased, and forests, grasslands, and available water in various parts have decreased.[21] Mongolia also faces rapid DLD from climatic and non-climatic causes, including excessive grazing by goats.[22] Similar cases of DLD are spotted in various parts of North-East Asia, leading to increased release of $CO_2$ into the atmosphere, jeopardizing livelihoods and ecosystem services.

[14] Hansis, et al. (2015), Houghton & Nassika (2017), and Gasser, et al. (2020)
[15] Lamb, et al (2021)
[16] Lamb, et al (2021)
[17] Pearson, et al. (2017), IPCC (2019), Hong, et al. (2021)
[18] IPBES (2018)
[19] IPBES (2018)
[20] Lamchin (2020), Liu et al. (2013), Xue et al. (2017)
[21] Fu, et al. (2017), Muyibul, et al. (2018), Xie, et al. (2014)
[22] Liu, et al. (2013)

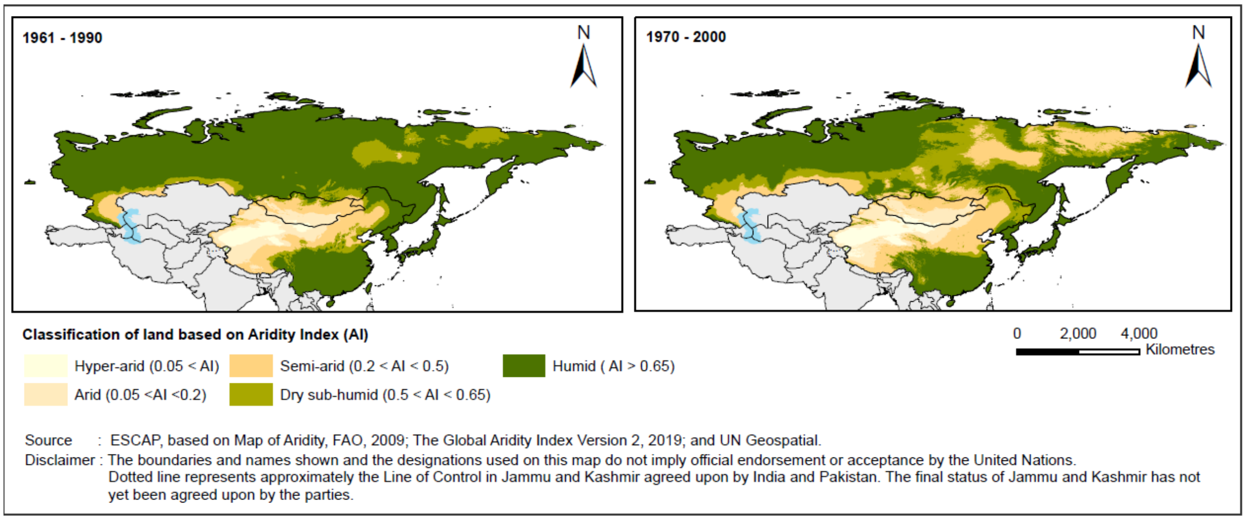


**Figure 1.** Land classification based on Aridity Index in North-East Asia[23]

However, aside from the country-level reports on carbon emissions to the United Nations Framework Convention on Climate Change (UNFCCC) and National Green House Gas Inventories (NGHGI), there are very limited scientific studies addressing carbon emissions in Nor-East Asia, especially from land use and land management sources. This requires support for focused scientific studies to understand carbon emissions from land use and management sources and improve assessment methods for a more accurate estimation of carbon fluxes to guide policy and programmes.

Improved land use and management practices can reduce the emission of $CO_2$ and other GHG gases, prevent DLD, and contribute toward global climate goals such as Sustainable Development Goals, the Paris Agreement on climate change and Aichi Biodiversity Targets. Many interventions (such as sustainable land management, sustainable forest management, etc.) to achieve land degradation neutrality (LDN) can deliver adaption and mitigation benefits and produce co-benefits to combat DLD and vice versa.[24] Such responses also contribute to halting biodiversity loss with sustainable development co-benefits to society.

Given the importance of the socio-ecological challenges posed by land use and management, which are further exacerbated by climate change, countries in North-East Asia decided at the 24th Senior Officials Meeting (SOM-24) of the North-East Asian Subregional Programme for Environmental Cooperation (NEASPEC) in 2020 to **refocus its programmatic area on DLD and the interlinkages with other sectors including climate change.** Member Governments of NEASPEC also decided to develop a subregional approach to create synergies among actions on

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[23] The classification of Aridity Index is: Humid AI > 0.65, Dry sub-humid 0.50 < AI ≤ 0.65, Semi-arid 0.20 < AI ≤ 0.50, Arid 0.05 < AI ≤ 0.20, Hyper-arid 0.05 < AI. Data: ESCAP, based on MAP of Aridity, FAO, 2009; The Global Aridity Index Version 2, 2019; and UN Geospatial.
[24] IPCC (2019)

addressing DLD and climate change to achieve land degradation neutrality.[25] In this regard, the current situation on carbon emissions from LULUCF, the causes, and current responses should be understood first.

### *1.2 Objectives, scope, and limitations of the stock-taking study*

The primary objectives of the stocktaking study include the following components, which formed Chapters II to V of this study:

i) reviewing the existing assessment of carbon emission from land use and management in North-East Asia;
ii) reviewing assessment methods and identifying assessment methods suitable for the subregion;
iii) identifying gaps in the assessment of carbon emissions from land use and management; and
iv) making recommendations for developing a sub-regional approach.

**Scope and limitations**

i) **The comparison of carbon emissions from LULUCF at the national level is limited due to data and reporting inconsistency and unavailability**.
   - Lack of consistency and standardization in reporting emissions from LULUCF by countries makes comparative assessments of North-East Asian countries difficult. The emissions data from land use and land management is not published for all countries during the same period for all sub-sectors of LULUCF.
   - Most studies reviewed did not assess carbon from multiple sub-sectors of LULUCF but were focused on single land categories such as forest land or cropland. This made it challenging to derive trends and compare emissions holistically. For example, the Republic of Korea did not report emissions from the settlement sector, and Mongolia reported only for the forest sector.
   - With data inconsistency in timeframes, a comparative assessment of emissions was conducted based on the data in the year 2014, which may be outdated. For instance, while Japan, the Republic of Korea and the Russian Federation reported emissions data up to 2019 or 2020, Mongolia and China reported emissions data up to 2014.
   - The NGHGI reporting of the Republic of Korea and the Russian Federation was only found in their national languages and had to be translated. However, the National Inventory Submissions from the Russian Federation to the UNFCCC were in English, where they reflected the same carbon emissions data as a supplementary reference.
   - Data from scientific studies and from NGHGI reports may have further updates in 2022, noting this study was conducted in 2021.

ii) **The literature search resulted in a very limited number of scientific studies relating to carbon emissions from land use and management in North-East Asian countries**.

[25] NEASPEC is an inter-governmental environmental cooperation mechanism established by People's Republic of China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea, and the Russian Federation in 1993.

- The search did not reveal any credible scientific article or national GHG inventory report for DPR Korea. China has the maximum publications, followed by the Russian Federation, Japan, the Republic of Korea, and Mongolia.
- Most of the local level studies were small-scale experiments and, as such, not useful for regional level implications due to the socio-ecological and geographical heterogeneity of North-East Asia.
- The scoping review approach and search systems used may limit the scope of references assessed in this study. While the scoping review approach is exhaustive and proven, the current review may be limited by the selection of keywords. The use of Western search systems may have excluded valuable North-East Asian perspectives that are often published in smaller, excluded journals.

Noting the abovementioned limitations and challenges, the stock-taking study made utmost efforts to synthesize the available findings along an increasing timeline to ascertain carbon emissions and storage in the North-East Asian countries. The synthesis of the review is presented in the findings and discussion sections.

# Chapter II. Review of the existing assessments on carbon emissions from land use change and management in North-East Asia

## 2.1. Overview of carbon emissions from land use and management in North-East Asia

According to the IPCC good practice guidelines, GHG emissions and removals in the LULUCF sector consists of carbon stock changes in five carbon pools (i.e. above-ground biomass, below-ground biomass, deadwood, litter, and soil) in each land use sub-category (i.e. forest land, cropland, grassland, wetland, settlements, and other lands).[26] This study used the data on carbon emissions from the LULUCF sector available from World Resources Institute Climate Analysis Indicators Tool, which provides emission figures for all countries up to 2018, as presented in Table 1.[27]

**Carbon emission from LULUCF in North-East Asia has steadily decreased from -1,491.50 MtC to -1,280.59 MtC in 2016 and then remained steady around -1,280 MtC until 2018.** Mongolia and DPR Korea were the main emitters from the LULUCF sector, with an average annual emission of 3.13 MtC and 3.3 MtC, respectively, while scientific studies on carbon emissions from land use and management in these two countries are scarce. In general, China, Japan, the Republic of Korea, and the Russian Federation have steadily decreased the sequestration of carbon in LULUCF pools.

[26] IPCC (2019)
[27] WRI-CIAT (2021)

**Table 1.** Annual carbon emissions from LULUCF in North-East Asian countries (MtC)

| Country | Source | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| China | WRICIAT | -710.17 | -710.17 | -650.10 | -650.10 | -650.10 |
| | NGHGI | -1150.91 | - | - | - | - |
| Japan | WRICIAT | -49.71 | -49.75 | -32.06 | -32.07 | -32.07 |
| | NGHGI | -61.00 | -56.60 | -52.40 | -56.50 | -55.90 |
| Mongolia | WRICIAT | 3.17 | 3.17 | 3.11 | 3.09 | 3.10 |
| | NGHGI | -24.45 | - | - | - | - |
| DPR Korea | WRICIAT | 3.20 | 3.20 | 3.29 | 3.29 | 3.29 |
| | NGHGI | - | - | - | - | - |
| ROK | WRICIAT | -50.46 | -50.46 | -45.80 | -45.80 | -45.80 |
| | NGHGI | -43.30 | -44.40 | -45.60 | -41.30 | -41.30 |
| Russian Federation | WRICIAT | -687.53 | -687.51 | -559.03 | -558.95 | -558.50 |
| | NGHGI | -707.02 | -628.36 | -646.45 | -642.70 | -636.40 |
| Total | WRICIAT | -1491.50 | -1491.52 | -1280.59 | -1280.54 | -1280.08 |
| | NGHGI | -1986.68 | -729.36 | -744.45 | -740.50 | -733.60 |

Note: WRICIAT 2018: World Resources Institute- Climate Analysis Indicators Tool;
NGHGI: National Green House Gas Inventory reports (and/or Biennial Update Reports, where applicable) available from each country from 2014 to 2018

NGHGI reports also show a steady increase in emissions except for China and Mongolia (Figure 2). Differences in the two data may be attributed to the fact that some NGHGI reports only rely on emissions from forest lands, while WRI-CIAT uses emissions from all sub-categories. While cropland, wetland, and settlements are large emitters of carbon into the atmosphere, forest land followed by grassland serves as significant carbon pools, especially in the Russian Federation, China, and Japan (Figure 3; Table 2).

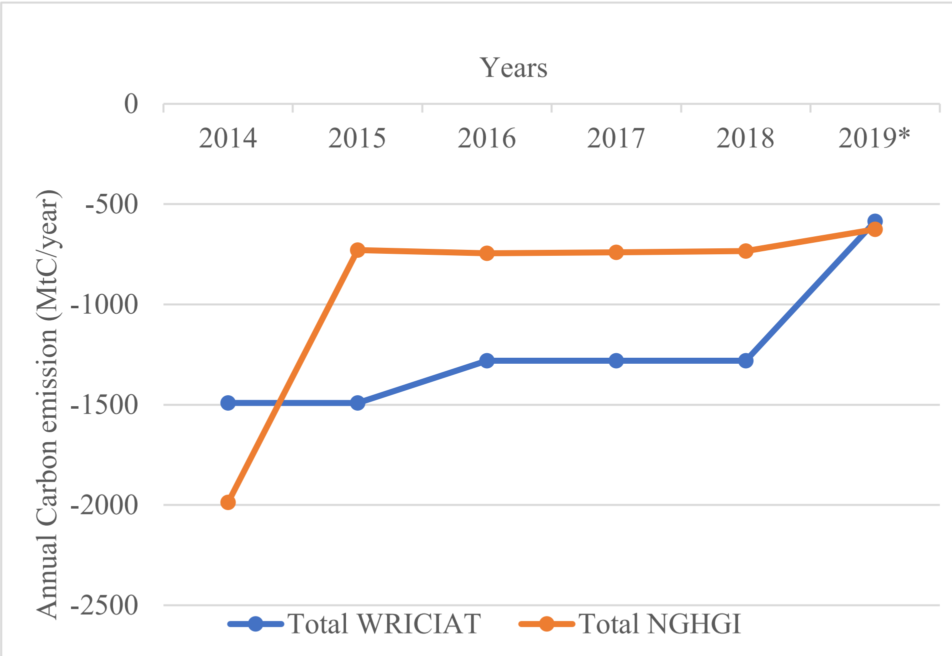


**Figure 2.** Total annual carbon emission trends from LULUCF in North-East Asia
Data source: NGHGI reports available from each country (2014 to 2019)

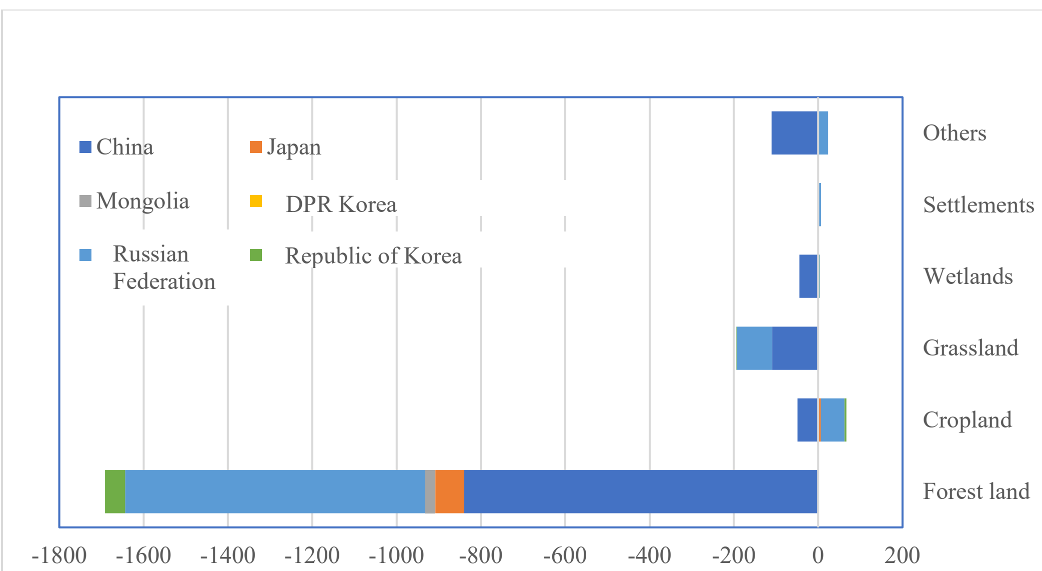


**Figure 3**. $CO_2$ emissions from LULUCF in North-East Asia based on 2014 NGHGI data (MtC)
Data source: NGHGI reports available from each country (2014 to 2019)

It was difficult to ascertain a total emission for LULUCF at the national level based on published articles as there is no consistent reporting for all LULUCF sub-categories. In addition, studies were carried out at different times using different periods. **However, emissions from forest land are**

**the most frequently reported, and it indicates increasing sequestration** (Annex 2). For example, Chinese sequestration increased sharply due to the Government's aggressive afforestation programs, ecological restoration projects, and agricultural management.[28] It is reported that between 1990 and 2010, China experienced a net increase in forest land, farmland, urban land, and other lands (sandy land, Gobi, saline-alkali land, swampland, bare land, rock and gravel, and other unused land).[29] In the Russian Federation, carbon emissions dropped significantly from 2000 but picked up again in 2010 and then decreased due to increased sequestration in the abandoned agricultural land post-SOVIET regime.[30]

The stock-taking of published articles found that China is the most studied country, followed by the Russian Federation, Mongolia, the Republic of Korea, and Japan. No published articles were found for DPR Korea. The current emissions estimated by academic institutes and scholars exhibit discrepancies mainly emerging from data sources and methods. Emissions from LULUCF are synthesized by sub-categories in the following sections.

**Box 1: key highlights on carbon emissions from LULUCF**

- Land is a huge repository of carbon. However, its ability to continue sequestering carbon is threatened due to desertification and land degradation in North-East Asia. In particular, the subregion is dominated by arid and semi-arid land, which is highly vulnerable to the slightest changes in the environment.
- Estimates of carbon emissions from LULUCF vary due to different sources of data, methods of accounting, reporting period and selection of emission factors. For instance, NGHGI reports a significantly lower emission compared to WRI-CIAT figures. Similarly, scientific assessments also report varying carbon emission estimates.
- Forest land is the largest carbon sink in North-East Asia with a total of 1,691.76 MtC sequestered in 2014. This is followed by grassland, other lands, and wetlands sequestering 191.79 MtC, 87.105 MtC, and 41.201 MtC, respectively, in the same year. As Mongolia and China did not report emissions data after 2014, it was difficult to ascertain a meaningful trend. The WRI-CIAT database has no emissions data for LULUCF subsectors either.
- Except in China, sequestration by forest land in other North-East Asian countries is on the decline, signaling the need for improved management interventions.
- Overall, according to data from both WRI-CIAT and NGHGI, China represents the largest carbon pool in the LULUCF sector with an annual average (from 2014 to 2018) of 674.13 MtC sequestered, followed closely by the Russian Federation with mean sequestration of 610.304 MtC a year.
- Figures from WRI-CIAT show Mongolia and DPR Korea as net emitters of carbon from the LULUCF sector, indicating opportunities for targeted mitigation interventions.
- Conversion of forest land, grassland and wetland into other land uses (e.g. agriculture and settlements) is a major driver of land degradation and its subsequent carbon emissions. Excessive grazing, forest fires and climate change exacerbate land degradation and carbon emissions in North-East Asia.

[28] Fang, et al. (2018); Feng, et al. (2016)
[29] Lin, et al. (2021)
[30] Romanovskaya (2008), Kurganova, et al. (2014)

## 2.2. Carbon emissions from forest land

Forests sequester carbon (removing it from the atmosphere) in their biomass and soils as they grow, but they also emit carbon during harvesting, planting activities, and fires. According to the national GHG data, forests in North-East Asia sequestered over 1,691.76 MtC in 2014, while data from DPR Korea is missing, and Mongolia only reported forest biomass (Table 2). As specific values of carbon emissions from the LULUCF sub-categories are difficult to source aside from the NGHGI reports, regional level reports are difficult due to differences in available reports in their methods, data sources, study duration, and reporting years.

At a country level, China and the Russian Federation are the largest forests carbon pools sequestering over 839 MtC and 711 MtC, respectively. Especially, China's land use emissions continued to increase from 1990 to 2016, but forest emissions decreased over the years.[31] Between 1982 and 1999, China's annual carbon emissions from forest soil were estimated at -43.4 TgC.[32] This decreased to -70.2TgC in 2013[33] and -144 TgC in 2016,[34] although it increased to -18.5 TgC in 2018.[35] This increase in sequestration (or decrease in emissions), as reflected earlier, is due to increasing forest biomass during the 1980s and 1990s, resulting from the Government's afforestation programmes.[36]

Japan's forest land has offset all the emissions from other LULUCF sub-categories, making it a net carbon sink sector since 1990. This is mainly attributed to removals in forest land, a decrease in the amount of carbon loss in mineral soils in cropland and a decrease in emissions due to the decrease of areas of forest land conversion. However, Japan's NGHGI reported decreasing trends in net removals from 2004 to 2019, mainly caused by the decrease of removals in forest land.[37] In 2019, Japan's forests removed about 55.90 MtC, which decreased 30.1 per cent and 6.7 per cent from the 1990 and 2018 values, respectively. High removals from large scale plantations in the 1960s have reduced as sequestration capacities have started to peak off. WRI-CIAT data also indicate sequestration capacity of Japan has decreased since 2010. In 1990, it was estimated that forest biomass stored about 1,100 TgC,[38] while in 2004, a total of about -4,570 TgC in forest soils, of which 48 per cent were contained in the top 30 cm.[39]

[31] Lin, et al. (2021), Piao, et al. (2009), Fang, et al. (2018)
[32] Piao, et al. (2009)
[33] Guo, et al. (2013)
[34] Lia, et al. (2016)
[35] Fang, et al. (2018)
[36] Fang, et al. (2018), Feng, et al. (2016)
[37] NIES (2021)
[38] Matsumoto and Kanomata (2001)
[39] Morisada, et al. (2004)

**Table 2.** Carbon emission from LULUCF sub-categories based on National GHG Inventory Data (2014)

| | Forest land | Cropland | Grassland | Wetlands | Settlements | others | total |
|---|---|---|---|---|---|---|---|
| China[40] | -839.73 | -49.46 | -109.16 | -44.54 | 2.53 | -110.55 | -1150.91 |
| Japan[41] | -68.28 | 6.21 | 1.72 | 0.02 | -0.27 | 0.19 | -60.40 |
| Mongolia[42] | -24.45 | 0 | 0 | 0 | 0 | 0 | -24.45 |
| DPR Korea | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROK[43] | --47,90 | 4.30 | -0.10 | 0.30 | 0.00 | 0.00 | -43.40 |
| Russian Federation [44] | -711.40 | 56.49 | -84.25 | 3.02 | 4.60 | 23.26 | -708.29 |
| Total | -1691.76 | 17.54 | -191.79 | -41.20 | 6.86 | -87.11 | -1987.46 |

Mongolia's reporting of the overall LULUCF emissions and removals has discrepancies depending on different data sources. Figures from the WRI-CIAT dataset show that its LULUCF removals decreased by 5 per cent from 1990 to 2012, mainly driven by changes in forest land. This decrease was caused primarily by forest fires, disease, pests, mining activities, and illegal logging.[45] For instance, in 2010, 375,700 hectares of land with forest reserves were affected by various factors, including fires (104 incidents were recorded), diseases and pests, and mining activities. In the period 2008 to 2010, the total land area for mining increased by 29 per cent due to an increase in gold, copper, and coal mining sites.

However, there is a substantial discrepancy in reported figures for Mongolia. For instance, emissions were 3.17 MtC in the WRI-CIAT dataset, while the Mongolian NGHGI reported a negative 24.63MtC emissions in the same year. Although it is not clear why there are discrepancies, there is a lack of scientific research to estimate carbon emissions, especially from LULUCF in Mongolia. A study reported that deforestation and forest degradation emitted about 3.48 MtC, without considering natural growth on forest land remaining forest land.[46] It also reported an annual average removal of 29.13 MtC when including natural growth on forest land remaining forest, which shows an increasing sequestration trend compared to the removal of 24.63 MtC reported in 2014.

The Republic of Korea has a very successful afforestation history that has led to offsetting carbon emissions in the country. However, in recent years, removals from forest land have steadily declined since 2010. According to its NGHGI report, carbon sequestration has steadily decreased

[40] China (2018)
[41] Japan (2016)
[42] Mongolia (2017)
[43] Republic of Korea (2019)
[44] Russian Federation (2016)
[45] WRI (2012)
[46] Enkhtaivan, et al. (2018)

from -58.8 MtC in 2010 to -45.6 MtC in 2018.[47] The ageing of the trees is a probable major cause of this decline in sequestration.[48] A study using a land use map and domestic method revealed that forest trees alone only sequester -2,680.50 TC/year, similar to the result (-2,607.30 TC/year) where the IPCC method was applied.[49] This probably indicates that forest inventory in the Republic of Korea has been quite thorough, and unless older trees are replaced, sequestration could drop further.

Forests play very critical roles in carbon sequestration in the Russian Federation. NGHGI report from the Russian Federation showed that their carbon sequestration by forests has increased over the years from -248.41TgC in 1990 to -777 TgC in 2010 and then slowly declined to -660.48TgC in 2019 and -634.35 TgC in 2020.[50] Except for the study on net carbon removal by abandoned land/soil,[51] all major studies focussed on assessing emissions or storage in forest land.

Other studies on forests carbon in the Russian Federation presented similar findings to what was reported in its NGHGI reports. For example, it was found that in 1990 a total of 181,800 TgC was sequestered in forests.[52] While there has not been a significant increase in forest area, annual carbon sequestration has gradually increased since then.[53] Estimates show that the quantity of carbon in forests fluctuated between the years of study with an overall increasing trend of sequestration from -210 TgC/year between 1961 and 1998 to -345 TgC/year between 1990 and 2014 to -691.9 TgC/year in 2007. The post-2007 data in these studies were close to the NGHGI data reporting.

A study showed that the Russian forests sequestered 47 per cent more carbon in their live biomass than what was reported by the NGHGI in 2014.[54] The study attributed this inconsistency to an information gap when the Russian Federation decided to move from the old Soviet Forest Inventory and Planning System to a new National Forest Inventory system for the collection of forest information on the national scale.

It is also observed that the ongoing climate change drives changes in the boreal forests in the Russian Federation in terms of productivity, forest cover, carbon budget and disturbance regimes.

Despite different methodological approaches, these studies collectively indicate that forests in the Russian Federation are important for carbon sequestration through live biomass, dead wood and soil (Annex 2).

[47] GIR (2021)
[48] Kim, et al. (2014)
[49] Kim, et al. (2018)
[50] Russian Federation (2021) and Russian Federation (2022)
[51] Rommanovskaya (2008)
[52] Goodale, et al (2002)
[53] Schepaschenko, et al. (2021)
[54] Schepaschenko, et al. (2021)

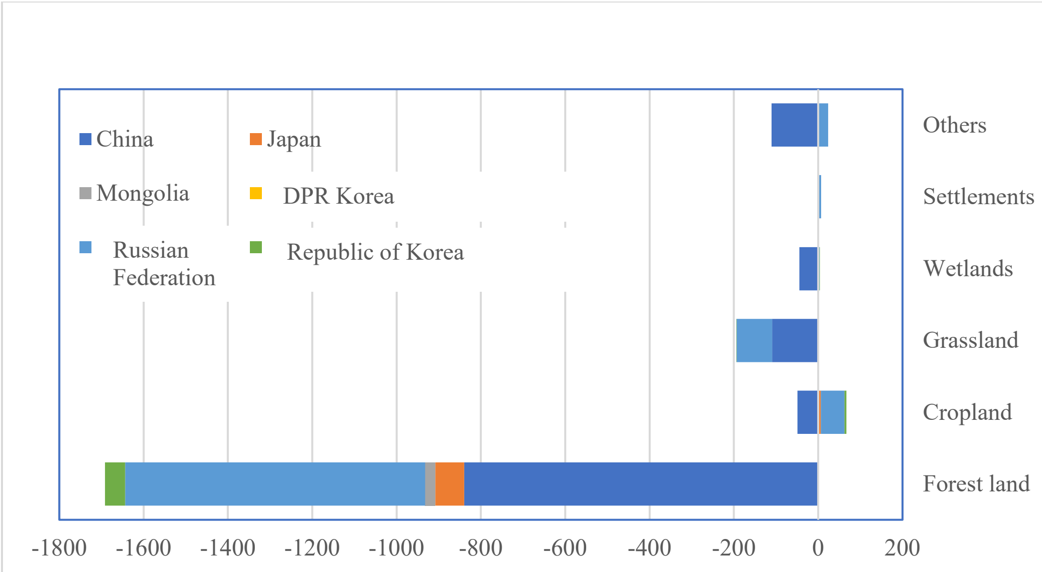


**Figure 4**. $CO_2$ emissions from LULUCF in North-East Asia based on 2014 NGHGI data (MtC)[55]

### 2.3. Carbon emissions from cropland

As shown in Table 2 above, based on the 2014 NGHGI reports of each country in North-East Asia, cropland could be either a carbon source or sink. Cropland in China removed 49.46 MtC in 2014, a decrease of 25 per cent compared to the 2010 removal of 66.04 TgC.[56]

In Japan, the NGHGI report in 2021 noted 5,143 KtC emissions from cropland in 2019, a 42.8 per cent reduction of carbon emissions compared to 8,985 KtC in 1990. In the Republic of Korea, emissions from cropland increased sharply from 0.7TgC in 1990 to 4.8 TgC in 2010. It decreased to 3.8 TgC in 2015 but grew to 4 TgC in 2018. A study estimated carbon emission from cropland at 4.58 TgC for the year 2014,[57] and this was very close to the figure reported in ROK's NGHGI report in 2021 (Annex 2).

In the Russian Federation, the NGHGI reported that emissions from cropland have steadily dropped from 77.97TgC in 1990 to 54.40TgC in 2010. It increased to 66.34TgC in 2015 followed by a slight decrease to 65.77TgC in 2019. One of the most significant contributions to reducing carbon emissions in the Russian Federation was the abandonment of farming land post-Soviet Union period, where a lot of abandoned farmlands reverted to vegetation, thereby storing carbon.[58] However, estimates differ widely, and some attribute this disparity to differences in methods, periods, and inconsistency in the area of abandoned land among different statistical sources.[59] For

[55] See references: China (2018), Japan (2016), Mongolia (2017), Republic of Korea (2019) and Russian Federation (2016)
[56] China (2018) and China (2018b)
[57] Park, et al. (2016)
[58] Rommanovskaya (2008), Dolman, et al. (2012), Kurganova, et al. (2014)
[59] Dolman et al. (2012)

example, using data from 1990 to 2009, it is estimated that abandoned farmland sequestered about 42.6 TgC a year, which is equivalent to about 10 per cent of all Russian forest-based sequestration.[60] While some reported a higher estimate of 46.1 TgC a year,[61] others estimated a significantly lower figure of 5.2 TgC a year in forest soils.[62]

### 2.4. Carbon emissions from grassland

Grassland refers to land covered by perennial pasture and is used mainly for harvesting fodder or grazing. They play an important role in the terrestrial carbon cycle, especially under climate change scenarios.[63] Accurate estimation of soil organic carbon and emissions from grasslands based on modelling and experimental approaches comes with high uncertainties at regional levels.[64]

China's grasslands sequestered about 109.16 MtC in 2014, which is a significant increase from -45.13TgC in 2010.[65] More recently, based on a field survey and remote sensing (2011-2017), a study reported that grassland in China sequestered about -25,400 TgC.[66] Other studies reported that carbon sequestered by the grassland biomass is much smaller at 3.36 TgC/year and 6.84 TgC (2015), respectively (Annex 2).[67] This indicates that carbon storage in grassland soil is much larger than those in grassland biomass. While grassland remains a net carbon sink in China, it is alarming that there are carbon losses due to the rapid conversion of grassland, especially for settlement and farming purposes. A study reported an emission of 7.1 because of the conversion of grassland to other land uses (Table 3) but that grassland soil sequestered about 12.4 TgC annually (between 1990 and 2010).[68]

Japan's grassland is a net emitter of carbon that emitted about 961 Kt $CO_2$ in 2019, which was a 45.0 per cent increase over 1990 emission values and a 63.1 per cent increase from 2018.[69] This was mainly due to increased manure application coupled with warmer weather. While Japan's grassland remains a net emitter of carbon, a study, using the 1990 base year estimated that Japan's grassland area (including natural grasslands, semi-natural grass, lands, meadows⁄ pastures and artificial grassland for non-agricultural use) covered about 5 per cent (or 18,700 $km^2$) of total land area with a total carbon stock of 214 TgC which is 8 per cent of the carbon stock in Japanese topsoil).[70]

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[60] Kurganova, et al. (2014)
[61] Doman, et al. (2012)
[62] Rommannovskaya (2008)
[63] Xin, et al. (2020)
[64] Groisman, et al. (2018)
[65] China (2018)
[66] Tang, et al (2017)
[67] Fang, et al. (2018), Lin, et al. (2021)
[68] Liu et al. (2019)
[69] NIES (2021)
[70] Matsuura, et al. (2012)

With a total area of about 792,000 km$^2$ of grassland, Mongolia represents a significant carbon stock. However, in recent years climatic and anthropogenic factors have been steadily degrading grasslands, thereby leading to the emission of carbon into the atmosphere. For instance, grazing intensity has increased threefold from 1949 to 2010, leading to the degradation of about 65 per cent of the native grasslands.[71] Several studies have attempted to understand soil organic carbon in grassland. Still, their results were inconsistent, while the high level of variability in results was attributed to data sources and methods used.[72] It was recently attempted to quantify soil organic carbon dynamics in Mongolian grassland based on a soil survey from 2007 to 2011. It found that soil organic carbon stock has decreased by about 0.52 per cent a year.[73] Spatially, the declining trends were observed from North-East to the South-West. Another study, using the Century model and field soil inventory in grassland in Mongolia, found that reducing the intensity of grazing may be an effective strategy for the restoration of degraded grasslands.[74]

In the Republic of Korea, emissions from grassland increased slowly from -0.5 TgC in 1990 to -0.1TgC in 2015. Since 2017, emissions from grassland have peaked at 0 TgC, which indicates that grassland in the Republic of Korea could become a carbon source.

In the Russian Federation, NGHGI reported the grassland sequestered 35.42 TgC in 2020, while in 1990, it was a carbon source emitting 50.08 TgC.

### 2.5. Carbon emissions from settlements

Settlements are increasingly becoming the major source of carbon emissions globally and in North-East Asia.[75] China's rapid development leads to urbanization with conversions to settlements at an ever-increasing scale. For instance, between 1990 and 2010, urbanization in China caused a loss of about 142 TgC from terrestrial ecosystem carbon storage due to the expansion of settlements (Annex 3).[76] Moreover, under the business-as-usual scenario, China is expected to lose about 115.2 TgC due to settlement by 2030.[77] In the NGHGI data, China showed 2.53 MtC emissions in 2014 (Table 2), but no recent data is available. A study found that emissions were the largest when forest lands were converted into settlement lands, and emissions were less when waterbodies and grasslands were converted into settlements compared to forests.[78]

Japan's settlements were responsible for emitting about 178 KtC in 2020. This reflects 94 per cent decrease from the 1990 value (i.e.2,873 KtC) 88.9 per cent decrease)[79].

[71] Chen, et al. (2018)
[72] Xin, et al. (2020)
[73] Xin, et al (2020)
[74] Chang et al. (2015)
[75] Settlements include developed land such as transportation, infrastructure, and human habitats.
[76] Lia, et al. (2016)
[77] Lia, et al. (2016)
[78] Xu, et al. (2016)
[79] NIES (2022)

The Republic of Korea did not report carbon emissions from settlements in its 2021 or other NGHGI reports. A pilot study, based on 2010-2017 data, estimated that settlements in Incheon Metropolitan City emitted about 466.31 TgC.[80]

Overall, emissions from settlements in the Russian Federation substantially increased from 18.37 TgC in 1990 to 23.99 TgC in 2000 and 46.14 TgC in 2015. Then, there was a sharp drop to 8.87 TgC in 2018, followed by an increase to 12.48 TgC in 2019 and another sharp drop to 2.2 TgC in 2020. [81] It is not clear why there was a sudden decrease.

### 2.6. Carbon emissions from wetland

Wetland is defined as land covered with or soaked in water throughout the year and consists of 3 categories: peat land, flooded land, and other wetlands.[82] Wetlands in China are a carbon sink. In China, emissions from wetlands decreased from 45.08TgC in 2010 to -44.54 TgC in 2014 and became a carbon sink (Table 2). It was estimated that carbon stocks in Chinese wetlands were around 6,400 TgC (Annex 2).[83]

Wetlands in Japan, the Republic of Korea and the Russian Federation emitted 0.02 TgC, 3.02 TgC, and 0.3 TgC, respectively, in 2014. Japan also reported a significant decrease in emissions from wetlands in 2019, standing at 23 KtC, a 74.1 per cent reduction from the 1990 value and a 14.5 per cent reduction from the 2018 value.

Emissions from wetlands in the Republic of Korea have oscillated around 0.3 TgC a year. In the Russian Federation, wetland emissions reported in the NGHGI have also remained steady at around 2.5TgC a year,[84] while a study reported net sequestration of Russian wetlands at 53.4 TgC a year.[85]

### 2.7. Carbon emission from other lands

Other lands refer to areas that are rocky, bare, ice or any other land that doesn't fall under the five other land types.[86] While many countries do not report emissions from other lands, China has reported them in their Biennial Update Report (BUR) and Third National Communication (TNC), while Japan and the Russian Federation have reported them in their National Inventory Report to the UNFCCC. China's other lands were reported as carbon sinks with increasing sequestration

[80] Choi, et al. (2020)
[81] Russian Federation (2022)
[82] IPCC (2006)
[83] Tang, et al (2016), Lia, et al. (2016)
[84] Russian Federation (2021)
[85] Dolman, et al. (2012)
[86] IPCC (2019)

from 2010 (95.86 TgC) to 2014 (110.55 TgC). This is probably due to massive plantation efforts on bare lands. Compared to 1990, value emissions from other land uses have dropped by over 20 per cent in 2019 (280 KtC).

Japan and the Russian Federation have reported 0.19 TgC and 23.26 TgC emissions for 2014. Emissions from other lands in the Russian Federation have also dropped significantly from 230 MtC in 2000 to 1.29 Mtc in 2019.[87]

### 2.8. Overview of key challenges and responses in land use and management sector

Desertification and land degradation are emerging as major land management challenges in the North-East Asian region. Large areas of land in China, Mongolia, and the Russian Federation face expedited desertification due to existing arid conditions exacerbated by climate change and human pressure.[88] Changes in land use from the forest, grassland, and wetland into agricultural land, settlements, and other land uses, including mining, etc., are the dominant causes of these challenges.[89] Climate change also intensifies desertification and land degradation through droughts, landslides, erosions, etc. About 27.20 per cent of China was occupied by desertification land in 2014.[90] Similarly, desertification is progressing in Mongolia, exacerbated by excessive grazing by livestock and mining, forest fires, and pests. Unsustainable use of land, such as cultivation in water-scarce drylands, draining wetlands to grow agriculture, etc., are also serious drivers of land degradation and thus exacerbate carbon emissions into the atmosphere.

Increasing carbon sinks and ensuring sustainable land and forest management practices are essential to address land degradation, carbon emission, and climate change impacts in North-East Asia. Adopting and scaling up to more sustainable management practices in the land use sector not only holds significant mitigation potential. In addition, it often provides short-term benefits in terms of land productivity and food security and helps ensure the long-term resilience and adaptive capacity of the more vulnerable communities.

In this recognition, governments and development partners have implemented mitigation programmes such as sustainable land management, landscape restoration/rehabilitation, sustainable forest management, etc., reducing land degradation and carbon emissions from land use and land management. Specific responses are presented below:

| Country | Major responses |
|---|---|
| China | • Pledged in the NDC to peak $CO_2$ emissions before 2030 and achieve carbon neutrality before 2060. Furthermore, China will lower its CO2 emissions per unit |

[87] NGHGI reports from Japan and the Russian Federation (2016)
[88] Feng, et al. (2016)
[89] IUCN (2015)
[90] Feng, et al. (2016)

| | |
|---|---|
| | of GDP by over 65 per cent from the 2005 level and increase the forest stock volume by 6 billion $m^3$ from the 2005 level, among other national goals in the NDC.[91]<br>• Initiated large-scale forestry and restoration projects such as natural forest resources conservation project, grain to green project, Beijing and Tianjin sandstorm source control project, and shelter belt programmes. China has increased its forest coverage to 23.04 per cent by 2020 and aimed for a further increase to 24.1 per cent by 2025. [92]<br>• China took initiatives to increase grassland carbon sink. By 2016, China increased grassland fences by 2.993 million hectares, improved degraded grassland by 3.127 million hectares, and planted 13.07 million hectares of artificial grassland. In addition, China prohibited grazing on 105 million hectares of grassland.[93]<br>• In 2020 alone, China afforested 6.77 million hectares of forests, newly planted 2.83 million hectares of grassland, and saved 2.096 million hectares of land from desertification.[94]<br>• In addition, China also brought more wetlands under management through its flagship project of developing a marine blue carbon sink. |
| Japan | • Committed to reducing GHG emissions by 46 per cent from 2013 levels by 2030 and achieving net-zero by 2050.[95] As of April 2021, the Ministry of Agriculture, Forestry, and Fisheries (MAFF) has developed a global warming countermeasure plan that seeks to sequester an additional: 27.8 million tons of $CO_2$ above the 2013 levels in forest sink by 2030; 7.9 million tons through cropland and grazing land management; and 1.2 million tons through revegetation of urban green spaces. MAFF also allocated US$ 1.1 billion to support activities such as annual thinning and selective logging operations to increase carbon removal from the atmosphere. [96] |
| Mongolia | • Committed to reducing its GHG emissions by 22.7 per cent by 2030 compared to a business-as-usual scenario, excluding LULUCF. Furthermore, if conditional mitigation measures are implemented (e.g. carbon capture and storage technology) and measures to remove GHG emissions by forests are determined, the total mitigation target of Mongolia aims to be 44.9 per cent GHG emissions reduction by 2030.[97]<br>• Planned to<br>- increase carbon sink by 29 million tons per year by improving pasture management;<br>- increase carbon sink by practicing low carbon cropping practices and reducing bare fallow to 30 per cent in the rain-fed cropland; and |

[91] China (2021)
[92] The State Council of China (2021)
[93] China (2018)
[94] Xinhua News (2021)
[95] Japan (2021)
[96] United States Department of Agriculture (2021)
[97] Mongolia (2020)

| | |
|---|---|
| | - increase forest area by 9 per cent by 2030.[98] |
| Republic of Korea | • Pledged to reduce its GHG emissions by 40 per cent from the 2018 level by 2030.[99]<br>• Adopted the 2nd comprehensive plan for improvement of carbon sinks in 2018.<br>• Committed in 2021 to becoming carbon neutral by 2050 through its 2050 Carbon Neutral Forest Sector Promotion Strategy.<br>• Plan to plant 3 billion trees over the next 30 years.[100] |
| Russian Federation | • Committed to reducing GHG emissions by up to 70 per cent by 2030 compared to the 1990 level.[101] |

### 2.9. Summary

Policies and incentives that promote sustainable land management, including enhanced carbon stocks through land rehabilitation and ecosystem restoration, may be one of the missing pieces of the climate puzzle. It helps to reduce the remaining emissions gap in a demonstrable and cost-effective manner.

A summary of the review of carbon emissions from land use and management in North-East Asia is presented below:

- Scientific research to assess carbon emissions from land use and management is limited, especially at national and regional levels. Most available scientifically published assessments are from China and the Russian Federation. Reports of published papers vary most probably due to different data sources and methods. There is an opportunity to standardize data collection protocols and harmonize emission models to reduce these inconsistencies.
- On the National Green House Gas Inventory (NGHGI), NGHGI reports are available in 2022 for Japan, the Republic of Korea and the Russian Federation. While reporting emissions for LULUCF sub-categories is incomplete in NGHGI reports of all the North-East Asian countries. Mongolian NGHGI data is available only up to 2014 and only for the forest sub-sector. Chinese NGHGI report was not available online, and for this study, data was extracted from BUR and TNC.
- Overall, mean carbon sequestration was highest in China, followed by the Russian Federation, while Mongolia and DPR Korea were net carbon emitters from 2014 to 2018 (Figure 4).
- Forest land was the primary sink of carbon, with a total of 1,691.76 MtC sequestered in 2014 alone. However, except in China, this pool has been declining in Japan, the Republic of Korea and the Russian Federation in recent years.
- One of the major drivers of land degradation and subsequent carbon emissions are conversion of forest land, grassland, and wetlands into agricultural and settlements. Excessive grazing, forest fires, and climate change further are additional drivers.

[98] Mongolia (2015)
[99] Republic of Korea (2021)
[100] EcoWatch (2021)
[101] Russian Federation (2020)

- North-East Asian countries have committed to reducing carbon emissions by improving carbon pools, especially through afforestation, restoration of grasslands, and cutting down on grazing. Recent commitments to reduce carbon emissions and increase carbon sinks in some areas are promising steps.

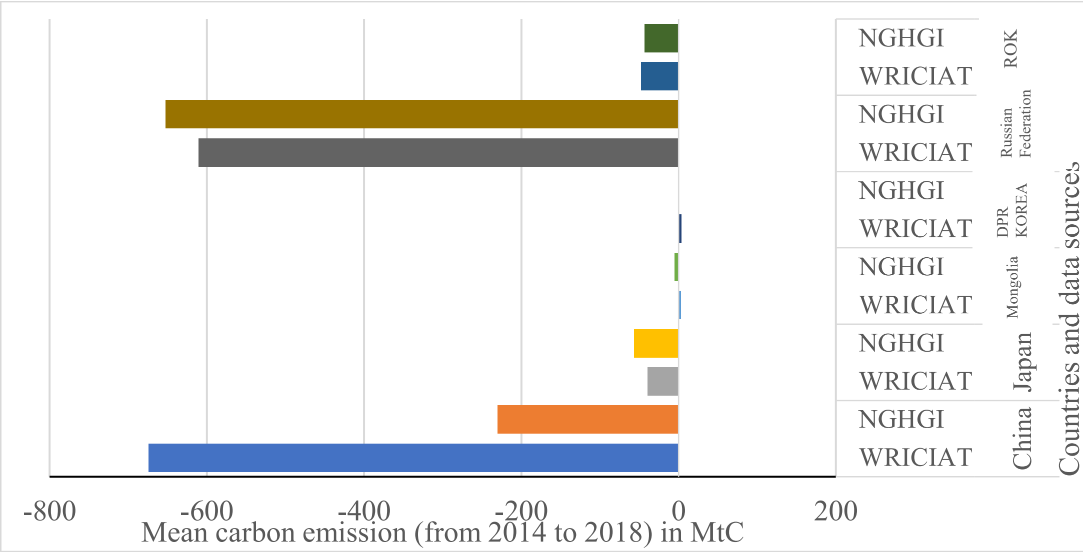


**Figure 4.** Mean carbon emission (MtC) by countries in North-East Asia from NGHGI and WRICIAT sources.

# Chapter III. Review of methodologies and their assessment results

An evaluation of popular methods to assess carbon emissions from LULUCF has been presented in Annex 3. The review was guided by a model description, inputs, outputs, disadvantages and benefits by their structure, assumption, parameter, and calibration. However, complete information was not available to all. The reviewed models are either statistical data, process, or inversion based.

**NGHGI reports revealed that methods used to calculate emissions and removals in the LULUCF sub-category vary between countries and land use categories** (Table 3). For instance, the Russian Federation used only Tier 1 (T1) method with country-specific emission factors except for cropland, where the IPCC default emission factor was used. In contrast, China used the T2 method for calculating carbon emissions from the LULUCF sub-categories except for other lands where the IPCC default emission factor was used. Japan used more than one method and a combination of country-specific and IPCC default emission factors. This heterogeneity in assessing GHG emissions introduces complexity in comparing results, especially at landscape levels involving multiple nations.

**Table 3**. Type of methods and emission factors (EF) used by countries to calculate carbon emissions and removals in different LULUCF.

| Country | Forest land | | Cropland | | Grassland | | Wetlands | | Settlements | | Other lands | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Method | EF | Method | EF | Method | EF | Method | EF | Method | EF | Method | EF |
| China | T2 | CS | T3 | CS | T2 | CS | T2 | CS | T2 | CS | T1 | D |
| DPR Korea | - | - | - | - | - | - | - | - | - | - | - | - |
| Japan | T1, T2, T3 | CS ,D | T1, T2, T3 | CS ,D | T1, T2, T3 | CS, D | T1, T2 | CS ,D | T1, T2 | CS ,D | T2 | CS, D |
| Mongolia | T1/T2 T1 | CS ,D | - | | - | | - | | - | | - | |
| ROK | T1,T2 | CS ,D | T1, | CS ,D | T1 | D | T1 | CS | - | CS | T1 | CS, D |
| Russian Federation | T1 | CS | T1 | D | T1 | CS | T1 | CS | T1 | | - | |

Note: EF=Emission factors: CS=country specific; D: default as given in IPCC guidelines

Activity data to estimate emissions and removals of carbon in the NGHGI reports come mainly from national statistics. The accuracy of the national statistics then defines the quality of emissions results. Such data include the area of each LULUCF category, the area affected by changes and the amount of harvest. The most popular source of information is the national forest inventory data and agricultural and forest statistics. One major cause of low accuracy with this estimation is the fact that it is dependent on the accuracy of activity data, for instance, the intensity of national forest inventory. This demands robust and efficient methods with easy-to-use activity data collection tools. Based on a field study from China to identify better methods for forest inventory, a study recommended the biomass expansion factor method for forest stands and the mean biomass density method for economic and bamboo forests.[102] **It is evident from the review that there is a need to develop standardized activity data collection tools that could be applied irrespective of geographic location.**

Published scientific articles also use various methods to estimate land use and management carbon emissions. Results vary depending on the model used and the type of data inputs. While studies to evaluate multiple models for their efficacies are rare, a study compared inventory satellite-based, process-based, and inversion models to estimate the terrestrial carbon balance of China during the 1980s and 1990s.[103] The study used biomass and soil carbon inventories extrapolated by satellite greenness measurements, ecosystem models and atmospheric inversions and concluded that they produced similar estimates of net carbon sink ranging from 0.19 to 0.26 PgC a year.

Inversion models are constrained by regionally scarce atmospheric networks. The inversion models do not account for land use changes in their settings yet produced results close to those of inventory satellite-based estimation. This was attributed to the importance of climate and $CO_2$ as drivers. In addition, they are sensitive to transport model errors and biases from assumed fossil fuel emissions.[104] The inversion models are in good agreement with the inventory-based findings. When five process-based ecosystem models were applied to estimate changes in $CO_2$ and climate on the carbon balance of China, the models were consistent in estimating carbon sink despite different settings and parameters.[105]

Process-based models are the most used by researchers. While models are continuously evolving into more intelligent and robust models, the challenge remains to find a model that fits all LULUCF sub-categories. A good model should utilise the advantages of both ground measurements and remoting sensing data in terms of i) highly accurate ground measurements and; ii) the spatially comprehensive coverage of remoting sensing products and methods.

Major sources of uncertainties in models are different definitions of forests, dynamic inventory methods and the emergence of new technology, and inadequate samples.[106] This is especially the case when assessments are done for smaller areas such as water bodies and settlements.[107] For

[102] Guo, et al. (2013)
[103] Piao, et al (2009)
[104] Stephens, et al. (2007), Gurney, et al. (2005)
[105] Sitch, et al. (2008)
[106] Pan (2004)
[107] Lai, et al. (2016)

instance, assessing emissions from settlement presents a suite of challenges, including using population and energy use data alongside urban green spaces (including urban woodlands).

The Republic of Korea has yet to report emissions from the settlement sub-category but is finalizing assessment protocols. A pilot study on Incheon Metropolitan City, Seo gu (Western district), used IPCC's crown cover method to estimate carbon emissions from settlements.[108] The study recommended to establish a clear spatial definition for settlement, along with activity data such as national statistics for urban forests, emission factors, and allometric functions using crown cover. Under such conditions, another study recommends using the wall-to-wall method, which is proven to perform better in the presence of sufficient spatial data for small sub-categories like wetlands, grasslands, settlements, etc.[109]

From the preceding discussions, it is evident that data sources and varying methods are primarily responsible for inconsistencies in assessing emissions. This problem can be best addressed by adopting an integrated model that draws from the power of both processes.

**Based on such models, the North-East Asian countries could develop a technical guideline for assessing emissions from LULUCF** that details harmonized methods for estimating carbon emissions and removals, including tools for collecting activity data. To help advance such a programme, a shortlist of the models is presented below (Table 4). These models are shortlisted as candidates for further development based on the robustness and flexibility of the methods to accommodate future requirements such as changes in climate, higher accuracy, and recommended by researchers.

The current review recommends forming a technical expert group to analyze each of the shortlist models in detail, assess potentials for integration and pilot them in the field, and improve their accuracy further. Best models can then be selected and adopted in member countries to develop them for regional application fully. In the process of developing such a harmonized and integrated model for North-East Asia, experts must consider: i) generating annual land cover systems (especially deciding on how many land cover types to be included); ii) making a decision on the special resolution to be used; iii) cross-checking national emissions factors, as most existing emission factors are developed based on biomass, and integrating field observations to develop models to reach Tier 3; and iv) using local flux and national model to validate global and/or regional models.

[108] Choi, et al. (2020)
[109] Park, et al. (2018)

**Table 4.** Shortlist of models for further development to assess carbon emission from LULUCF in North-East Asia

| Models | Methods | Scale | Satellite | Cycles | Biosphere submodules | Inputs | Outputs |
|---|---|---|---|---|---|---|---|
| **AIM** (Asia-Pacific Integrated Model) | S, P | GCM | PM | C | Bp, Mc | Temperature, wind speed, rainfall, cloudiness, soil texture, field capacity | Evapotranspiration, vegetation, vegetation move possibility |
| BIOME (Biogenic Model for Emissions) | S | GCM | | C | Bc, Mc | Temperature, PAR, transpiration, $CO_2$, rainfall, soil water content, evergreen tree, deciduous tree, daylength | Vegetation distribution, Annual precipitation, annual average air temperature |
| CEVSA | P | GCM | PM | C | Bp, Bc | - Monthly precipitation, temperature, Atmospheric CO2, humidity, climate, soil moisture, soil carbon, vegetation type | - Vegetation distribution – Soil carbon storage – NPP – NEP – Vegetation carbon storage |
| CBM-CFS3 (Carbon Budget Model of the Canadian Forest Sector) | S | GCM, RCM | PM | C | | Aboveground biomass – Belowground biomass – Aboveground dead organic matter – Belowground dead organic matter | Litter – Deadwood – Slow DOM – Soil carbon – Snags and aboveground Biomass – Belowground biomass stocks |
| EPIC (Environmental Policy Integrated Climate Model) | P | GCM | PB | W | Bc | Daily min. temperature,<br>max. temperature,<br>precipitation,<br>solar radiation,<br>relative humidity,<br>wind speed,<br>Soil dataset,<br>Topography,<br>Fertilizer | crop yields,<br>water use,<br>nitrogen cycle,<br>soil loss, water quality etc. |
| G4M (Global Forest Model) | P | GCM RCM | PM | C | Bp,Mc | Forest biomass, litter, crop rotation length, wood prices, harvesting costs, decay rate, planting costs, temperature, precipitation, age of growing stock, population, | NPP, annual increment, harvest amount |

Methods: S=Statistical; P=Process based; I=Inversion
Scale: GCM=Global Climate Model; RCM=Regional climate model
Satellite: PM=Prognostic Models; DM=Diagnostic Models
Cycles: C=Carbon; W=Water; Bp=Biophysical
Biosphere sub models: Bc=Biogeochemical; Mc=Micro climatic; Bp=Bio-physical, Vp= Vegetation production

## Chapter IV. Assessment gaps

The stock-taking study identified the following gaps among the concerned assessment models:

- Carbon emissions reporting from the LULUCF sector is incomplete, especially for sub-categories other than forests.
- Information regarding emissions is limited due to language barriers. Even some of the national reports, such as NGHGI, are in the national language and thus difficult for knowledge sharing and technical and policy level coordination amongst countries and experts.
- There is a lack of clarity on reporting for activity data and emissions factors for some sub-categories such as land under conversion, settlements, urban green spaces, and other disturbances and climate change effects. This makes regional comparability of trends in land use changes and subsequent emissions difficult.
- There is a lack of scientific studies to assess carbon emissions from LULUCF. No study has applied any method to assess carbon emissions at a landscape level involving North-East Asia or more than one country.
- There is a lack of studies that evaluate the efficacies of models for assessing carbon emission from the LULUCF sector.
- Definitions of forests, wetlands, other land etc. vary.
- Financial support is not sufficient for rolling out mitigation actions, building technical and human capacity for developing methodologies for estimating emissions, preparing national inventories, etc.
- Coordination amongst various sectors at national and regional levels is poor.
- There is high variability in emission estimates due to varying data sources and methods.
- There is a lack of an evidence-based accounting framework for carbon debits and credits in the land sector.

## Chapter V. Recommendations for sub-regional approach for assessing carbon emissions from LULUCF

This review has revealed that most member countries are global leaders in reducing GHGs emissions. However, more efforts to improve scientific assessments are needed, especially regarding LULUCF. Yet, the LULUCF represents huge potential for improving the ability of

North-East Asia to sequester carbon and contribute to land degradation neutrality and carbon neutrality which some member countries have committed to.

Most countries in North-East Asia are also economically and technologically in a good position to launch initiatives to protect the land from degradation and desertification and reduce carbon emissions. Review findings indicate that an effective sub-regional approach must advocate policies and incentives that promote sustainable land and forest management, including increasing carbon stocks through land rehabilitation, ecosystem restoration, greener urban centers, etc., to help reduce the remaining emissions gap in a demonstrable and efficient manner, and contribute towards land degradation neutrality goals, Paris Agreement on climate change, the Sustainable Development Goals, among others.

A set of technical and policy-level recommendations are proposed below. These recommendations are aligned with the four building blocks of the UNCCD's land degradation neutrality framework,[110] as the framework was used for target setting by countries and sustainable development goals.[111]

### 5.1. Technical recommendations

Depending on the current forest sink, competition with land-use and watershed protection, and environmental factors affecting forest sustainability and resilience. The suitability and effectiveness of mitigation techniques within regions vary. A list of technical recommendations is presented here for countries in North-East Asia to consider:

- Improve completeness of reporting in land use category (other than forest land) and for the land converting to other categories (Assessing LDN).
- Improve the reporting of the soil carbon pool, particularly of organic soils (Assessing LDN). They represent a large carbon store and thus a considerable potential source of GHGs.
- Enhance reporting of emissions from disturbances in forest land (Assessing LDN).
- Give more emphasis on the requirements for more clarity on methodology, emission factors, and recalculations (Assessing LDN; Setting LDN targets and associated measures).
- Identify an integrated approach for reducing carbon emissions from land use and management and DLD (Setting LDN targets and associated measures).
- Make a joint decision to finalize the number of land cover types and spatial resolution for generating land use maps (Leveraging LDN; Assessing LDN).

[110] They are 1. Leveraging LDN; 2. Assessing LDN; 3. Setting LDN targets and associated measures; and 4. Achieving LDN.
[111] This referred to SDG target 15.3, "by 2030, combat desertification, restore degraded land and soil, including land affected by desertification, and strive to achieve a land degradation neutral world."

- Standardize definitions of LULUCF sub-categories for better comparability in the region and globally. For instance, the forest can be defined using parameters such as area, canopy closure, and tree height (Assessing LDN).
- Invest in research and expert consultation to develop common integrated assessment models (both process and statistics based) for North-East Asia, based on the models recommended in Table 4 (Setting LDN targets and associated measures).
- Countries to lead in developing harmonized methods for estimating carbon emissions from each sub-category of LULUCF. For example, China- forests and other lands, Japan-wetlands, Mongolia-grasslands, Republic of Korea-Settlement, Russian Federation–croplands (Leveraging LDN; Assessing LDN; Setting LDN targets and associated measures).
- Apply integrated (harmonized) models that are feasible, and low-risk, as North-East Asia is highly heterogeneous. For example, afforestation and reforestation, increasing carbon density of existing forests, reducing emissions from deforestation and degradation, increasing use of the wood products in buildings, etc. (Setting LDN targets and associated measures; Achieving LDN).

### 5.2. Policy recommendations

Member countries strengthen collaboration to advance programmes and policies that promote carbon neutrality, especially in the LULUCF sector. Member countries help each other through technical, financial, and logistical support. For instance, Mongolia needs financial and technological assistance to complete its assessments. Increased engagement of DPR Korea is also needed (Leveraging LDN; setting targets and associated measures; Achieving LDN). A list of policy recommendations is presented here for countries in North-East Asia to consider:

- Establish a regional technical expert group to oversee the development of harmonized methods (Integrated Assessment Models) for assessing carbon emissions from LULUCF in North-East Asia (Assessing LDN).
- Develop a standardized user guide for estimating emissions and sinks from LULUCF using harmonized methods (Setting LDN targets and associated measures; Achieving LDN).
- Develop an evidence-based accounting framework for carbon debits and credits to measure progress in the land sector and assess its contribution to net carbon fluxes (Assessing LDN; Setting LDN targets and associated measures; Achieving LDN).
- Encourage all member countries to improve the completeness of reporting on all LULUCF categories other than forest land (Setting targets and associated measures).
- Improve natural resource governance to achieve fair land degradation near-neutrality outcomes (Achieving LDN).

- Strengthen institutional ties and communication between GHG inventory agencies and resource management agencies so that existing data and information can be accessed more easily, and research for new data and methodologies may be developed (Leveraging LDN; Achieving LDN).
- Advocate sustainable forest management and integrated land management through restoration, sustainable management, and utilization of land (Setting LDN targets and associated measures; Achieving LDN).
- Improve synergy with other programmes in agriculture, forestry, livestock, urban planning, marine management etc. (Assessing LDN).
- Mobilize innovative funding schemes at national and regional levels for supporting programmes and activities to enhance carbon sink, reduce land degradation, develop more robust methods for assessing carbon emissions, and enhancing knowledge sharing and coordination amongst national sectors and regional countries (Leveraging LDN; Setting LDN targets and associated measures; Achieving LDN).
- Develop policies and strategies to reduce the intensity of grazing, restoration of degraded lands, and low carbon settlements (Leveraging LDN; Achieving LDN).
- Provide policy and financial support for developing adequate technical, human, and institutional capacities to develop technical assessment methods, carry out scientific inventories, prepare emissions reports, and implement mitigation and adaptation programs (Setting targets and associated measures; Achieving LDN).
- Adopt policies and programmes that retain carbon in high biomass forests, extend harvest cycles, replant and afforestation, and change in forest management to increase the land sink and reduce emissions (Leveraging LDN, Achieving LDN).

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# Annexes

## **Annex 1.** Approaches used for the stock-taking study

**Review of existing scientific assessments on carbon emissions from land use change and management in North-East Asia**

Due to the broad scope and extensive literature base, the review focused on carbon emissions from land use and management that are specific to North-East Asia. Interdisciplinary review of the peer-reviewed articles and technical reports from national, regional, and international sources including IPCC, International Union for Conservation of Nature (IUCN), United Nations, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Asia-Pacific Economic Cooperation (APEC) were used to narrate carbon emissions from land use and management in North-East Asia (Figure 5).

Peer reviewed papers and technical reports were retrieved using a systematic search in Google Scholar using different combinations of key words including: "emission of carbon from land use and management, emission from forest land, emission from grassland, emission from cropland, emission from wetland, emission from settlements, desertification, land degradation, mitigation, etc." After obtaining an initial batch of published articles and technical reports, further screening was carried out by limiting to North-East Asia, China, DPR Korea, Japan, Mongolia, Republic of Korea, and the Russian Federation. The reference lists of these papers were browsed to identify more papers that met these criteria. To account for regional and country specific publications, regional and country-based journals (such as Korean Journal of Forest Science and Technology, Chinese Agricultural Journal, etc.) were also browsed. Websites and data bases of regional and international agencies such as IPCC, IUCN, IPBES, APEC and WRI (World Resources Institute) were browed to obtain technical reports and data on the subregion. Additional papers and technical reports were also obtained by browsing government websites of the North-East Asia. While all the references used in this stock taking study are presented in the reference section, the final list of evaluated scientific publications used in this stock taking study is documented in Annex 2. As is evident from the reference list, except for a few national and local (within country) level studies that assessed emissions from LULUCF, the search didn't produce any regional level studies.

Selected articles and technical reports were reviewed for empirical data and explanations following land use classification recommended for reporting emissions by the IPCC Good Practice Guidance for land use, land change and forestry.[112] In particular, information on: i) the quantity and trends of carbon emission from different land use categories; ii) major drivers of land use changes and land management that releases $CO_2$; iii) the current state of mitigation responses. Efforts were made to analytically synthesize and describe this information at country and regional levels. In addition, any information gaps detected in the assessments and policy implications for mitigation

[112] IPCC (2019)

of carbon emission were also noted. Due to the lack of consistent emission data from both the scientifically published studies and emissions reported by member countries to UNFCCC, the stock taking study also used additional emission data from World Resources Institute Climate Analysis Indicators Tool (WRI-CIAT, 2021) to gain a holistic understanding of carbon emission from LULUCF. However, the WRI-CIAT data is not available for sub-categories of LULUCF. The national GHG inventory reports provided carbon emissions by sub-categories but cross-country comparison and deriving a regional level measure of emission were constrained by i) not all countries reported for the same year; ii) not all countries reported for all the LULUCF sub-categories. For instance, the latest figures for China and Mongolia were available only up to 2014. In addition, Mongolia only reported for emissions from forest land, while the Republic of Korea did not report for settlements, and there is no information from the DPR Korea.

### Review of methodologies and their assessment results

Major models used for assessing carbon emission from LULUCF that were reviewed are presented in Annex 2. This included popular models that are process based, statistic based, or inversion based, and some that are combinations of these three. Each method was assessed for its popularity, accuracy, and efficacy, flexibility to adapt to different conditions. The review used model characteristics such as methods, the scale of application, and considered whether the models were prognostic or diagnostic; what cycles were used; biosphere submodules; inputs; outputs; and noted advantages and disadvantages wherever such information was available. Based on this evaluation, a short list of models that presents high potentials for further development to assess carbon emission from LULUCF at a regional scale in North-East Asia are documented in Table 4.

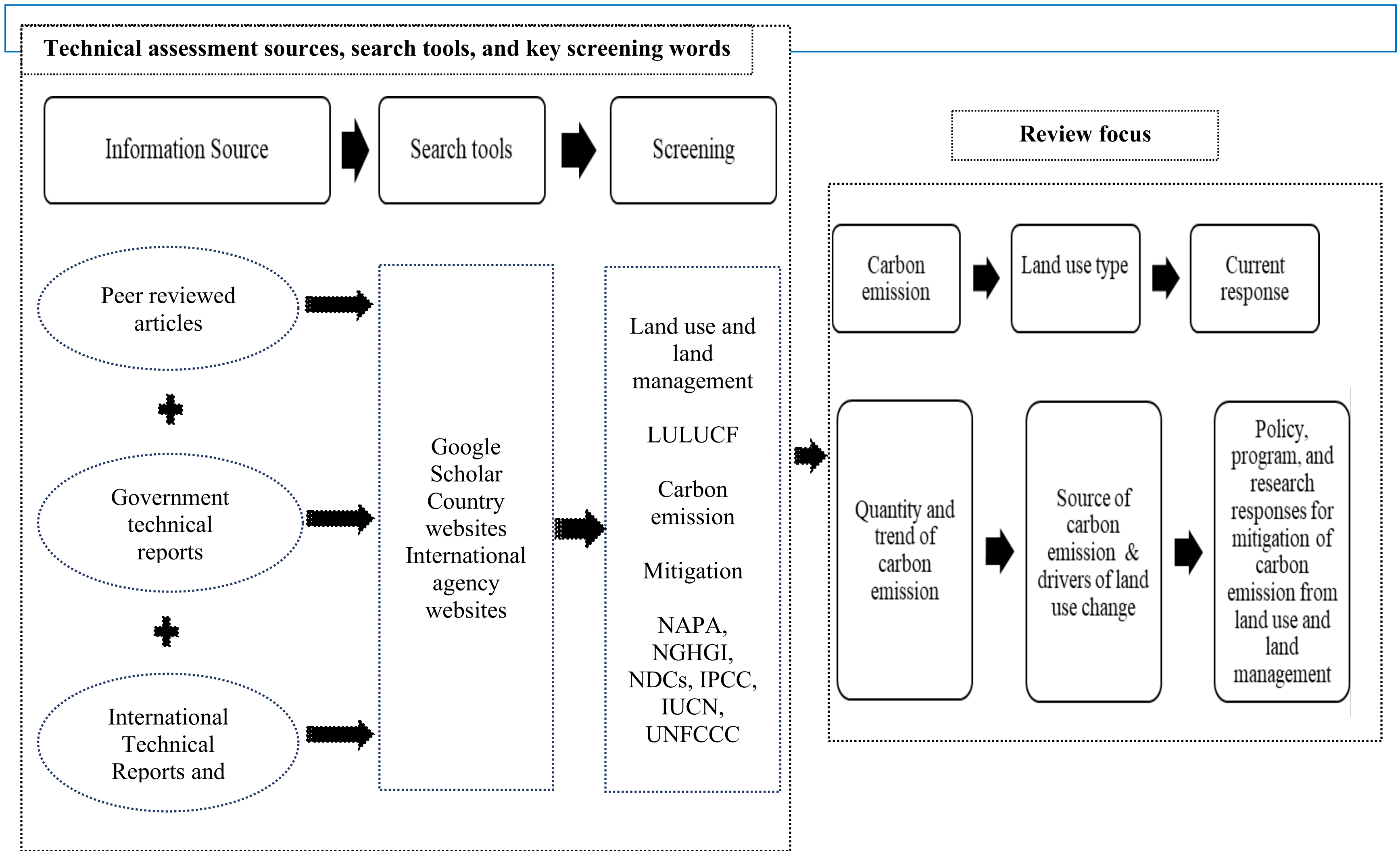


**Figure 5.** Framework for reviewing existing scientific assessments on carbon emissions from land use change and management in North-East Asia

**Annex 2.** Evaluation of major scientific assessment of carbon emission from LULUCF in North-East Asia

| **Authors** | **Method** | **Category** | **Specific LULCF source** | **Study Period** | **CO₂ emissions from LULUCF sources** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| China | | | | | **Year** | **UNIT** | **Forest land** | **Crop land** | **Grass land** | **Settle ments** | **Wet land** | **Other land** |
| Lin,et al. 2021 | Direct and indirect estimation based on sink and emissions | vegetation, settlement | forests, grasslands, croplands, settlements, others | 2006-2016 | 2006 | TgC/yr | -15.97 | | -6.78 | 2447.1 | | |
| | | | | | 2011 | | | | | 3551.5 | | |
| | | | | | 2015 | | -17.56 | 56.88 | -6.84 | 5516.2 | | |
| Tang, et al.. 2017 | Filed survey, remote sensing | vegetation, dead organic matter, soil organic carbon | Forest, grassland cropland, shrubland | 2011-2015 | | TgC | -37510 | - 16320 | - 25400 | | **- 6,450** | |
| Xu, et al. 2018 | Modified Carnegie-Ames-Stanford Approach model and on gray relational analysis | buildings, vegetation | buildings, vegetations | 2000-2012 | | | | | | 0.38 | | |
| Fang, et al. 2018 | Field survey and remote sensing | vegetation, dead organic matter, soil organic carbon | Forests, grasslands, shrublands, croplands | 2001-2010 | 2010 | TgC/yr | -180.5 | -23.98 | -3.36 | | | |
| Lia, et al. 2016 | Remote Sensing based on land use data, national forest inventory and soil map | vegetation, soil organic carbon | forests, grassland, cropland, settlement, forest management | 1990-2010 | 2010 | TgC/yr | -144 | -15.3 | -12.4 | 74.6 | | **16.5** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Zheng, et al. 2013 | Inventory data - remote sensing | wetlands | wetlands | 2007-2009 | 2009 | TgC | | | | -6320 |
| Guo, et al. 2013 | Inventory data -continuous biomass expansion factor | vegetation | Forest biomass | 1977-2008 | 2008 | TgC/yr | -70.2 | | | |
| Zhao, 2013. | literature review | building, vegetation, humans | vegetation, building, soil | 2006 | | TgC | | | 577 | |
| Lu, et al. 2006 | | Fire | forest fire | 1980-2000 | | TgC/yr | 3 | | | |
| Piao, et al.2009. | Inventory satellite-based estimation | soil | shrub, grassland, forest | 1982-1999 | | TgC | -43.4 | | | |
| Pan, et al. 2004. | satellite imagery using inventory data | Vegetation | Forests, bamboo, woodlands | 1989-1993 | | TgC | -4340 | | | |
| Japan | | | | | | | | | | |
| Matsuura, et al.2012. | Remote sensing, GIS and Soil carbon data 1990 | soil | grassland soil | | 2012 | TgC | | 214 | | |
| Morisada, et al. 2004. | National soil data, field sample analysis | soil | forest soils | | 2004 | TgC | -4570 | | | |
| Matsumoto and Kanomata, 2001. | | vegetation | forest biomass | 1990 | | TgC | -1100 | | | |
| Mongolia | | | | | | | | | | |
| Dulamsuren, et al. 2016 | remote sensing-NDVI | vegetation and soil | boreal forest land | 1999-2013 | | TgC | -1600 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Enkhtaivan, et al. 2018 | National Forest Inventory Method | vegetation | forest land, deadwood, litter | 2005-2015 | | TgC | -0.75 | | |
| Li, et al. 2014 | review | vegetation | forest land | | 2008 | TgC | -719 | | |
| | | | forest land | | 1949 | TgC | -417 | | |
| | | | forest land | | | TgC/yr | -4 | | |
| Dagvadorj, D., Munkhtsetseg, M. Lee. J. 1996 | IPCC methods | vegetation | forest land | 1990 | 1990 | | -11.8 | | |
| Republic of Korea | | | | | | | | | |
| Choi, et al. 2020. | Crown Cover Method | buildings, | development of activity data for settlement GHGs | 2010-2017 | | T | | | 466.31 |
| Kim, et al. 2018. | Land cover map and domestic method | vegetation | Trees | | | TC/yr | -2,680.5 | | |
| | Land cover and IPCC method | | | | | | -2,607.3 | | |
| Park, et al. 2016. | | vegetation and soil | cropland | 1990-2014 | 2014 | TgC | | 4.58 | |
| Kim, S. 2015. | Econometric analysis by FMOLS, VECM, GDP | vegetation and soil | LULUCF | 1990-2011 | 1990 | | | | |
| | | | | | 1990 | | | | |
| Russian Federation | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Schepaschenko, et al. 2021. | Glob Biomass GSV15 and CCI Biomass GSV, NFI and remote sensing | vegetation | forest | 1988-2014 | | TgC/yr | -345 | | | | | |
| Dolman, et al. 2012 | Landscape-Ecosystem Method (LEA) | vegetation | forests | | | TgC/yr | -691.9 | -78.3 | -145.6 | | -53.4 | -46.1 |
| Pan, et al. 2011. | FIP | | | 1990-2007 | | TgC/yr | -209.4 | | | | | |
| Shvidenko, A. & Nilsson, S. 2003 | | vegetation/soil | forest | 1988-1992 | | TgC/yr | -322 | | | | | |
| Shvidenko, A. & Nilsson, S. 2002 | Forest inventory and planning | vegetation | forest | 1961-1998 | 2002 | TgC/yr | -210 | | | | | |
| Goodale, 2002 | Review based on forest C balance | vegetation | forest land | 1990 | 1993 | TgC | 181800 | | | | | |
| Rommanovskaya, A.A. 2008 | ROTHC model | soil | soil | 2000-2002 | | TgC/yr | | | | | | 5.2 |

## **Annex 3**. Evaluation of methods used for assessing carbon (GHG) emissions

| Models | Methods | Scale | Satellite | Cycles | Biosphere submodules | Inputs | Outputs |
|---|---|---|---|---|---|---|---|
| AIM (Asia-Pacific Integrated Model) | S, P | GCM | PM | C | Bp, Mc | Temperature, wind speed, rainfall, cloudiness, soil texture, field capacity | Evapotranspiration, vegetation, vegetation move possibility |
| BIOME (Biogenic Model for Emissions) | S | GCM | PM | C | Bc, Mc | Temperature, PAR, transpiration, $CO_2$, rainfall, soil water content, evergreen tree, deciduous tree, daylength | Vegetation distribution, Annual precipitation, annual average air temperature |
| BIOCLIM (Bioclimatic Prediction System) | S | GCM | PM | C | Mc | Temperature, rainfall, radiation, evaporation, bioclimatic parameters | Vegetation distribution |
| CEVSA | P | GCM | PM | C | Bp, Bc | Monthly precipitation, temperature, Atmospheric CO2, humidity, climate, soil moisture, soil carbon, vegetation type | - Vegetation distribution – Soil carbon storage – NPP – NEP – Vegetation carbon storage |
| CBM-CFS3 (General Circulation Model) | S | GCM, RCM | PM | C | Bp,Vp | Aboveground biomass – Belowground biomass – Aboveground dead organic matter – Belowground dead organic matter | Litter – Deadwood – Slow DOM – Soil carbon – Snags and aboveground Biomass – Belowground biomass stocks |
| CENTURY | P | GCM, RCM | PM | C | Bp, Bc | Temperature, precipitation, soil texture, Soil C, N, P, S | Evapotranspiration, soil water content, organic matter (C,N) |
| EPIC (Environmental Policy Integrated Climate Model) | P | GCM | PB | W | Bc | Daily) min. temperature,<br>max. temperature,<br>precipitation,<br>solar radiation,<br>relative humidity,<br>wind speed,<br>Soil dataset,<br>Topography,<br>Fertilizer | crop yields,<br>water use,<br>nitrogen cycle,<br>soil loss, water quality and etc. |
| EFISCEN | P | GCM | PM | C | Bc | Area, average growing stock volume, current annual increment per age class | Growing stock, increment, actual harvest, natural mortality, tree species distribution, age class distribution |
| FAOSTAT | S | GCM | PM | C | Bp | Air temperature, Soil temperature, Soil moisture, | Net C flux from land use change, split into the contributions |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | soil pH, and N | of different types of land use (cropland vs. pasture expansion, afforestation, wood harvest); 1970–2017 |
| GAP | P | RCM | PM | C | Bc | Temperature, soil nutrition, | Vegetation distribution |
| G4M (Global Forest Model) | P | GCM RCM | PM | C | Bp,Mc | Forest biomass, litter, crop rotation length, wood prices, harvesting costs, decay rate, planting costs, temperature, precipitation, age of growing stock, population, | NPP, annual increment, harvest amount |
| IMAGE (Integrated Model to Assess the Greenhouse Effect) | S | GCM | DM | C | Mc | Precipitation, temperature, evapotranspiration, wind speed, solar radiation – Gridded maps of soil texture, rock fraction, soil radiation, soil depth, soil texture, bulk density | - Actual evapotranspiration – Soil carbon – Run off – Total tree NPP – Max LAI trees and grasses – vegetation ecosystem Modeling and analysis |
| InVEST | S | RCM | PM | C | Bp, Bc | Land use map – Aboveground biomass – Belowground biomass – Soil organic matter – Dead organic matter | - Total carbon stock |
| MC1 (MAPSS-Century Model) | S, P | GCM, RCM | PM | C | Bp, Bc | Precipitation, temperature, evapotranspiration, wind speed, solar radiation – Gridded maps of soil texture, rock fraction, soil radiation, soil depth, soil texture, bulk density | - Actual evapotranspiration – Soil carbon – Run off – Total tree NPP – Max LAI trees and grasses – vegetation ecosystem Modeling and analysis project (VEMAP) vegetation classes |
| ORCHIDEE | P | GCM | PM | C | Bc, Bp | air temperature<br>wind speed<br>solar radiation<br>air humidity<br>precipitation<br>land use and land cover maps | |
| Statistical forest growth model | G | R | DM | C | Vp | - FTM – HyTAG – NFI – Final cutting age | - Forest volume<br>- Carbon storage |
| Trendy V7 | P | G | Pm | C | Bc | Air temperature, wind speed, solar radiation, air humidity, precipitation, wood harvest, Agricultural, Land cover | Carbon,<br>Hydrological |
| VISIT | P | G | PM | C | Bc, Bp, | Climate data: Daily maximum temperature, daily minimum temperature, daily precipitation, daily shortwave radiation, daily wind - Vapor pressure | NPP - NEP - GPP - Soil respiration - Heterotrophic respiration |

| | |
|---|---|
| | deficit - Soil data: Percent clay content, percent sand content, percent silt content, field capacity, wilting point, saturated water content, rooting depth, soil depth, soil type |

Note:
Methods: S=Statistical; P=Process based; I=Inversion
Scale: GCM=Global Climate Model; RCM=Regional climate model
Satellite: PM=Prognostic Models; DM=Diagnostic Models
Cycles: C=Carbon; W=Water; Bp=Biophysical
Biosphere sub models: Bc=Biogeochemical; Mc=Micro climatic; Bp=Bio-physical, Vp= Vegetation production