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Overview of the Linkages between Land-Based Sectors and Climate Change towards Carbon Emissions Neutrality

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Land-based sectors play significant roles in carbon emissions, and removals, including agriculture, forestry, other land uses (AFOLU), as well as land use and cover change (LUCC). More than 20 % of carbon emissions globally are from land-based sectors. It is increasingly crucial to identify and model the relationship between land-based sectors and climate change, especially toward the carbon emissions neutrality target or net-zero emission goal. However, few works so far were systematically and comprehensively designed for this topic. The boundary of land-based sectors is not clearly defined, and the linkages between land-based sectors and carbon emissions are not well identified. This paper overviewed the relationship between land-based sectors and climate change toward the carbon emissions neutrality goal to narrow the research gaps. The AFOLU-related greenhouse gas (GHG) emissions were identified, the implications for land-based emissions reduction were discussed, and the potential priority action areas were summarised. This study provides a better understanding of the relationship between land use and climate change.

1. Introduction

Increasing GHG emissions, along with sequence global warming, have been the main challenge worldwide. Fossil fuel consumption and generation, as well as relevant economic activities, are the crucial contributors to GHG emissions (Wang et al., 2022). It has been promised that 137 countries have committed to carbon emissions neutrality targets, and 73 % of global emissions are currently covered by the net-zero emission goal (Content, 2021). However, only six countries have passed their carbon neutrality targets into law, and only 24 countries have their targets set as an official policy (Content, 2021). Increasing effort and activities should be put into practice to mitigate GHG emissions. Global GHG emissions are mainly from energy, especially fossil fuel, and consumption-related activities. However, there is an increasing interest in that land-based sectors account for significant GHG emissions, which contribute to 23 % of the whole figure, including Agriculture, Forestry, and Other Land Uses (AFOLU) (Wang et al., 2019). The AFOLU sector encompasses managed ecosystems and offers significant mitigation opportunities while delivering food, wood and other renewable resources as well as biodiversity conservation, provided the sector adapts to climate change.
However, the relevant topics haven't been thoroughly studied. Based on the most recent Sixth Assessment Report released by the Working Group III of the Intergovernmental Panel on Climate Change (IPCC), the measures of land-based GHG emissions mitigation represent some of the most important options currently available (IPCC, 2022a). The land-based sectors encompass managed ecosystems and offer significant mitigation opportunities while delivering food, wood and other renewable resources as well as biodiversity conservation, provided the sector adapts to climate change. They can both deliver carbon dioxide removal (CDR) and substitute for fossil fuels, thereby enabling emissions reductions in other sectors. The rapid deployment of AFOLU measures is essential in all pathways to staying within the limits of the remaining budget

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for a 1.5 ℃ target (Roe et al., 2019). Based on the contribution of Wang et al. (2019), AFOLU account for around 14 % - 20 % of all GHG emissions. However, the above number is possibly underestimated. Dynamic global vegetation model simulations suggest that GHG emissions from land-use change have been substantially underestimated because processes such as tree harvesting and land clearing from shifting cultivation have not been considered (Arneth et al., 2017). According to the study by Roe et al. (2019), the transformation of the land sector and measures deployment in agriculture, forestry, wetlands and bioenergy would significantly contribute to about 30 % of the global GHG emissions mitigation for achieving the goal of 1.5 °C by 2050, which would be around 15 Gt of CO_2 equivalent (CO_2-eq) per year. However, it would require substantially more effort than the 2 °C targets. Human beings must take much more serious carbon emissions mitigation measures, especially focusing on the land-based sectors, AFOLU. However, there is few studies have been systematically designed and conducted, despite some of them already made contributions to this topic.

According to the contribution by Wang et al. (2019), AFOLU accounts for a significant part of global GHG emissions, including CO_2 emissions, and especially methane emissions. Tian et al. (2021) studied that carbon emissions from land use and land-use change are an important part of anthropogenic carbon emissions. However, the size and location still need more in-depth exploration. The relationship between AFOLU and GDP remains partial and uncertain. It is quantified that the carbon emissions directly caused by the land-use change from 1992 to 2015 were 26.54 Pg C, which was 1.15 Pg C/y (Tian et al., 2021).

The carbon emissions embodied in the inter-regional trade are also remarkable from the consumption side. Inter-regional trade makes goods and services produced in one country to be consumed elsewhere, separating consumption from its environmental impacts. Based on the most recent study by Hong et al. (2022), international trade separates the consumption of goods from related environmental impacts, including GHG emissions from agriculture and land-use change. They used the new emissions estimates and a multiregional input-output model and evaluated the land-use emissions embodied in global trade from 2004 to 2017. They found that annually 27 % of land-use emissions and 22 % of agricultural land are related to agricultural products ultimately consumed in a different region from where they were produced, and roughly three-quarters of embodied emissions are from land-use change, with the largest transfers from lower-income countries (Hong et al., 2022).

Methane is one other important GHG, accounting for about 20 % of the warming induced by long-lived GHG since pre-industrial times. Kirschke et al. (2013) assessed the global methane sources and sinks of the past three decades, revealing that a rise in natural wetland emissions and fossil fuel emissions probably accounts for the renewed increase in global methane levels after 2006, although the relative contribution of these two sources remains uncertain. Land-based sectors, especially agriculture, are the key methane emitters as well. Jackson et al. (2020) pointed out that increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources.

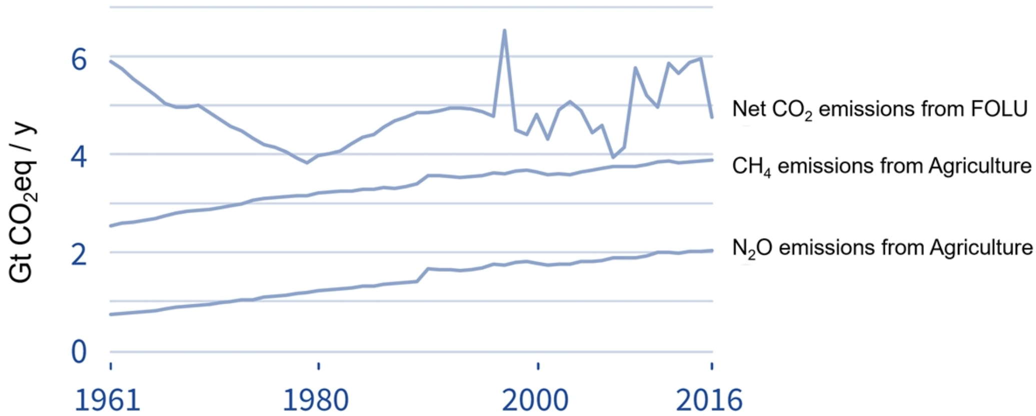
Although the land-based sectors have been drawing increasing attention in terms of carbon emissions, previous works haven't clearly understood the linkages between land use and carbon emissions. For example, what exactly number of carbon emissions are from land use? What are the proportions of carbon emissions from natural land-use change processes, human land-use activities or relevant energy consumption? How do mitigate the carbon emissions from land-based sectors, including agriculture and forest? What measures should be taken when cooperating with other sectors to achieve carbon emissions neutrality? To better answer those questions, this paper aims to review the relationship between land-based sectors and climate change, especially regarding the carbon emissions neutrality target. The following sections are arranged: section 2 reviews the linkages between AFOLU and GHG emissions; section 3 concludes the approaches used for assessing or modelling AFOLU-related GHG emissions; section 4 presents discussions and Implications for the carbon emissions neutrality target, and section 5 is the conclusions section.

2. Linkages between AFOLU and GHG emissions

The role of AFOLU activities in the mitigation of GHG emissions and climate change has long been recognised. Human activities affect changes in carbon stocks between the carbon pools of the terrestrial ecosystem and between the terrestrial ecosystem and the atmosphere (UNFCCC, 2022).

The land is a critical resource of carbon emissions, according to the IPCC report. The land is already under growing human pressure, and climate change is adding to these pressures. As shown in Figure 1, GHG emissions from AFOLU showed an increasing trend during the past few decades. Keeping global warming to well below 2 ºC can be achieved only by reducing GHG emissions from all sectors, including land and food (IPCC, 2022b). Agriculture, forestry and other types of land use account for 23 % of human GHG emissions, including CO_2, CH_4 and NOx combined as CO_2 equivalents in 2007 – 2016 (IPCC, 2020). Natural land processes absorb carbon dioxide equivalent to almost a third of carbon dioxide emissions from fossil fuels and industry (IPCC, 2022b). The linkages between land and carbon emissions are quite complicated. When land is degraded, it becomes less productive, restricting what can be grown and reducing the soil's ability to absorb carbon. This

exacerbates climate change, while climate change, in turn, exacerbates land degradation in many different ways. Coordinated action to address climate change can simultaneously improve land, food security and nutrition and help to end hunger. The most recent IPCC report highlights that climate change is affecting all four pillars of food security: availability (yield and production), access (prices and ability to obtain food), utilisation (nutrition and cooking), and stability (disruptions to availability) (IPCC, 2022a).
Policies that are outside the land and energy domains, such as on transport and the environment, can also make a critical difference in tackling climate change. Acting early is more cost-effective as it avoids losses. There is real potential here through more sustainable land use, reducing over-consumption and waste of food, eliminating the clearing and burning of forests, preventing over-harvesting of fuelwood, and reducing GHG emissions, thus helping to address land-related climate change issues.



*FOLU: Forestry and Other Land Uses, exclude agriculture.

Figure 1: GHG emissions changes from AFOLU, 1961-2016, adapted from (IPCC,2020)

The role of AFOLU activities in the mitigation of climate change has long been recognised. It is revealed that taking precedence act on land-based sectors can significantly contribute to cutting down a third of the GHG emissions that are needed to achieve the goal of below 1.5°C increase, which is additional to the 30 % of carbon emissions that land already sequesters naturally (United Nation, 2019). Human activities affect changes in carbon stocks between the carbon pools of the terrestrial ecosystem and between the terrestrial ecosystem and the atmosphere. Mitigation can be achieved through activities in the land use, land use change and forestry (LULUCF) sector that increase the removals of GHG from the atmosphere or decrease emissions by halting the loss of carbon stocks.
It is predicted that, between 2020 and 2050, mitigation measures in forests and other natural ecosystems provide the largest share of the economic AFOLU mitigation potential, followed by agriculture and demand-side measures (IPCC, 2022c).

Figure 2: AFOLU sector GHG emissions and removals in the EU, by main land use category. Developed from (European Environment Agency, 2022c)

As shown in Figure 2, AFOLU sectors contribute to a huge amount of GHG emissions, fortunately, which removes more than emits. Through its LULUCF activities, the EU currently removes a net total of 249 Mt CO_2eq from the atmosphere every year, equivalent to 7 % of its annual GHG emissions (European Environment Agency, 2022).

3. Assessing/modelling AFOLU-related GHG emissions

GHG emissions and removals from AFOLU sectors place significant roles in the mitigation of global climate change. It is crucial to precisely assess or model the AFOLU-relevant GHG emissions. Increasingly works have been focusing on this topic and several different methods are used in the assessing processes. The most important process is to identify the boundary of the assessment. GHG emissions from land-based sectors are shown in Table 1, which is modified based on the study of Hong et al. (2021). The land-based GHG emissions sources mainly include land-use emissions, land-use change emissions and agricultural emissions.

Table 1: GHG emissions from AFOLU

GHG emissions sources, level 1	GHG emissions sources, level 2
Land-use emissions	1. CO_2 emissions from transitions in land use (which could include, for example, the clearing of native habitat for agriculture or changes in agricultural use), harvesting of forest products, peat drainage and peat burning; 2. uptake of CO_2 from regrowth of forests and recovery of abandoned agricultural land (that is, negative emissions); 3. N_2O released from soils related to the application of nitrogenous fertiliser, manure applied to soils, manure left on pasture, and agricultural residues left on pasture; 4. CH_4 from enteric fermentation of livestock; 5. CH_4 and N_2O from manure management; 6. CH_4 from rice cultivation; 7. CH_4 and N_2O from burning of agricultural residues.
Land-use change emissions	1. Conversion of natural land to cropland; 2. Conversion of natural land to pasture; 3. Harvest of forest products; 4. Recovery and abandonment of cropland or pasture.
Agricultural emissions	1. CH_4 emissions from enteric fermentation of livestock and rice cultivation; 2. N_2O emissions from synthetic fertilisers; 3. manure applied to soils; 4. Manure left on pasture; 5. Agricultural residues left on pasture; 6. CH_4 and N_2O emissions from manure management and burning of agricultural residues.

The impact of land-use changes within terrestrial ecosystems on carbon balance has been a focus of global change research in recent decades. Several studies have researched the disturbance of carbon pools by human activities using bookkeeping models, which track changes in the areas of different land-use types and use standard growth and decomposition curves to calculate changes in carbon pools (Lai et al., 2016). Life cycle assessment (LCA), Input-Output (IO) model, etc., were also widely used for assessing GHG emissions.

4. Discussions and Implications

Several strategies, targets and policies have been set up and revolve around GHG mitigation and improving energy efficiency, especially raising the share of renewable energy. AFOLU is of global importance, with significant implications for changes in GHG emissions, removals and carbon storage. It is quite complicated to identify the boundary of land-based sectors. In addition to the widely researched land-use types of forest, grassland, and agriculture, other significant kinds of land-use should be more seriously considered, including water area, built-up land, unexploited land, and other land uses. A comprehensive assessment covering all kinds of land use is mandatory for more precisely evaluating the contribution from land-based sectors to global climate change.

Although energy-relevant activities are the main contributors to GHG emissions, those emitted from land-based sectors have been drawing increasing attention. Different regions, countries, and governments take measures and make policies to assess, model, and mitigate the GHG emissions from AFOLU parts. The European Union (EU) set a good example on this topic. Under current EU legislation, EU Member States must ensure that accounted GHG emissions from land use, land-use change or forestry are balanced by at least an equivalent accounted removal of CO2 from the atmosphere in the period 2021 to 2030. It is in line with its more ambitious target of achieving net emission reductions of at least 55 % by 2030, compared to the level in 1990 (European Commission, 2022).

AFOLU mitigation measures have been well understood for decades, but deployment remains slow, and emissions trends indicate unsatisfactory progress despite beneficial contributions to global emissions reduction from forest-related options. More serious actions worldwide should be increasingly put forward, based on the guide of the Paris Agreements. The potential priority actions areas might include:

(i). Reducing deforestation, peatland drainage and burning, and mangrove conversion;
(ii). Enhancing soil carbon sequestration in agriculture across all agricultural countries;
(iii). Restoring forests, drained peatlands, and coastal mangroves;
(iv). Improving forest management and agroforestry;
(v). Reducing consumer food waste in developed and emerging countries;
(vi). Shifting people to primarily plant-based diets;
(vii). Reducing fertiliser consumption in agriculture.

The situation and linkages among different land-based sectors and economic activities are getting more complicated under the impacts of COVID-19. The economic activities are significantly influenced by the pandemic. The embodied energy transmission pattern is instability, especially for the agriculture relevant trades and energy consumption by land-use change activities. Consequently, the caused carbon emission transmissions network is getting complicated as well. It poses new challenges to the formulation of carbon emissions neutrality strategies. It would further complicate the sectoral, regional, national and global linkages and interdependencies, which would be taken into consideration in the following parts of this research moving forward.

5. Conclusions

This paper overviewed the linkages between land-based sectors and climate change toward the carbon emissions neutrality target. The AFOLU-related GHG emissions were identified, including the emissions from land-use emissions, land-use change emissions and agricultural. The implications for land-based emissions reduction were discussed, and the potential priority action areas were summarised. Agriculture, forestry and other types of land use account for 23 % of human GHG emissions. GHG emissions from AFOLU showed an increasing trend during the past 50 y. Keeping global warming to well below 2ºC can be achieved only by reducing GHG emissions from all sectors, which must include the land-based parts. At the same time, natural land processes absorb a large number of CO_2, which is equal to a third of CO_2 emissions from fossil fuels and industry. Human beings must take more serious actions, including legislation and carbon emission policy-making, more focusing on reducing deforestation, protecting wetlands, reducing food waste and reducing fertiliser utilisation.

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