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Tracing Agriculture's impact on Climate Change: Estimating the Carbon Footprint

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Abstract

Agriculture substantially contributes to climate change, primarily through its carbon footprint, which involves the emissions of greenhouse gases such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). The key metrics, such as Global Warming Potential (GWP) and Carbon Dioxide Equivalent (CO_2e) support quantifying the impact of various gases on global warming. Therefore, understanding and estimating the carbon footprint is crucial for identifying emission hotspots and developing strategies to reduce agricultural emissions' impact on rising temperatures. The major contributors to GHG emissions include livestock, fertilizer use, energy consumption and land-use changes. So, estimation protocols such as life cycle analysis, direct measurements and modelling techniques such as process-based models and input-output analysis are used to provide an extensive approach for accurate carbon accounting in agriculture and its mitigation strategies.

Introduction

Agricultural landscapes occupy more than 40% of the Earth's land masses, making land use transition an unavoidable process. According to the IPCC (2014) report, the AFOLU (Agriculture, Forestry, and Land Use Change) sector alone accounts for 24% of global greenhouse gas (GHG) emissions, a significant share compared to other sectors. The major GHGs involved include CO_2, released through microbial decomposition or the burning of plant litter and soil organic matter; CH_4, produced when organic materials decompose in oxygen-deprived conditions and through enteric fermentation; and N_2O, generated by manures and

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nitrogen fertilizers in soil through microbial activity. These gases are key contributors to the elevated GHG emissions from the agricultural sector.

The FAO (2016) updated its statistical report, highlighting the contribution of different continents to global greenhouse gas (GHG) emissions. In this report, Asia is responsible for about 44% of the world's agricultural GHG emissions. Of this, 34% is attributed to enteric fermentation, where feed materials are converted into methane (CH_4) in the rumen through the activity of various microbial species with methanogenic bacteria producing methane as the final step. Additionally, 22% of the emissions come from paddy cultivation, with Asia being the largest producer of rice, making it a major contributor to methane emissions. To meet the growing demand for food due to an increasing population, there has been a substantial rise in the use of synthetic fertilizers and energy in agriculture across Asia, leading to a 15% increase in N_2O and CO_2 emissions. Furthermore, manure left on pastures by grazing livestock results in 11% of N_2O emissions. These combined discharges from the agricultural sector detrimentally influenced global warming and its associated climate fluctuations. Such changes in climatic parameters highlighted the urgent need to address carbon footprints to mitigate the harmful effects of climate change and to achieve zero emissions by 2050 (IEA, 2021).

Global Warming Potential (GWP):

Before delving into the concept of carbon footprint, understanding the potency of individual gas equivalents and their contribution to global warming is crucial. Global Warming Potential (GWP) is a criterion used to compare the efficiency of different greenhouse gases (GHGs) in terms of their ability to trap heat in the atmosphere over a specific period.

GWPs are typically calculated over a 100-year time period, meaning they examine the impact of GHGs over the course of a century. This timeline was selected because it reflects a balance between the immediate and long-term effects of different gases. Carbon dioxide (CO_2)

is used as the baseline reference gas, with a GWP value of 1. This means that over 100 years, one ton of CO_2 causes a certain amount of warming, and other greenhouse gas is compared according to this baseline. For example, methane (CH_4) has a GWP of about 25 over 100 years, meaning that one ton of methane causes 25 times more warming than one ton of CO_2 over the same period. The GWP values are evaluated according to two main determinants i.e., heat-trapping potential and life span of the gas in the atmosphere.

Greenhouse gases (GHGs)	Global Warming Potential (GWP over 100 years)
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_2O)	298

Carbon dioxide equivalent (CO_2e):

CO_2 equivalent (CO_2e) is a standard measure used to compare the emissions of different greenhouse gases (GHGs) based on their Global Warming Potential (GWP). The idea is to express the impact of various gases in terms of the volume of CO_2 that would have the same global warming impact over a specified time typically 100 years. This aids in interpreting the cumulative influence of various GHGs on global warming.

The formula for calculating CO_2e is:

MMTCDE= (Million metric tonnes of a gas) × (GWP of the gas)

where

MMTCDE- Million metric tonnes of Carbon Dioxide equivalents; GWP- Global warming Potential

This estimation is crucial because although methane, nitrous oxide (N_2O) and other gases are less abundant than CO_2, their potential to contribute to global warming is dramatically higher. By converting the emissions of various gases into CO_2e, we can determine a clearer and more accurate representation of their cumulative impact on climate patterns. Also, CO_2e estimation allows policymakers, scientists and industries to measure and compare the impacts of various GHGs in terms of their contribution to global warming. It indeed, plays an indispensable role in setting emission reduction targets and assessing climate mitigation strategies, such as the Paris Agreement's goal of limiting global temperature rise to below 2°C above pre-industrial levels.

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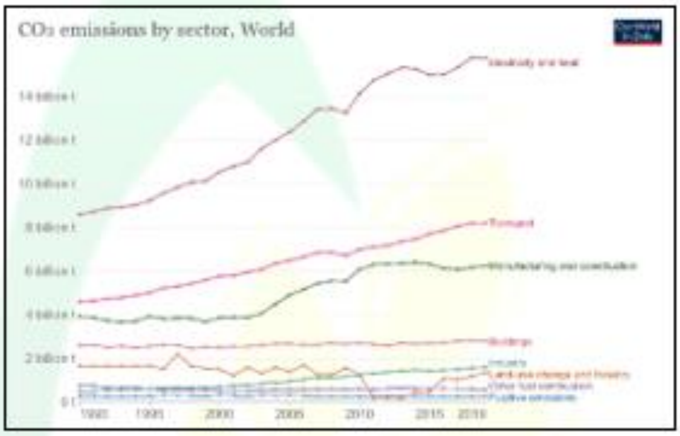
Major GHGs and their origin:

1. **Carbon Dioxide (CO_2)**
   - **Soil management practices**: Tillage accelerates the emission of CO_2 through the biological decomposition of soil organic matter.
   - **Agricultural production**: The manufacturing of farm implements, fertilizers and pesticides contributes to CO_2 emissions.
   - **Energy consumption**: The use of fuel for various agricultural operations along with the burning of crop residues, also results in CO_2 emissions.



2. **Methane (CH_4)**
   - **Methane (CH_4) sources** primarily arise from livestock enteric fermentation and rice cultivation.
   - **CH_4 production in soil** occurs during the microbial decomposition of organic matter under anaerobic conditions.
   - **Factors enhancing CH_4 emissions**: Continuous submergence, higher organic carbon content and the use of organic manure in puddled soil increase methane release.
   - **Ebullition (methane release as bubbles)** from paddy soils is a common and significant mechanism for CH_4 loss.
   - **CH_4 escape mechanisms**: Methane can exit the rice paddy soil via aerenchyma in the plant (90%), ebullition (10%), and diffusion through the soil and water layer (1%). During land preparation and early rice growth, ebullition is the primary release mechanism.

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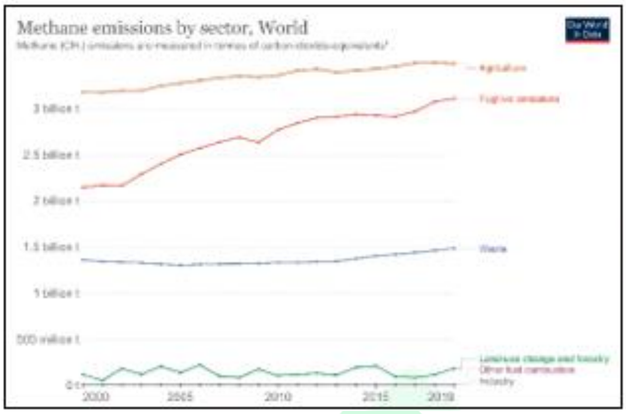
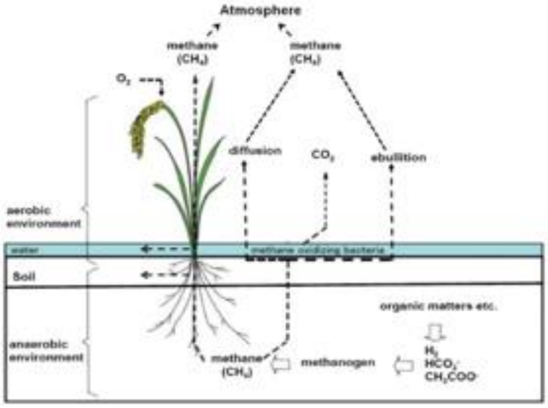
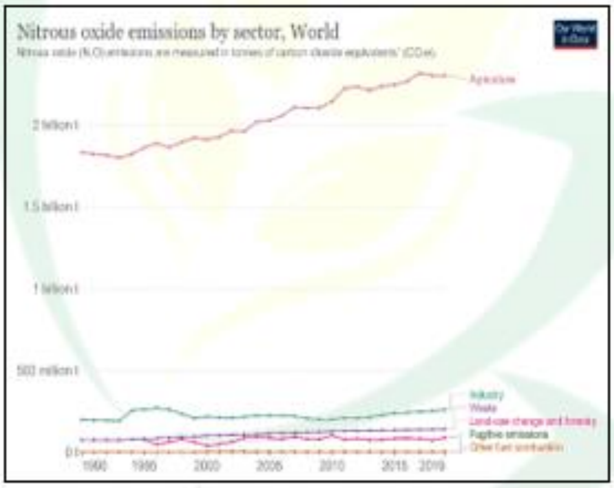




3. **Nitrous oxide (N_2O)**

- **Natural production**: N_2O is naturally produced in soils through the processes of nitrification and denitrification.
- **Role in denitrification and nitrification**: N_2O is a gaseous intermediate in the denitrification reaction sequence and a by-product of nitrification. It leaks from microbial cells into the soil and eventually escapes into the atmosphere.



What is a Carbon footprint?

A carbon footprint refers to the total amount of greenhouse gas (GHG) emissions associated with human production or consumption activities that contribute to climate change. It is expressed in terms of carbon dioxide equivalent (CO_2e). Initially, only CO_2 was considered when determining carbon footprints, but currently, all major GHGs including CO_2, methane (CH_4) and nitrous oxide (N_2O) are considered into account in terms of their CO_2e potency. The carbon footprint (CF) is a crucial parameter for quantifying the environmental impact of GHG emissions and assessing their contribution to global environmental sustainability.

Why to evaluate Carbon footprint?

- To assess and compare greenhouse gas (GHG) emissions.
- To improve environmental quality and resource use efficiency.
- For emission management and the evaluation of mitigation measures.
- To identify emission "hotspots" and select climate-friendly sources.
- To reduce GHG emissions in cultivated soils.
- To serve as an indicator of sustainable development.

Computation process of Carbon Footprint:

Selection of Boundary and tiers

Objectives	Boundary
Carbon footprint of cultivation	From planting to the point where crops are harvested and ready for sale.
Carbon footprint of finished farm products	From farm production to when the products are packaged and transported to stores.
Carbon footprint of food	From farm production to when the food reaches the consumer's table.

In agricultural systems, Tier 1 covers direct emissions including methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) from soil and fossil fuel combustion. Tier 2 includes emissions from electricity use for activities such as irrigation, while Tier 3 accounts for emissions from agricultural inputs like fertilizers, pesticides and herbicides.

Estimation procedure for Carbon footprint removal/ emissions:

- **Closed chamber systems** are a commonly used, cost-effective and straightforward method for measuring greenhouse gas (GHG) fluxes in agricultural studies.
- **Gas analysis** of samples collected from the chambers is typically performed using gas chromatography and infrared gas analyzers**,** which are standard tools for detecting gases like CO_2, CH_4 and N_2O.

- **Emission factors** are available for discharges from farm machinery and electricity use enabling consistent and comparable GHG emission calculations through agricultural practices.
- Simulation models are also adopted for the estimation of carbon footprint that include:

Model	Inputs used for estimating Carbon footprint
Roth C	Soil temperature, soil water and clay content – for modelling soil organic carbon dynamics.
C-TOOL	Monthly air temperature, clay content, C/N ratio and organic carbon inputs – for carbon sequestration.
ICBM	Crop type, soil temperature, rainfall, soil characteristics and tillage – for carbon and nitrogen cycling.
Day Cent	Temperature, precipitation, soil texture, vegetation type and nutrient amendments – for daily carbon/nitrogen simulations.
DNDC	Site/climate data, crop type, tillage, fertilizers, manure, irrigation, grazing and cutting – for modelling carbon and nitrogen cycling.
CERES-EGC	Weather, soil properties, crop management and organic matter – for crop growth and carbon sequestration.
Info-RCT	Precipitation, manure, soil carbon, labour and equipment use – for estimating carbon dynamics and emissions.

Calculation of Carbon footprint:

- **Calculation of GWP of Tier$_i$ (i = 1, 2 or 3):**

GWP (Tier$_i$) = (Emission/Removal of CH_4*25) + (Emission/removal of N_2O*298) + (Emission/Removal of CO_2*1)

- **Yield-scaled Carbon Footprints:**

Carbon footprint = $\sum_{n=i}^{3}[\mathrm{GWP}(\mathrm{Tier_i})]$; $\mathrm{CF_y} = \frac{\mathrm{CF}}{\mathrm{Grain\ yield}}$

where,

GWP is in kg CO_2e ha^{-1}.

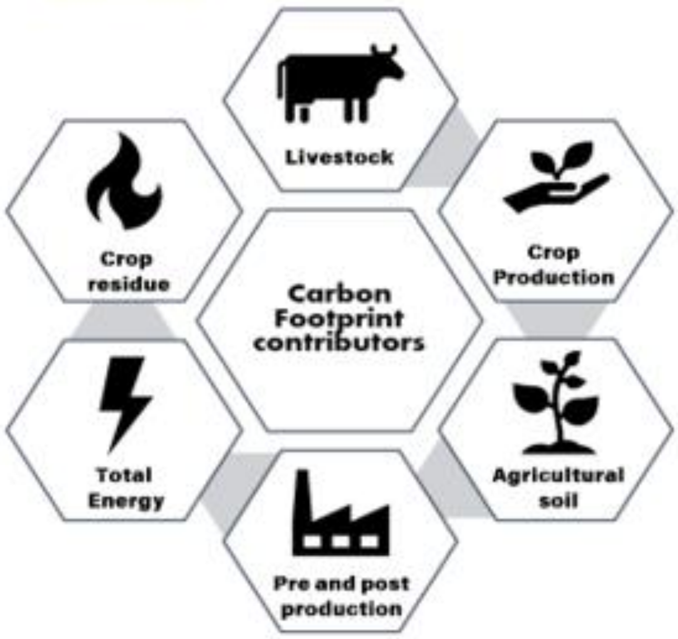
CFy is yield-scaled carbon footprint (kg CO_2e Kg^{-1} yield).

Generally, emissions are represented as positive values while carbon removal is considered negative, with all values expressed in kg ha^{-1}. The carbon footprint is calculated by summing the Global Warming Potential (GWP) of emissions across all tiers. Yield-scaled carbon footprints which normalize emissions by crop yield provide a more accurate and comparable measure for assessing the sustainability of different cropping systems.

Major contributors to Carbon footprint and their mitigation strategies:

Mitigation strategies:

- **Crop Diversification**: Growing different crops like legumes and cereals can improve soil fertility and reduce chemical fertilizer use. e.g., a crop rotation of wheat and peas.
- **Biochar Application**: Adding biochar to soil, like mixing it with compost, helps sequester carbon and improve soil health.
- **Organic Farming**: Organic methods such as using compost instead of synthetic fertilizers, reduce emissions and improve soil carbon storage.
- **Biofuel**: Using plant-based fuels like ethanol from corn instead of gasoline reduces reliance on fossil fuels.
- **Tillage**: No-till farming, like planting directly into undisturbed soil, helps store carbon and reduces soil erosion.



Conclusion:

Estimating the carbon footprint is essential for understanding and mitigating the impact of human activities on global warming and climate change. It refers to the total greenhouse gas emissions primarily in terms of carbon dioxide equivalent (CO_2e) produced by energy use, burning of crop residues, livestock feces, crop production, agricultural soil and pre and host production. Major greenhouse gases like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) contribute to the carbon footprint with each having a different global warming potential (GWP). Hence, calculating the carbon footprint helps identify key sources of emissions such as fossil fuel consumption and waste, enabling individuals, organizations and governments to develop strategies to reduce emissions. Thus, by monitoring the carbon footprint status, we can minimize its levels and work towards a more sustainable future, helping mitigate climate change and its harmful effects.

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