Agriculture, Forestry and Other Land Use

For a sustainable future

Vol. 2 – Carbon emissions management series

KEARNEY | Energy Transition Institute

Compiled by the Kearney Energy Transition Institute

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About the FactBook: Agriculture, Forestry and Other Land Use

The FactBook focuses on greenhouse gas (GHG) emissions (CO_2,CH_4 and N_2O) from Agriculture, Forestry and Other Land Use (AFOLU) sector. It identifies key sources of emissions in the sector along-with major trends. The factbook outlines key mitigations measures which offer an opportunity to reduce GHG emissions as well as enrich biodiversity and human well being. Relevant regulations and public policies across the globe are summarized with a focus on compliance and voluntary carbon markets. GHG emissions generated from natural unmanaged ecosystems, such as forests and wetlands are not classified as anthropogenic in emission inventories/sources (according to IPCC/FAO guidelines) and hence, not included in the estimation of AFOLU emissions reported in this factbook. However, they have been explained and estimated along-with their impacts on climate change in separate dedicated section.

About the Kearney Energy Transition Institute

The Kearney Energy Transition Institute is a nonprofit organization that provides leading insights on global trends in energy transition, technologies, and strategic implications for private-sector businesses and public-sector institutions. The Institute is dedicated to combining objective technological insights with economical perspectives to define the consequences and opportunities for decision-makers in a rapidly changing energy landscape. The independence of the Institute fosters unbiased primary insights and the ability to co-create new ideas with interested sponsors and relevant stakeholders.

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AFOLU & Voluntary markets

Vol.2 – Carbon Emissions Management Series

Agenda

AFOLU is a key element of climate change as it participates in the emission and removal of greenhouse gases (GHG)

Agriculture, Forestry, and Other Land Use (AFOLU) plays a critical role in climate change as it accounts for around 14% of global greenhouse gas emissions (GHG) through activities such as deforestation, livestock farming, and rice cultivation. Deforestation is the major carbon dioxide (CO_2) emitter among these, while enteric fermentation is the major methane (CH_4) emitter.

Despite being a global emitter sector, forestry and land use have the potential to remove CO_2 emissions from the atmosphere and store it in soils and forests.

In the past decades, **tree cover loss has been driven by increased forest fires and continuous deforestation, reducing forestland capacity to act as sink**. Emissions from the agriculture sector have increased mostly from livestock (enteric fermentation and manure management) and rice cultivation, by 13% and 37% respectively in the same period.

AFOLU faces several challenges including uncertainty in GHG estimation, limited land cover sinking capacities, and land availability, pressured by growing population, land use competition, and climate change.

AFOLU also embeds climate change mitigation potential through sustainable agricultural practices, bioenergy use, ecosystems conservation, and dietary and behavioral shifts. Up to 65 $GtCO_2eq$/year could be mitigated through a variety of solutions including reforestation, fire management, reduced land conversion and degradation, ecosystems restoration, shift to sustainable diets, and food loss and waste reduction. Most mitigation solutions of AFOLU emissions are available and ready to deploy and will play a key role in energy transition.

Policies and regulations for AFOLU have been in place since the 1990s. Governments, following the Paris Agreement, have increased or included AFOLU in their emissions mitigation objectives. Additional financial incentives and regulations have been pushed to encourage mitigation effort at global, national, and sub-national levels. In addition, plans and initiatives such as REDD+ and PPCDAm have been created to prevent deforestation and forest degradation.

AFOLU has also attracted investment flows through emissions trading markets and financing schemes. Forestry and land use projects have driven the voluntary market growth and hit a price premium around 5 USD/tCO_2eq.

Despite policy measures, high rates of deforestation impede AFOLU's ability to combat climate change

AFOLU's capacity to absorb global carbon emissions is declining

- Agriculture (in other words, all sources related to crops cultivation and livestock production activities in managed land) accounts for 80% of AFOLU's GHG emissions, LULUCF the remaining 20%.
- Forestland is the only GHG sink from the AFOLU activities.
- The ability of tropical forests to sequester carbon peaked in the 1990s and has been declining since; its capacity to remove emissions has decreased by 33%.

Global deforestation is decelerating, but still concentrated in tropical regions

- Global forest loss rate peaked in the 1980s and has been on a decreasing trend since then.
- Forest loss rates differ among regions with most of the losses concentrated in the tropical regions, which are the largest forest type globally and are home to more than half of the Earth's terrestrial species.

Deforestation is caused by multiple factors

- A third of global tree cover loss is due to fires, mostly in boreal forests.
- The remaining two-thirds results from agricultural expansion, infrastructure development and urbanization (and demographical changes), mining, fires, logging, and fuelwood harvesting, among others.

Some countries achieved net forest gain, but often exported deforestation

- China and several developed countries (such as Japan, Germany, Italy, France, the UK) have achieved net forest gains domestically but increased their non-domestic deforestation footprints.
- Large-scale imports of tropical deforestation-related commodities drive clearing of tropical forests in the producing countries.

Policies and regulations protecting forests are strengthening

- Many initiatives have been launched in the recent COP (Conference of the Parties) summits to protect and promote forest resources globally.
- 95% of NDCs (nationally determined contributions) have included agricultural and/or land use, land use change, and forestry emissions mitigations,

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Representing 14% of global GHG emissions, agriculture, food systems, and land use change are key to mitigate climate change

Emissions from land use change and agriculture have increased

- Net forest conversion was the largest emitter of emissions from LULUCF in 2020 followed by organic soil drainage with 2.95 GtCO_2eq and 0.83 GtCO_2eq respectively, exclusively in the form of carbon dioxide.
- Enteric fermentation, manure management practices, and rice cultivation are the largest sources (57%) of GHG emissions in agriculture. Emissions (CH_4 and N_2O) from livestock have increased by 13% and emissions from rice cultivation by 37% in recent decades.

Conversion of ecosystems to agriculture, urbanization, and infrastructure

- Agricultural expansion is driving almost 90% of global deforestation, including 49.6% from expansion for cropland and 38.5% for livestock grazing.
- Despite increased demand for food, feed, fuel, and fiber from a growing human population, global agricultural land area is projected to remain relatively stable during the next decade.
- Urban expansion leads to landscape fragmentation and urban sprawl with effects on forest resources and land use.

Agriculture food systems are dependent on climate change and vice versa

- The complex interaction between agriculture food systems and climate change impacts food security and nutrition.
- Emissions from food systems vary depending on geographies, habits, and infrastructure, and so do their potential for reduction. Globally, limiting food loss and waste and shifting diets could reduce emissions by 1.8 GtCO_2eq per year.

Food products have GHG footprint along the food system value chain

- The largest GHG footprint is associated with ruminant-related food products, largely due to the enteric fermentation process and manure practices.
- Plant -based products with significant GHG footprints—such as dark chocolate, palm oil, and soybean oil—are responsible for land use change.

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1. AFOLU and global GHG emissions

AFOLU GHG emissions account for 14 percent of global emissions, come from a variety of unique sources, and take place in complex land and food production systems

Anthropogenic greenhouse gas emissions from agriculture, forestry and other land use (AFOLU) are defined as those occurring on managed lands. They annually account for **~14 percent of global emissions** (7.58 $GtCO_2eq$ in 2020). AFOLU is then divided into two sub-sectors[1]: land-use, land use change and forestry (LULUCF; ~20%); and agriculture (the practice of cultivating the soil, producing crops, and raising livestock; ~80%).

AFOLU GHG are produced through biological (activity of microorganisms, plants, and animals) **and physical processes** (combustion, leaching: rain or irrigation, run-off: water surface flow or drainage). **Methane (CH_4) is the main source of AFOLU GHG emissions (4.17 $GtCO_2eq$, 55%), followed by nitrous oxide (N_2O; 2.24 $GtCO_2eq$, 30%) and carbon dioxide (CO_2, 1.17 $GtCO_2eq$, 15%).** Main methane sources are **enteric fermentation** and **rice cultivation**, while nitrous oxide comes mainly from **manure** left on pasture and **synthetic fertilizers** and carbon dioxide emissions come from land use change and forestry sources.

Main contributors to AFOLU GHG are **Brazil, India**, **D. R. Congo,** and **Indonesia** driven by forest conversion, enteric fermentation, and burning of biomass**.** China, France and the United States have almost a neutral GHG impact within AFOLU due to large CO_2 capture through forestland. Russia and Chile have a negative GHG impact also through forestland CO_2 capture.

AFOLU GHG emissions management faces great challenges as mitigation alternatives take place within land complex interactions, interdependencies and tradeoffs between socioeconomic and natural factors, such as **land-use competition**, **feedback mechanisms**.

Non-anthropogenic emissions generated by natural ecosystems, such as forests and wetlands, **are not considered in the scope of AFOLU emissions**. The GHG emissions generated by non-anthropogenic ecosystems are considered carbon-neutral, as being part of the natural carbon cycle. If most **uplands clearly act as carbon sinks** (through photosynthesis), **wetlands have a more debated contribution** due to large quantities of methane emissions (decomposition of organic matter) that are not always compensated by their CO_2 capture, which is particularly emphasized in boreal areas. If wetlands contribute to capturing and storing CO_2, their methane emissions make them potential radiative forcing contributors depending on the time horizon considered (the global warming potential of methane depends on the time horizon considered).

1. Please refer slide #10 for the detailed descriptions of the components under Agriculture and LULUCF

Agriculture, forestry, and other land use (AFOLU) account annually for about 14 percent of global greenhouse gas (GHG) emissions, with a total of 7.6 $GtCO_2eq$ in 2020

IPCC guidelines are designed to assist the estimation of **anthropogenic GHG emissions.**

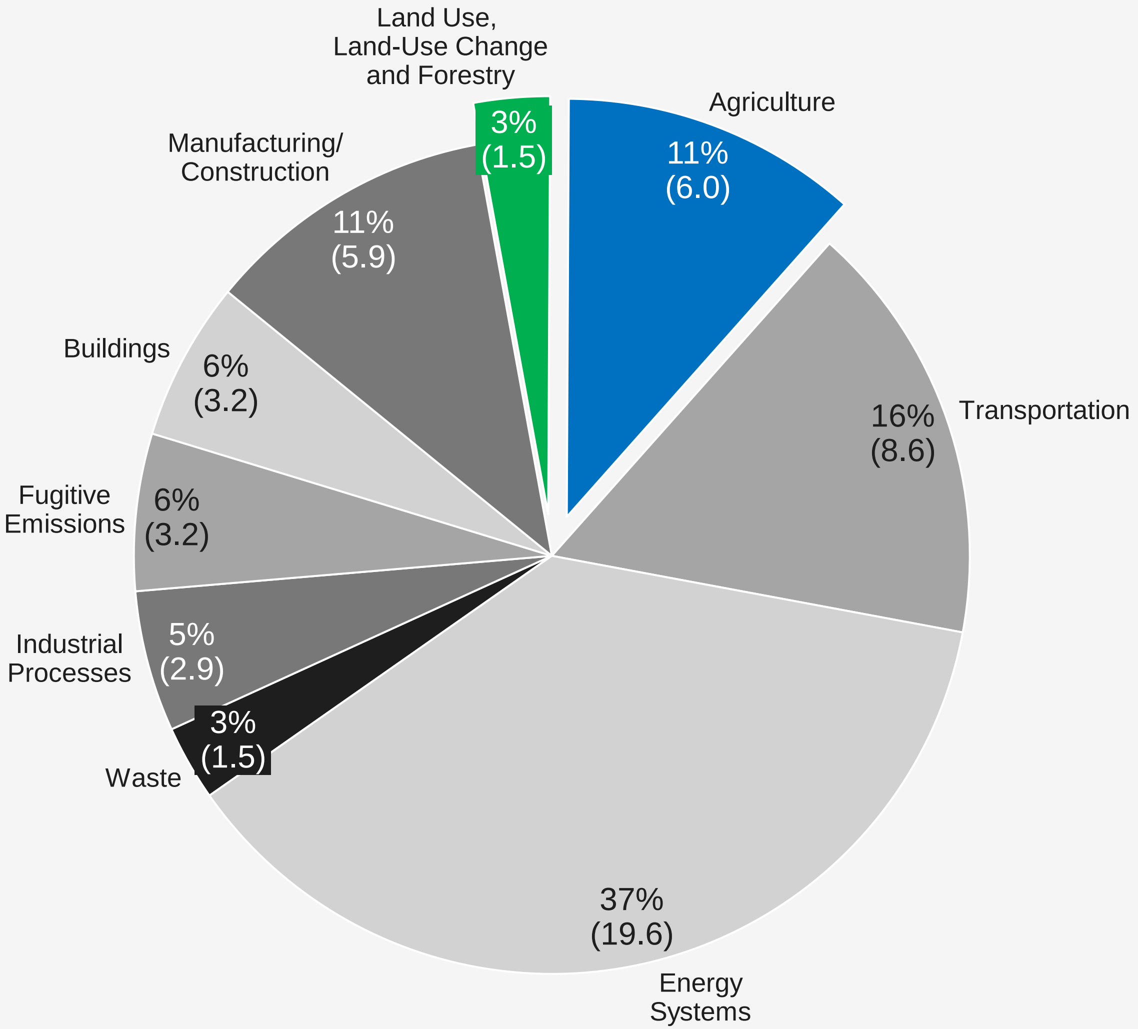
Managed Land is land where human interventions and practices have been applied to perform production, ecological, or social functions

Non-anthropogenic emissions generated by natural ecosystems, such as forests and wetlands, are not considered in the scope of AFOLU emissions

1.1 Overview of global AFOLU GHG emissions

Global anthropogenic GHG emissions per sector

$GtCO_2eq$, % of total GHG, 2020



Note: Graphic uses Global Carbon Project data for global carbon emissions 2021 combined with EDGAR v6.0 split between sectors and uses; Global Methane Budget 2020 for methane emissions by sources and sectors and EDGARv6.0 data (2018) for global CH_4 (GWP-100 (AR6)), N_2O, and F-gases emissions. AFOLU data from FAOSTAT.
Sources: Global Carbon Budget 2021, International Energy Forum Methane Initiative (2021), FAO, UNFCCC, IPCC Chapter 11 Agriculture, Forestry, and Other Land Use (AFOLU); Kearney Energy Transition Institute analysis

Land Use, land-use change, and forestry (LULUCF)

Greenhouse gas inventory sector that covers emissions and removals of GHG resulting from direct human-induced land use such as settlements and commercial uses, land-use change, and forestry activities

Agriculture

GHG emissions resulting from the practice of cultivating soils, producing crops, and raising livestock.

Direct emissions are mostly from methane (CH_4) produced by anaerobic fermentation or nitrous oxide (N_2O) from extensive use of synthetic N-fertilizers, manure, and residues practices.

Indirect emissions are the emission of precursor gases that will later transform into GHG in the atmosphere:

– Formation of NO_x and NH_3 from crop and manure practices

– Formation of NH_4^+ and NO_3^- from combustion gases deposition of biomass burning

AFOLU emissions are broken down into two categories that are further split into subcategories characterized by their emissions sources and types

Non-exhaustive

Defined sources cover the anthropogenic GHG emissions for the AFOLU sector. Non-anthropogenic emissions are assumed to be zero in inventories, since they have neutral impact in the long term as part of the carbon cycle of natural ecosystems

1.1 Overview of global AFOLU GHG emissions

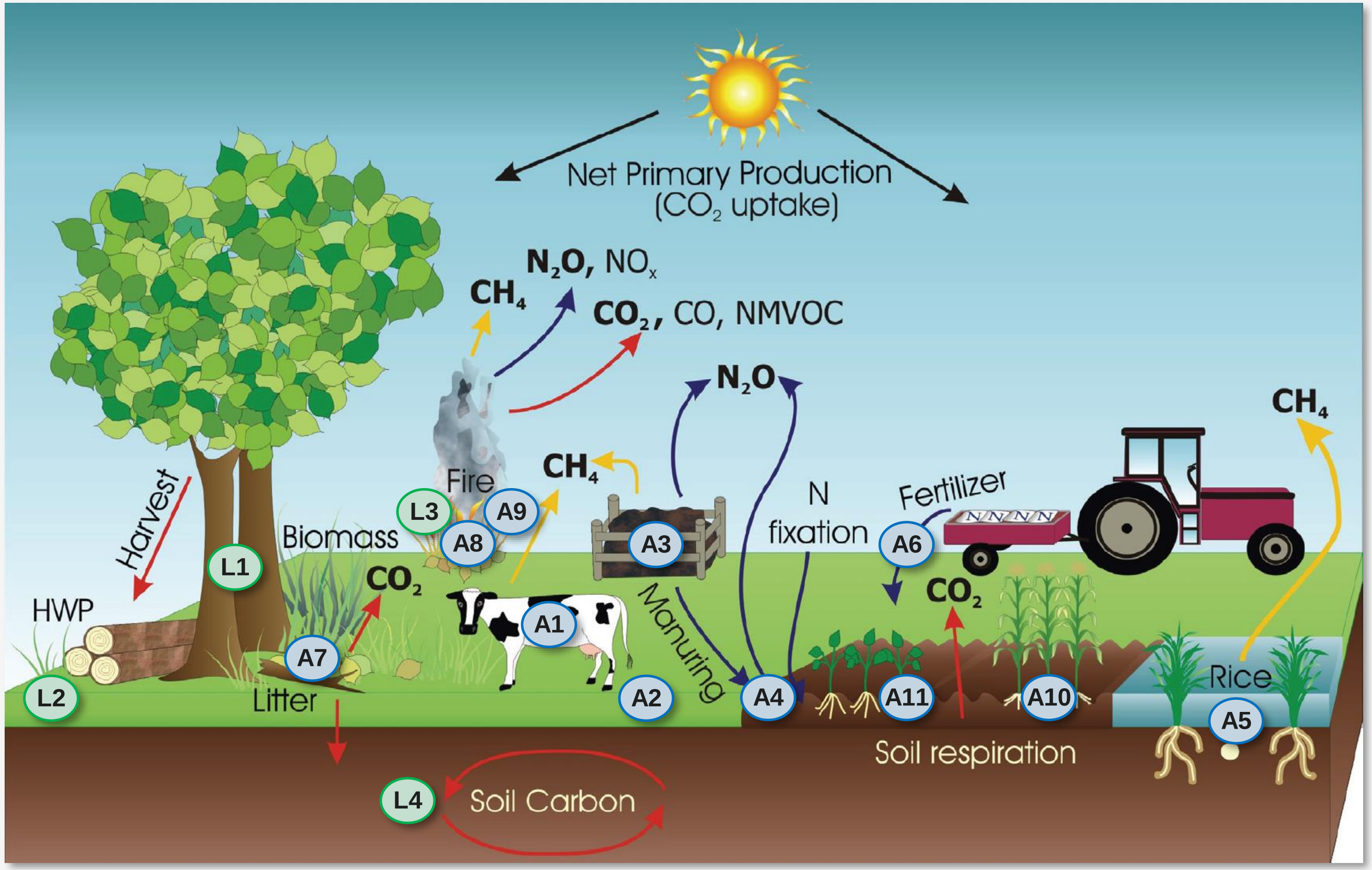
(IPCC)		Subcategories (FAO)	GHG emission
AFOLU	LULUCF	L1 Forestland	– CO_2 removals as a result of net carbon stock increase in the living biomass pool (above ground and below ground biomass) associated with **forestland growth**
AFOLU	LULUCF	L2 Net forest conversion	– CO_2 emissions from net carbon stock decrease in the living biomass pool (above ground and below ground biomass) associated with **forestland converted to croplands or grasslands**[1]
AFOLU	LULUCF	L3 Burning biomass (fires)	– CO_2, CH_4 and N_2O emissions produced by the **burning of biomass**. Subcategories included: *organic soil fires* (L3-a), *forest fires* (L3-b), and *humid tropical forest fires* (L3-c)
AFOLU	LULUCF	L4 Drained organic soils (CO_2)	– CO_2 emission following **soil drainage due to the cultivation of organic soils** for crop production or for livestock production (grasslands)
AFOLU	LULUCF	L5 Wetlands, settlements, and other land	– GHG emissions from underwater **anaerobic decomposition of organic matter in wetlands** (CH_4), developed lands converted to settlements, other land use change (bare soil, rock, ice)
AFOLU	Agriculture	A1 Enteric fermentation	– **Digestive process** by which carbohydrates are broken down by microorganisms into simple molecules for absorption. Methane emissions are produced as a by-product
AFOLU	Agriculture	A2 Manure left on pasture	– Nitrous oxide emissions produced by microbial processes of **nitrification** and **de-nitrification from manure left by grazing livestock** taking place on the deposition site
AFOLU	Agriculture	A3 Manure management	– Methane and nitrous oxide emissions from the **decomposition of manure** under low oxygen or anaerobic conditions
AFOLU	Agriculture	A4 Manure applied to soils	– Nitrous oxide emissions produced by **nitrification** and **de-nitrification from manure added to agricultural soils by farmers** as an organic fertilizer taking place on the application site
AFOLU	Agriculture	A5 Rice cultivation	– Methane emissions from **decomposition of organic matter** (mainly rice straw residue) under anaerobic conditions **in paddy fields**
AFOLU	Agriculture	A6 Synthetic fertilizers	– Nitrous oxide emissions produced by microbial processes of **nitrification** and **de-nitrification from nitrogen added to agricultural soils** by farmers taking place on the addition site
AFOLU	Agriculture	A7 Crop residues	– Nitrous oxide emissions from **nitrification and de-nitrification** of nitrogen **in crop residues** (above and below ground) and forage/pasture renewal left on agricultural fields by farmers
AFOLU	Agriculture	A8 Burning – crop residues	– CH_4 and N_2O gases produced from the **burning of materials left in fields or orchards** after crops have been harvested and/or processed (stalks and stubble (stems), leaves, seed pods)
AFOLU	Agriculture	A9 Savanna fires	– CH_4 and N_2O gases produced from the **burning of biomass vegetation** in the following five land cover types: savanna, woody savanna, open shrubland, closed shrubland, and grassland.
AFOLU	Agriculture	A10 Drained organic soils (Non-CO_2)	– Nitrous oxide emissions produced by **nitrification**, **de-nitrification** after nitrogen mineralization associated with gain of soil organic matter **resulting from drainage of organic soils**
AFOLU	Agriculture	A11 Liming; urea application	– CO_2 and water produced from bicarbonate, resulting from **lime stones dissolution or urea in the presence of water and urease enzymes**

1. Conversion to wood products is not included as this is considered a carbon transfer to another surface pool (harvested wood) and not a direct emission to the atmosphere
Sources: IPCC, FAO, European Commission, Kearney Energy Transition Institute

LULUCF and agriculture activities (from managed ecosystems) are intimately related and rely on multiple types of processes

Non-exhaustive

Main GHG emission sources/sinks from AFOLU



L1	Forestland	A4	Manure applied to soils
L2	Net forest conversion	A5	Rice cultivation
L3	Burning biomass (fires)[1]	A6	Synthetic fertilizers
L4	Drained organic soils (CO_2)	A7	Crop residues
L5	Wetlands, settlements	A8	Burning – crop residues
A1	Enteric fermentation	A9	Savanna fires
A2	Manure left on pasture	A10	Drained organic soils (non-CO_2)
A3	Manure management	A11	Liming; urea application

- Greenhouse gas fluxes are driven by both **biological** (activity of microorganisms, plants, and animals) and **physical processes** (combustion, leaching: rain or irrigation, run-off: water surface flow or drainage)
  - **CO_2:** Uptake through plant photosynthesis and releases via respiration, decomposition, and combustion of organic matter
  - **CH_4:** Emission through methanogenesis (microorganisms' activity) in soils and manure storage, through enteric fermentation, and during incomplete combustion of organic matter
  - **N_2O:** Emission as a by-product of nitrification and denitrification

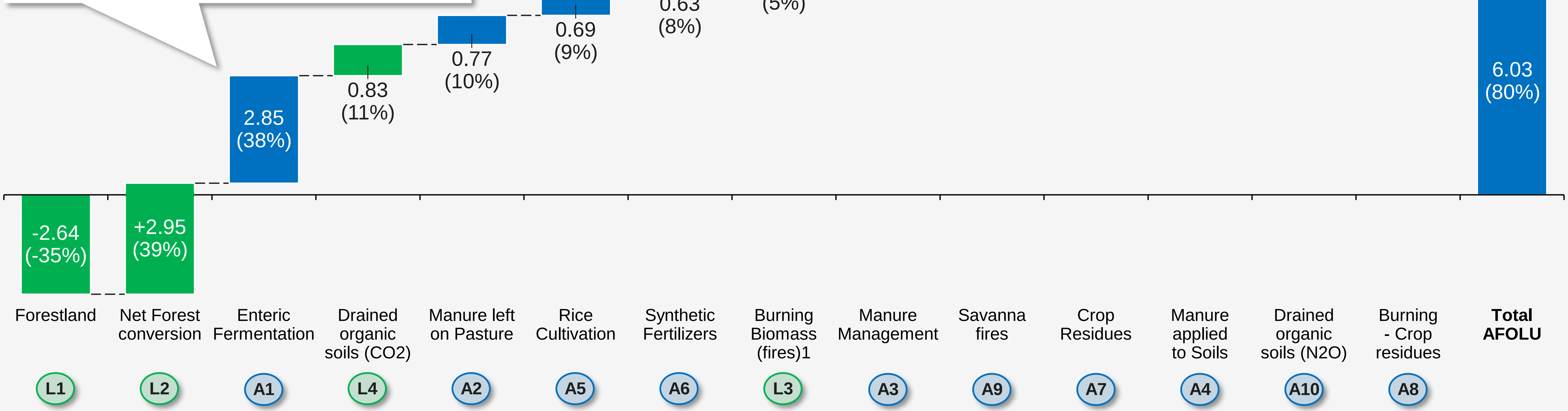
Note: Picture adapted from IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4 Agriculture, Forestry, and Other Land Use
1. Sub-categories included organic soil fires (L3-a), forest fires (L3-b) and humid tropical forest fires (L3-c)
Sources: IPCC (Volume 4 Agriculture, Forestry, and Other Land Use – Chapter 1. Introduction), FAO, Kearney Energy Transition Institute

AFOLU GHG emissions are mainly from net forest conversion and enteric fermentation while removals are only from forestland

AFOLU global GHG emissions / removals per subcategories

$GtCO_2eq$, FAO, 2020

- **Forestland is the only GHG sink** from the different activities within AFOLU
- Forest-related practices have **almost neutral impact**
  - Emissions from net forest conversion are offset almost entirely by forestland
- **Enteric fermentation is the second biggest source** and the most relevant within the agriculture sector



Note: Data retrieved from FAO, 2021. FAOSTAT Climate Change, Emissions, Emissions Totals (fao.org/faostat/en/#data/GT). Negligible sources: Wetlands, Settlements, and Other Land (L5) and Liming; Urea Application (A11)
1. Sub-categories included: Organic Soil fires (L3-a), Forest fires (L3-b) and Humid Tropical Forest fires (L3-c)
Sources: FAO; Kearney Energy Transition Institute Analysis

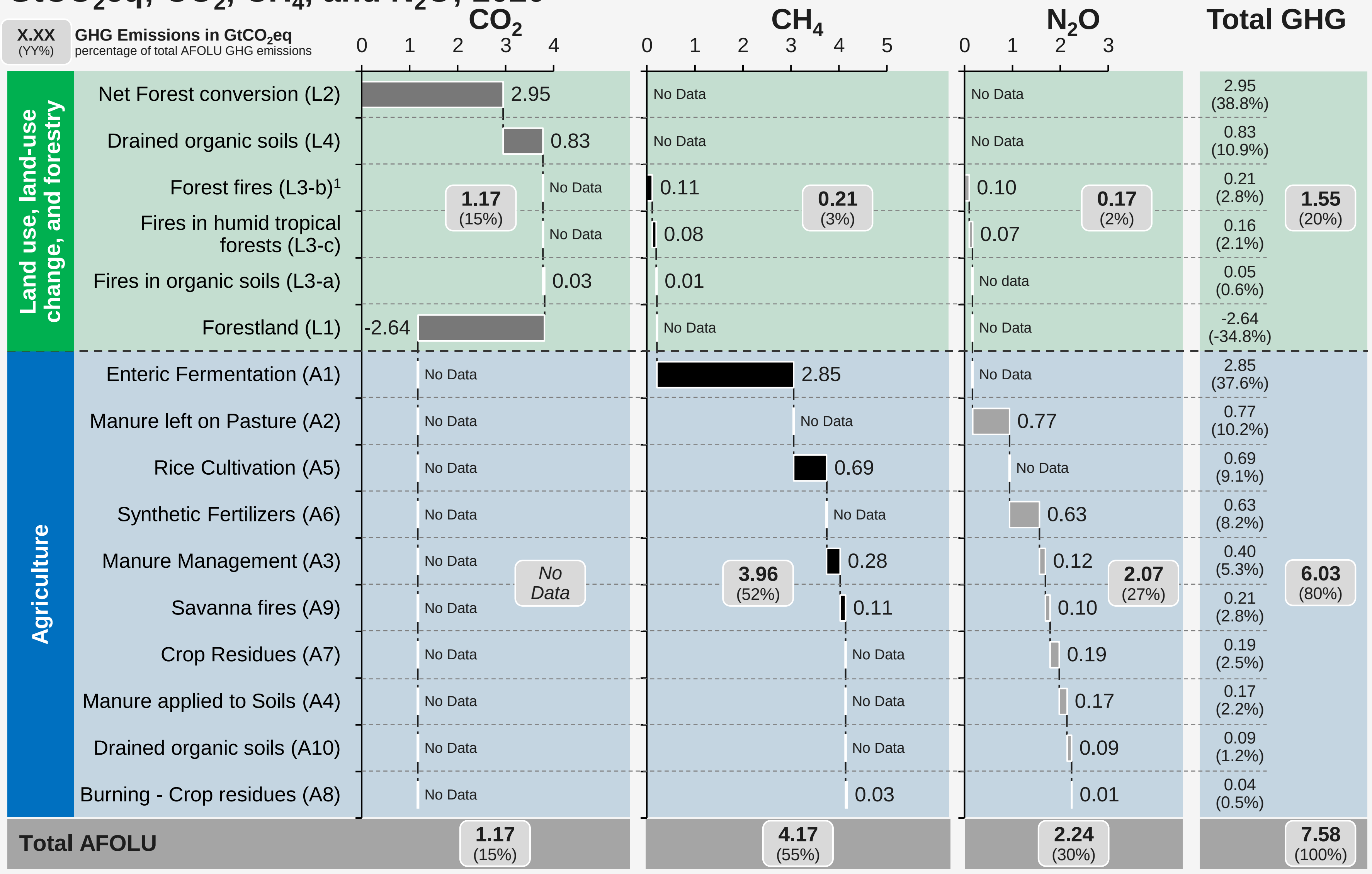
Methane is the primary GHG emitted from AFOLU activities, and is mainly released from agriculture sources such as enteric fermentation and rice cultivation

FAO emissions estimation methods and included GHG (CO_2, CH_4 or N_2O) are designed to avoid omissions or double counting (e.g. CO_2 from forest fires are covered in carbon stock changes calculations in forest sources (Forestland (L1) and Net forest conversion (L2))

1.1 Overview of global AFOLU GHG emissions

Global AFOLU carbon emissions by source

$GtCO_2eq$; CO_2, CH_4, and N_2O; 2020

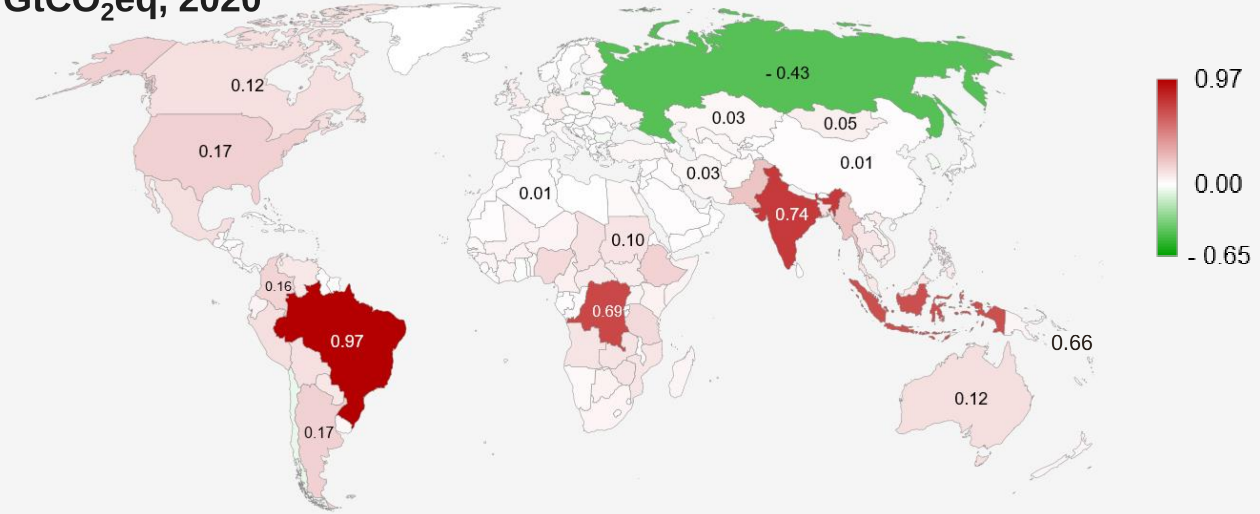


1. CO_2 emissions from fires within managed forests are not included in GHG inventories guidelines, but non-CO_2 emissions are (IPCC); Data retrieved from FAO, 2021. FAOSTAT Climate Change, Emissions, Emissions Totals (fao.org/faostat/en/#data/GT); Negligible sources: Wetlands, Settlements, and Other Land (L5) and Liming; Urea Application (A11)
Sources: FAO; Kearney Energy Transition Institute Analysis

The biggest AFOLU GHG emitters are Brazil, India, D. R. Congo, and Indonesia driven by forest conversion, enteric fermentation, and burning of biomass

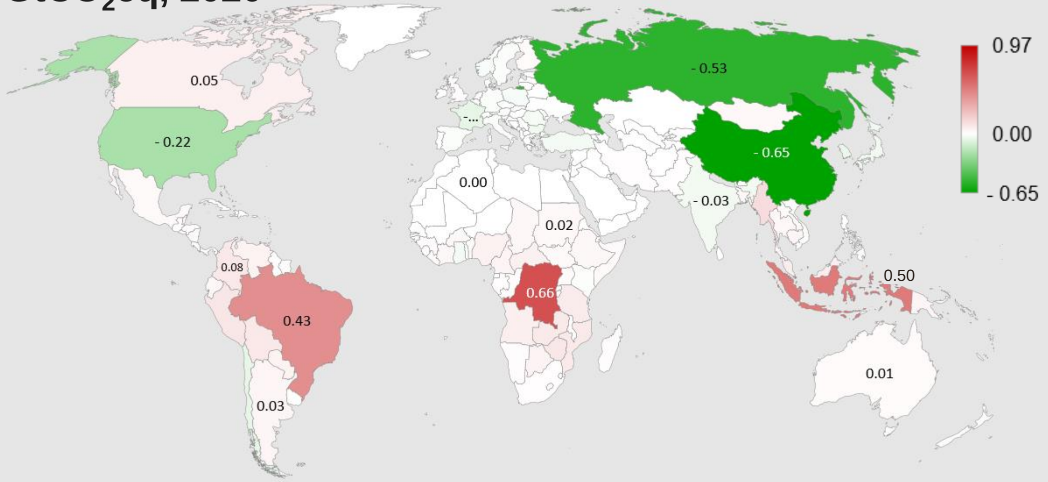
Global AFOLU carbon emissions by country

$GtCO_2eq$, 2020



LULUCF emissions by country

$GtCO_2eq$, 2020



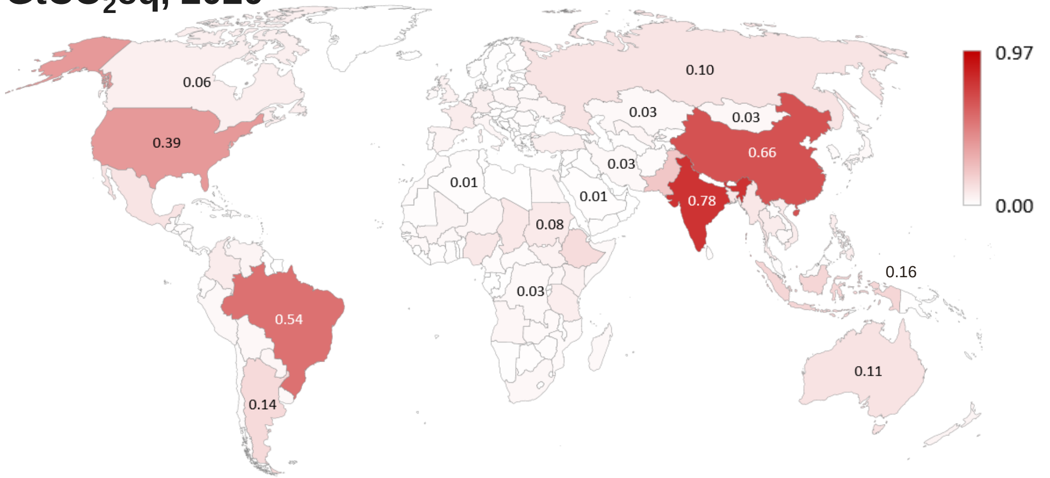
Relevant country data

$GtCO_2eq$, % of global emissions, 2020

	Country	Total	1° source	2° source	Forestland
Top emitters	Brazil	0.97 (12.7%)	Forest conversion (0.65)	Enteric fermentation (0.36)	-0.27
	India	0.74 (9.8%)	Enteric fermentation (0.39)	Rice cultivation (0.13)	-0.04
	Congo	0.69 (9.1%)	Forest conversion (0.60)	Forest fires (0.03)	-
	Indonesia	0.66 (8.7%)	Drained org. soils (0.24)	Forest conversion (0.22)	-
Neutral emitters Compensators	China	0.01 (0.1%)	Enteric fermentation (0.19)	Rice cultivation (0.15)	-0.65
	France	0.01 (0.1%)	Enteric fermentation (0.04)	Synthetic fertilizers (0.01)	-0.07
	US	0.12 (2.2%)	Enteric fermentation (0.17)	Synthetic fertilizers (0.06)	-0.33
Net removers World sinks	Russia	-0.43 (-5.6%)	Drained org. soils (0.05)	Enteric fermentation (0.04)	-0.62
	Chile	-0.05 (-0.6%)	Enteric fermentation	Manure left on pasture	-0.06

Agriculture emissions by country

$GtCO_2eq$, 2020



Note: Non-exhaustive data retrieved from FAO, 2021. FAOSTAT Climate Change, Emissions, Emissions Totals (fao.org/faostat/en/#data/GT)
Sources: FAO; Kearney Energy Transition Institute analysis

AFOLU GHG emissions have remained relatively flat since 1990, except for LUCUCF in specific regions

Non-exhaustive

LULUCF variation drivers

2011–2013:

1. Brazil reduces emissions from net forest conversion (deforestation).
2. China increases carbon removals from forestland activities.

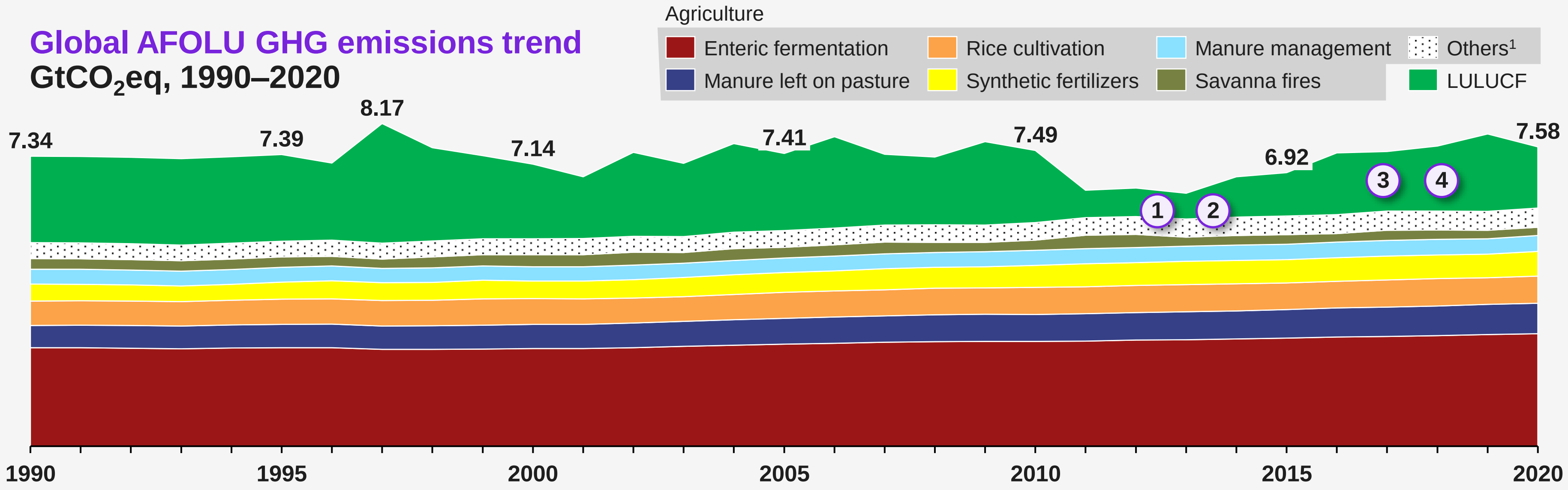
2014–2019:

3. Indonesia increases emissions from fires in organic soils and net forest conversion.
4. Net carbon removal from forestland is reduced, mainly in Brazil, United States, and Russia.

1.1 Overview of global AFOLU GHG emissions

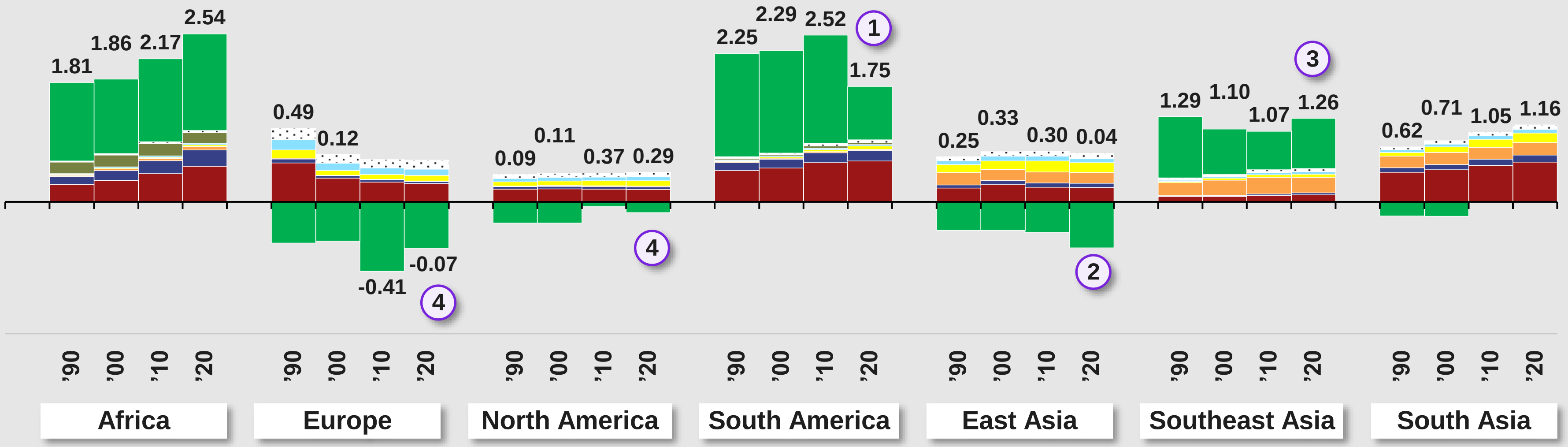
Global AFOLU GHG emissions trend

$GtCO_2eq$, 1990–2020



Emissions breakdown by region

$GtCO_2eq$, 1990–2020



1. Others: crop residues, burning – crop residues, manure applied to soils, and drained organic soils (N_2O)

Note: Data retrieved from FAO, 2021. FAOSTAT Climate Change, Emissions, Emissions Totals (fao.org/faostat/en/#data/GT)

Sources: FAO; Kearney Energy Transition Institute Analysis

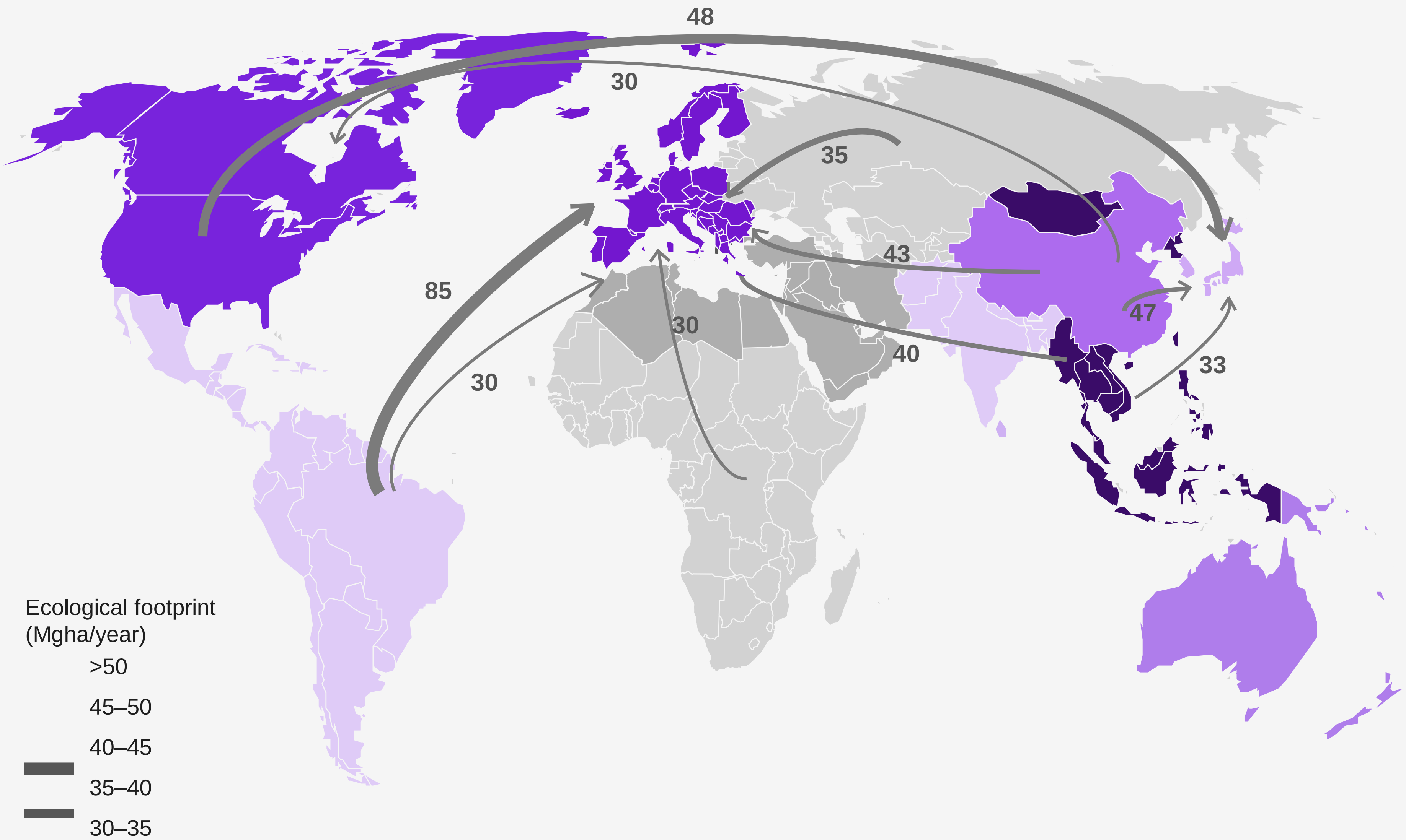
Some regions centralize imports of land use emissions while others are mainly emitters

Traded agricultural and forestry products displace GHG emissions in foreign countries. Such exported GHG emissions need to be considered for carbon footprint estimation.

1.1 Overview of global AFOLU GHG emissions

Top net displacements of land use globally

Million global ha/year



Note: Global hectare (gha) corresponds to the biologically productive hectare with world average biological productivity for a given year. Global Footprint Network (2023), *Glossary*.
Sources: European Energy Agency (2019) Climate change adaptation in the agriculture sector in Europe.

Emissions from LULUCF can be broken down into four main categories

Non-exhaustive

L1 Forestland

– Biomass in forest ecosystems (both above-ground and below-ground biomass) **uptake CO_2 while growing through photosynthesis process.**
– To ensure CO_2 removals, it is fundamental to have proper forest management practices (conservation).

L2 Net forest conversion (deforestation)

– Conversion of forest to other land types (for example, grasslands or croplands) **releases CO_2 to the atmosphere through decomposition of organic matter.**
– The natural carbon cycle is interrupted as no new growing trees will be present to reabsorb CO_2.

L3 Burning of biomass (fires)

– **CO_2, CH_4, and N_2O emissions from combustion of organic matter.** Biomass carbon stock is transferred directly to the atmosphere at a high rate.
– Affected areas face big recovery challenges to restore the carbon cycle and associated natural sink.

L4 Drained organic soils

– Drainage of land, as a **practice to enable cultivation of organic soils for crop and livestock production**, releases large quantities of CO_2 into the atmosphere due to increased oxidation rates of the underlying organic matter.

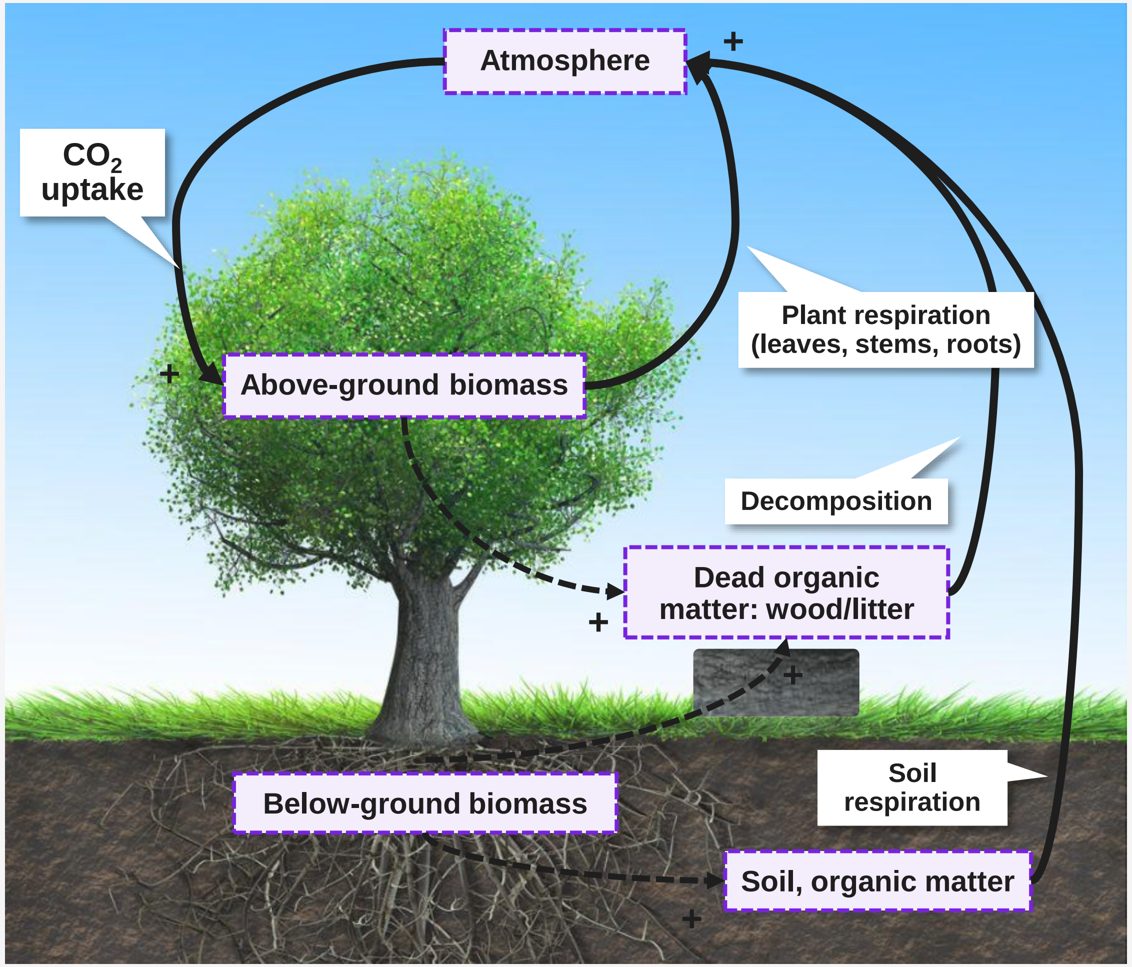
Emissions or removals in forest ecosystems are the result of the net carbon stock change from several carbon pools

Non-exhaustive

XX GHG source

1.2 Focus on LULUCF GHG emissions

Carbon cycle in forest ecosystems



Carbon flux

Carbon pool (reservoir where carbon/nitrogen reside in various chemical forms, the quantity of carbon is referred as **carbon stock**)

Sources: IPCC Guidelines for National Greenhouse Gas Inventories, FAO; Kearney Energy Transition Institute Analysis

Carbon fluxes

- Trees uptake CO_2 trough photosynthesis.
  - Sunlight, water, and carbon dioxide are used to create oxygen and energy in the form of glucose.
- Carbon is transferred between ground pools (biomass, soil, and dead matter) as plants follow its life cycle.
- CO_2 emissions are present naturally through plant and soil respiration, and decomposition of dead organic matter.
- Disturbances (fire, insects, diseases) may interrupt the natural cycle and accelerate emissions into the atmosphere.

L2 Net forest conversion

Net carbon stock decrease in ground carbon pools due to
- Conversion to grassland
- Conversion to cropland
- Decay

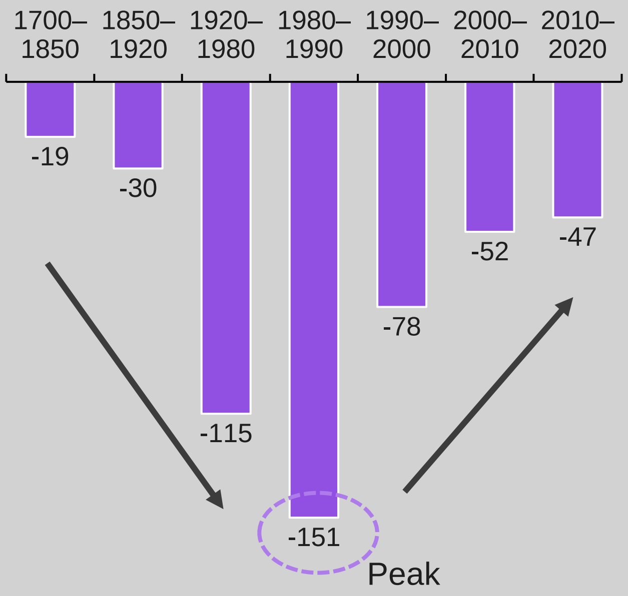
L1 Forestland

Net carbon stock increase in ground carbon pools due to
- Reforestation
- Forestation (other land converted to forest)
- Management and conservation

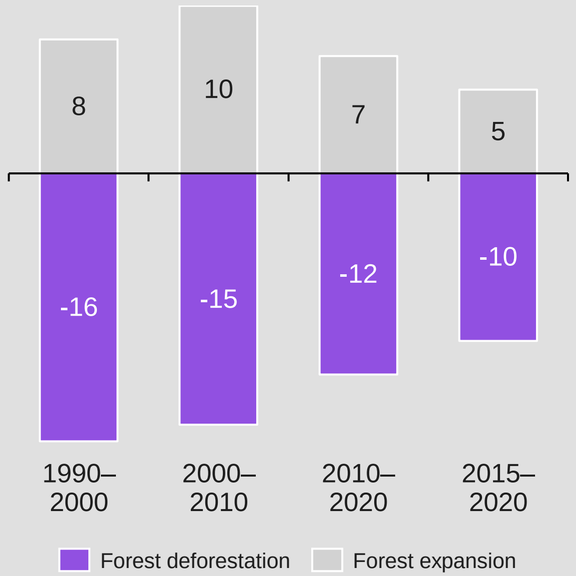
Over the past 5,000 years, about 1.8 billion hectares of forests were lost, and most of this loss, about 1.4 billion hectares, occurred in the past 300 years

Both **natural** (for example, fires, insects, diseases, and severe weather events) and **anthropogenic** (for example, deforestation, land conversion, and land degradation) factors drive forest loss.

Global annual forest area net change rate (on average)
1700–2020, Million hectares per decade

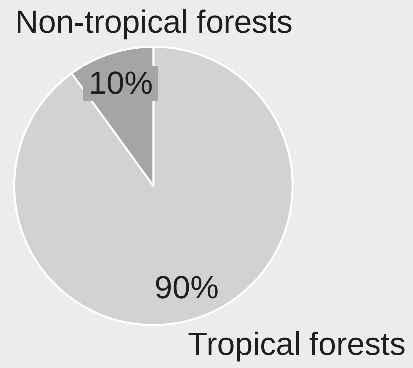


Global annual rate of forest expansion and deforestation (on average)
1990–2020, million hectares per year



More than 90% of the global forest loss during 1990–2020 took place in the tropical areas

Total = ~400 million hectares



Most forests are situated in the tropics (45%), followed by boreal (27%), temperate (16%), and subtropical (11%) domains.

Global forest cover continues to decline but the deforestation rate has been on the declining trend over the past 30 years.

– Forest loss rates differ among regions though the global trend is toward a net forest loss.

– Tropical forests are of great value as they enable climate change adaptation and mitigation by acting as an important terrestrial carbon sink: **1 hectare of tropical forest stores 200 tonnes of carbon** on average in the aerial parts of its trees (trunk, branches, and leaves). However, the tropical areas are losing forests at a rate of **10 million hectares per year.**

Forests are home to more than 80% of all terrestrial species of animals, plants, and insects.

– Tropical forests are rich in biodiversity as they're the natural habitat to more than **half of the Earth's terrestrial species.** They also provide key ecosystem services, social and cultural identities, and livelihoods to the communities.

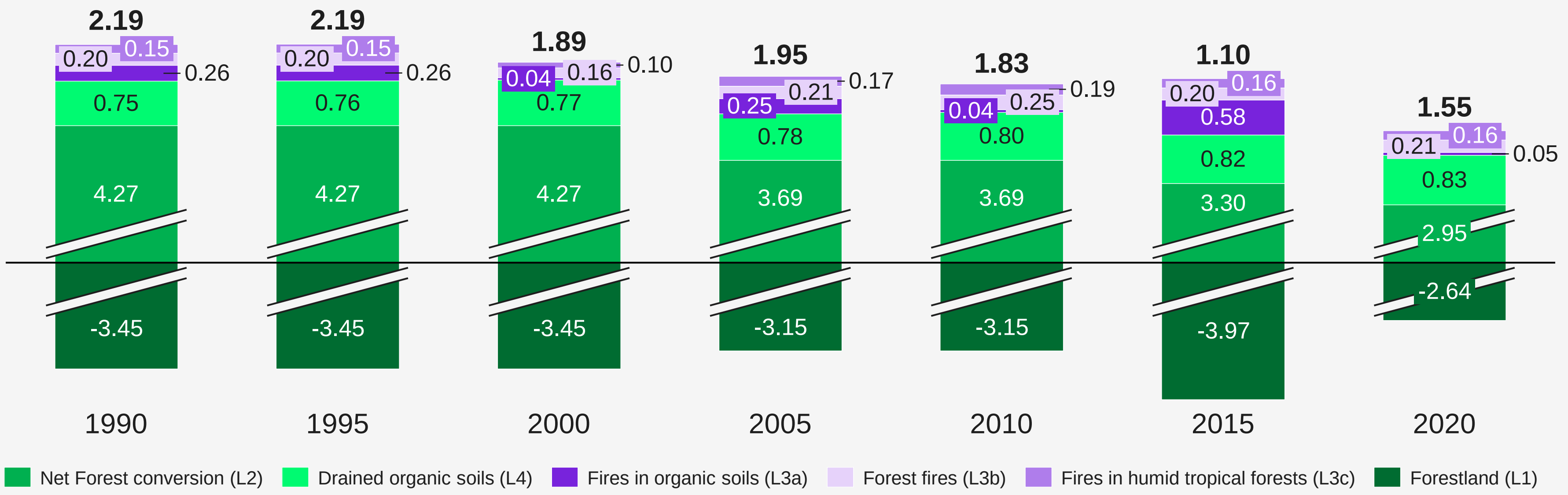
– Biodiversity is declining faster than at any other time in human history, with **~40,000 species documented to be at risk of extinction.**

Sources: FAO (2020) "*Global Forest Resources Assessment 2020*", Williams, M. (2003) *"Deforesting the earth: from prehistory to global crisis"*. ourworldindata.org; Kearney Energy Transition Institute analysis

Net forest conversion (deforestation) and forestland are the major contributors to land-use change and forestry emissions uptake

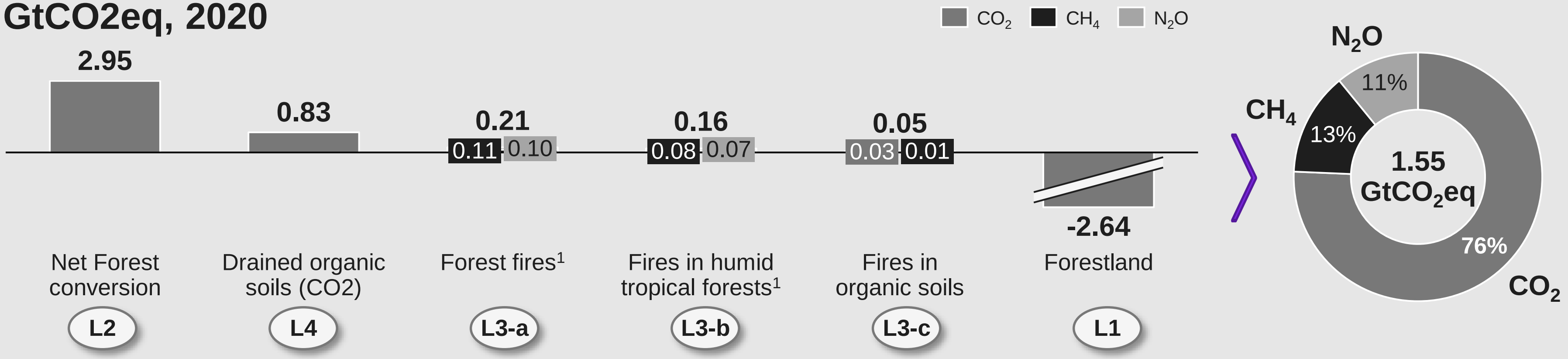
Land-use change and forestry global emissions trend

$GtCO_2eq$, 1990 – 2020



LULUCF emissions by GHG types

GtCO2eq, 2020



Note: Data retrieved from FAO, 2021. FAOSTAT Climate Change, Emissions, Emissions Totals (https://www.fao.org/faostat/en/#data/GT)
1. CO_2 emissions from this source are assumed to be zero in GHG inventories due to its recapture in regrowing vegetation and transfer to other carbon pools (for example, soils).
Sources: FAO; Kearney Energy Transition Institute Analysis

1.2 Focus on LULUCF GHG emissions

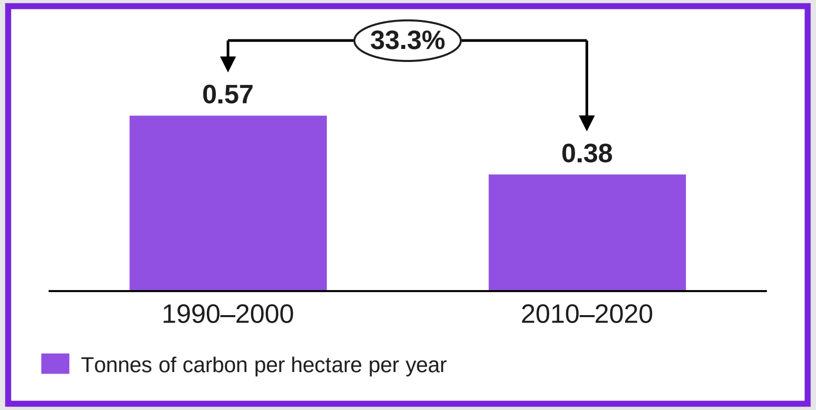
The ability of intact tropical forests to remove CO_2 from the atmosphere reached its peak in the 1990s and has been in decline since due to forest loss and reduced per unit sink area strength

Amazonian tropical forests are especially vulnerable due to inherent **higher tree death rate and lesser resilience to droughts** (caused by an increase in the temperature) compared to their African counterparts.

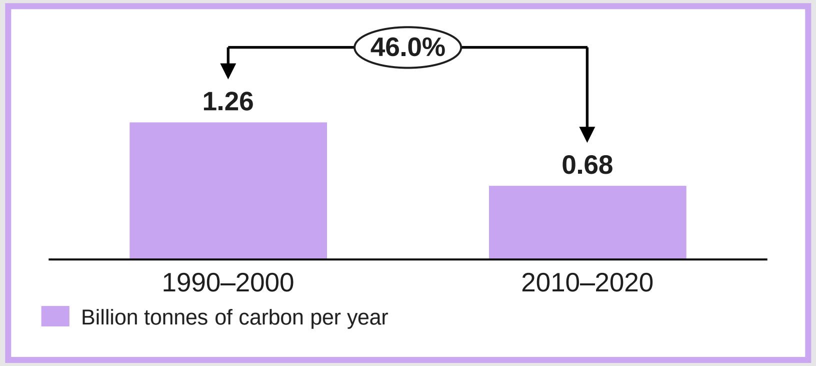
Consequently, Amazonian tropical forests' sink capacity reached its peak (1990s) before African tropical forests (2010s).

1.2 Focus on LULUCF GHG emissions

Carbon uptake ability
Tropical forests, per unit per year



Carbon uptake ability
Tropical forests, cumulatively per year

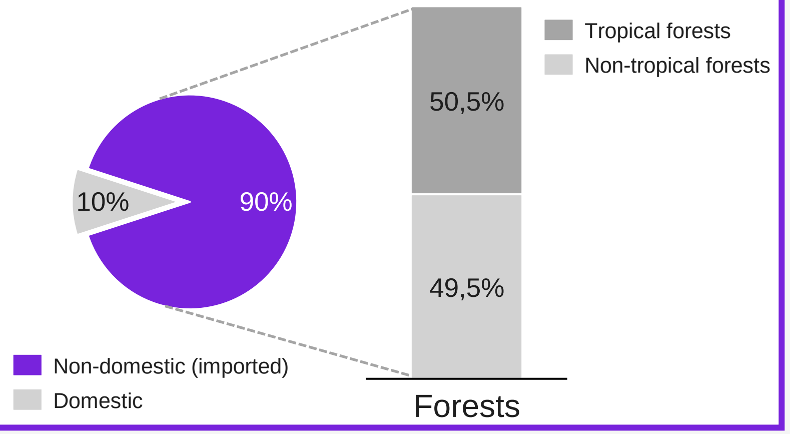


In the 1990s, the tropical forests were able to offset 17% of anthropogenic CO_2 emissions whereas in the 2010s this uptake dropped to 6% in 2010s.

Imported deforestation of tropical forests
Through global demand for commodities and international trade

While global deforestation is decreasing, the imports of tropical deforestation-related commodities are on the rise
- China, some EU countries, and Japan have become major importers of tropical deforestation-related commodities, while developing countries such as Brazil are the key exporters.
- Key tropical deforestation-related commodities are **coffee, chocolate, cattle, soy, palm oil, and timber.**

Deforestation footprints of selected G7 countries[1]
2015



Many countries have achieved net forests gains domestically, but they have also increased the deforestation footprints of their imports.
- Within this, tropical forests are the most threatened biome.
- Consumption patterns of G7 countries drive an average loss of **3.9 trees per person per year.**

1. Japan, Germany, France, the UK, and Italy
Sources: Hoang, N.T. and K. Kanemoto, 2021: "Mapping the deforestation footprint of nations reveals growing threat to tropical forests". Nature Ecology & Evolution, Lewis et all, 2020, "Asynchronous carbon sink saturation in African and Amazonian tropical forests", Nature, cirad.fr; Kearney analysis

Burning biomass emits several types of GHG, and has globally increased over the past two decades

Incomplete combustion of organic matter is the main reason for the large quantities of non-CO_2 GHG produced in fires.

XX GHG source

1.2 Focus on LULUCF GHG emissions

L3 GHG emission from burning of biomass

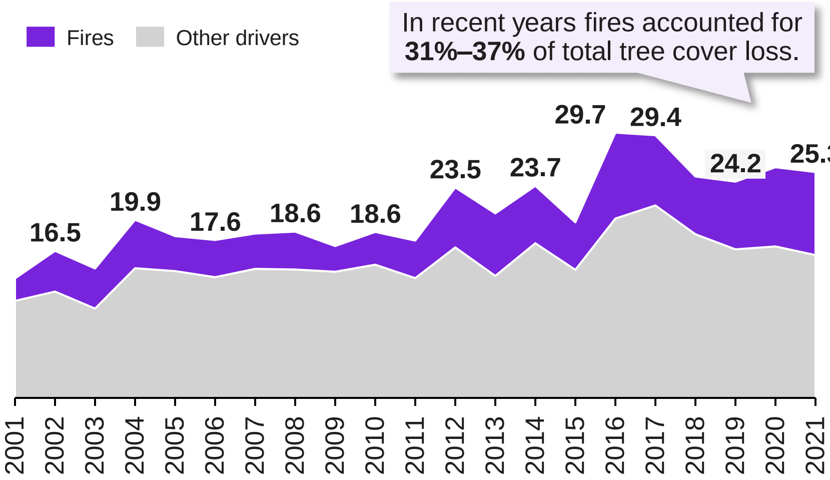
- Combustion of organic matter releases CO_2, CH_4, and N_2O; and affects both above- ground and below-ground carbon pools.
  - Incomplete combustion from biomass, due to the lack of oxygen, leads to non-CO_2 GHG gases production (direct and indirect emissions[1]).

GHG inventories considerations

	Organic soils fires	Above-ground vegetation
Inventories estimation	Include both CO_2 and non-CO_2 gases (CH_4 and N_2O).	Include just non-CO_2 gases. CO_2 from forest fires are excluded since they are covered in the carbon stock changes calculations in forest sources (Forestland (L1) and Net forest conversion (L2))

Global tree cover loss from fires

Million ha, 2001–2021, Global Forest Watch



Carbon offset vulnerability

- Disturbances such as fires release the CO_2 stored in the trees, putting at risk the permanent carbon sequestration principle on which forestry projects are based in order to issue carbon credits (emissions offset).

Case study (California, United States, *Financial Times*, 2022)

- Carbon released in recent blazes is expected to wipe out most of the buffer in Californian ETS (CO_2 removals for which carbon credits are not issued and function as a contingency strategy in case of disturbances).
  - Fires in 6 projects had released 5.7–6.8 $MtCO_2$ since 2015 (~95% of total CO_2 removals set aside (buffer) to insure against fire risk over a century-long period).

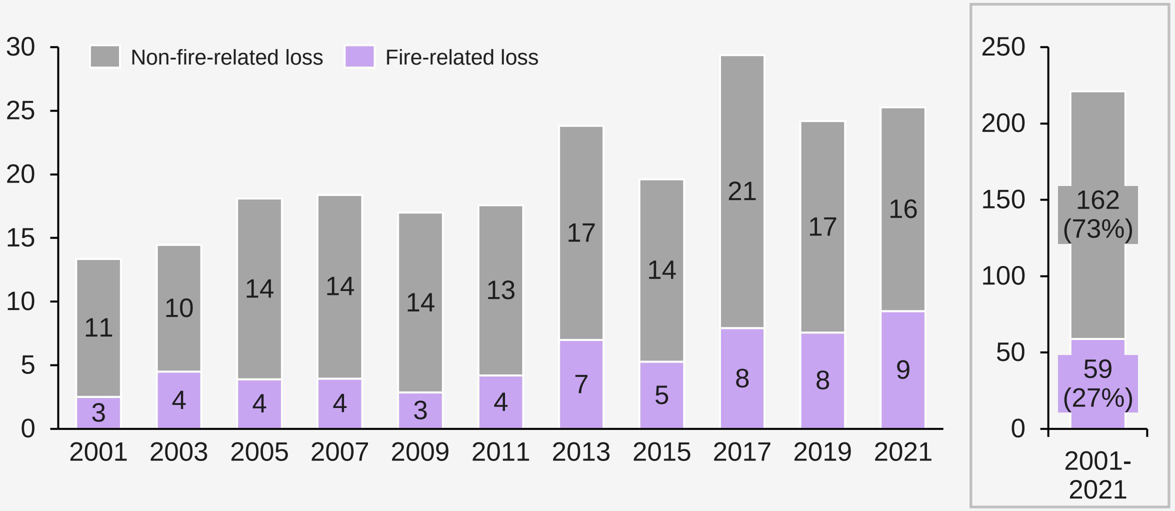
1. Indirect emissions: formation of GHG from precursor gases such as NH_4^+ and NO_3^- from combustion gases deposition of biomass burning.

Sources: IPCC, FAO, Global Forest Watch, "Wildfires destroy almost all forest carbon offsets in 100-year reserve, study says" from Financial Times, 05 August 2022; Kearney Energy Transition Institute Analysis

Forest fires are becoming more widespread, accounting for about a quarter of forest loss over the past two decades

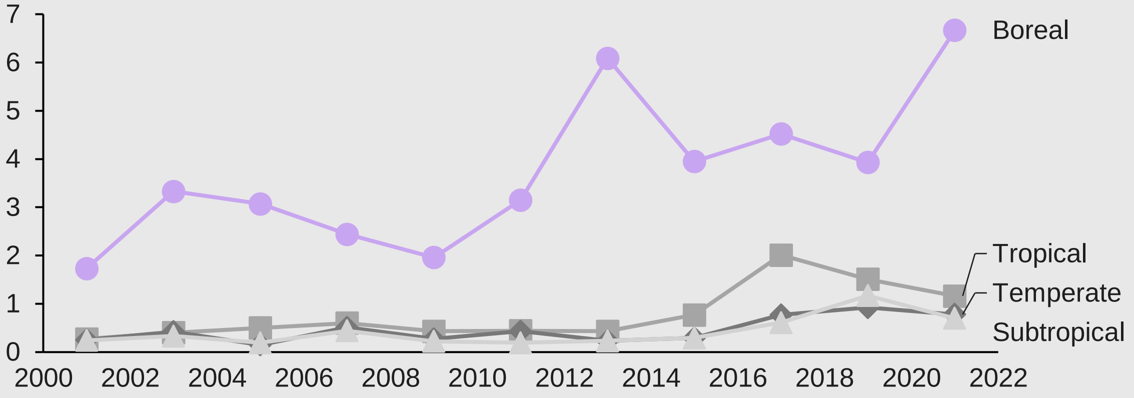
The large majority—roughly 70%—of all fire-related tree cover loss over the past two decades occurred in boreal regions.

Tree cover loss due to fires compared to other drivers of loss
Millions Hectares, 2001–2021



- 2021 was one of the worst years for forest fires since 2000, causing ~9.3 million hectares of tree cover loss globally which accounts for more than a third of all tree cover loss that occurred during the year.
- Fires have accounted for more than a quarter of all tree cover loss over the past 20 years.

Annual tree cover loss due to fires by climate domain
Millions Hectares, 2001–2021



Sources: Global Forest Watch (GFW), World Resources Institute; Kearney Energy Transition Institute analysis

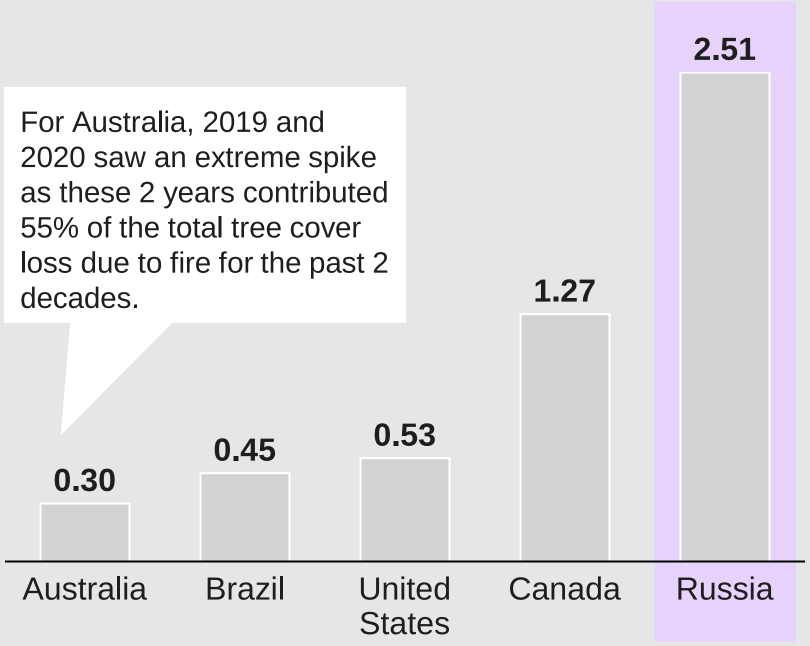
- Fire is a natural part of how boreal forests function ecologically. Fire-related tree cover loss increased by a rate of about 110,000 hectares (3%) per year over the past 20 years—about half the total global increase.
- Increasing fire-related tree cover loss in boreal forests is partially attributed to the fact that northern high-latitude regions are warming at a faster rate than the rest of the planet, contributing to longer fire seasons, greater fire frequency and severity, and larger burned areas in these regions.

Russia has the highest rate of tree cover loss due to fires over the past two decades

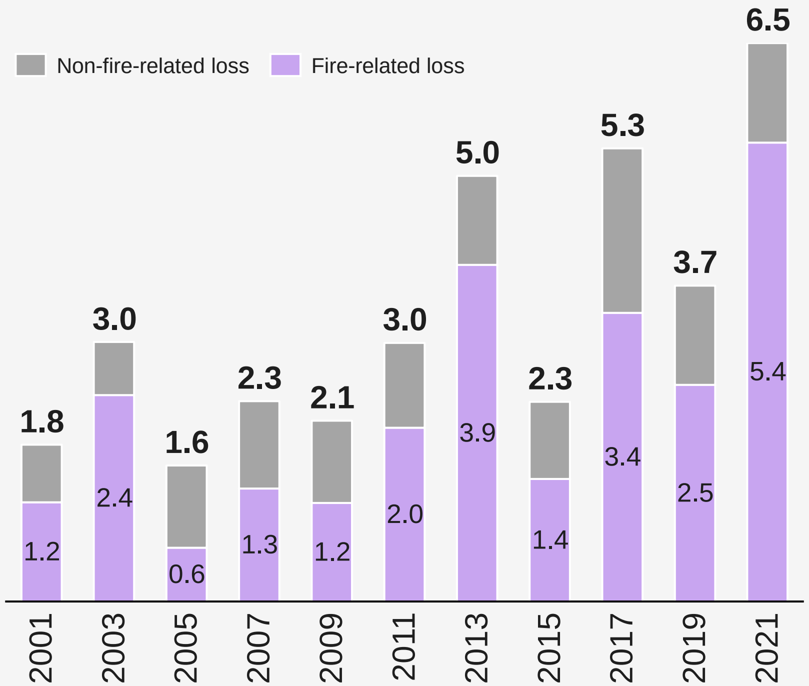
These forest fire dynamics, if left unaddressed, could eventually turn boreal forests from a carbon sink into a source of carbon emissions.

1.2 Focus on LULUCF GHG emissions

Worst 5 countries by tree cover loss rate due to fire
Million hectares per year, 2001–2021



Tree cover loss in Russia
Million hectares, 2001–2021



– In 2021, Russia, Canada, and the United States lost a combined 7.8 million hectares or 84% of all fire-related loss.
– In 2021, Russia experienced the largest area of tree cover loss the country has seen in this century, 82% of which was due to fires.

Sources: Global Forest Watch (GFW), World Resources Institute; Kearney Energy Transition Institute analysis

Wildfire severity has been increasing across all regions mainly due to impacts of climate change such as warmer temperatures and drought seasons

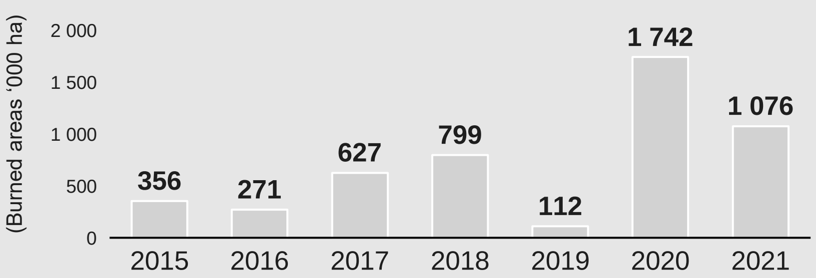
Case studies

Further rise in global temperature will increase frequency and severity of wildfires, releasing even more CO_2 into the atmosphere.

California

– Fires are a natural element in California; its ecosystems have evolved to burn frequently.
– Fire frequency has increased in recent years due to rising temperatures; longer and more intense droughts and drier vegetation

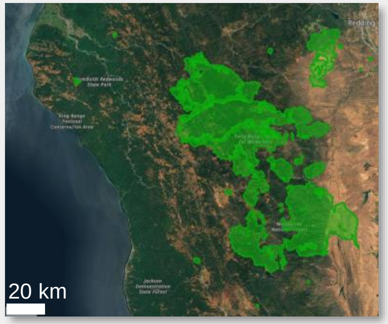
Number of fires, CO_2 emissions and burned area 2015–2021



	2015	2016	2017	2018	2019	2020	2021
# Fires	8,283	6,954	9,270	7,948	7,148	8,648	7,125
CO_2 (M ton)	19.2	10.5	31.3	39.1	4.8	106.7	85.1

Case study

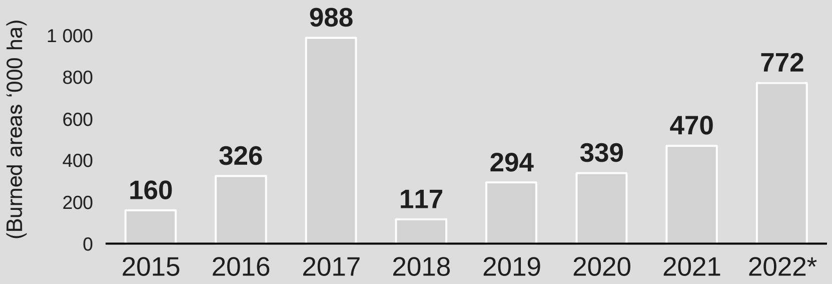
Name	August Complex
Date	Aug–Nov 2020
# of fires	37
Area	417,898 ha
Cause	Lightning strikes
Emissions	**27.7 M ton CO_2**



European Union

– Changes in the climate of European summer (heatwaves and prolonged dry conditions) resulted in increased wildfire activity and intensity.

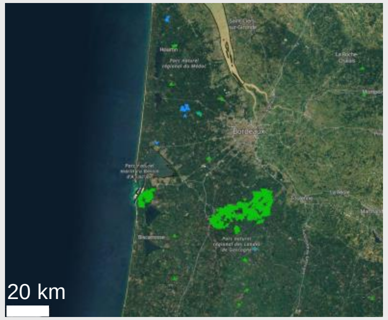
Number of fires, CO_2 emissions and burned area 2015–September 2022



	2015	2016	2017	2018	2019	2020	2021	2022*
# Fires	463	743	1,882	572	1,606	1,663	1,701	2,587
CO_2 (M ton)	4.2	5.6	11.4	3.8	4.0	3.7	7.5	-

Case study

Name	Gironde fires
Date	Jul–Aug 2022
Area	~28,200 ha
Evacuated	~46,750 people
Cause	Multiple
Emissions	**~1 M ton CO_2**



Sources: Cal Fire, California Air Resources Board; EFFIS; Kearney Energy Transition Institute analysis

1.2 Focus on LULUCF GHG emissions

The agriculture sector groups all sources related to crops cultivation and livestock production activities in managed land

Non-exhaustive

A1 Enteric fermentation

Methane is produced by microbial fermentation during animal digestion process.

A2 Manure left on pasture

N_2O is produced by microbial processes from manure left by grazing livestock taking place on the deposition site.

A3 Manure management

CH_4 and N_2O emissions are produced from decomposition of manure under low oxygen or anaerobic conditions.

A4 Manure applied to soils

N_2O is produced by microbial processes from manure added to agricultural soils as an organic fertilizer.

A5 Rice cultivation

Methane is produced by anaerobic decomposition during rice growth underwater.

A6 Synthetic fertilizers

Applied nitrogen, necessary to improve food production, is decomposed in soil and releases nitrous oxide (N_2O).

A7 Crop residues

N_2O is produced from nitrification of nitrogen in crop residues and forage/pasture renewal in agricultural fields.

A8 Residues burning

CO_2, CH_4, and N_2O are produced from the burning of materials left in fields after crops have been harvested or processed.

A9 Savanna fires

CO_2, CH_4, and N_2O gases are produced from the burning of biomass vegetation.

A10 Drained organic soils

Agriculture drains organic soils, releasing N_2O from oxidation of underlying organic matter.

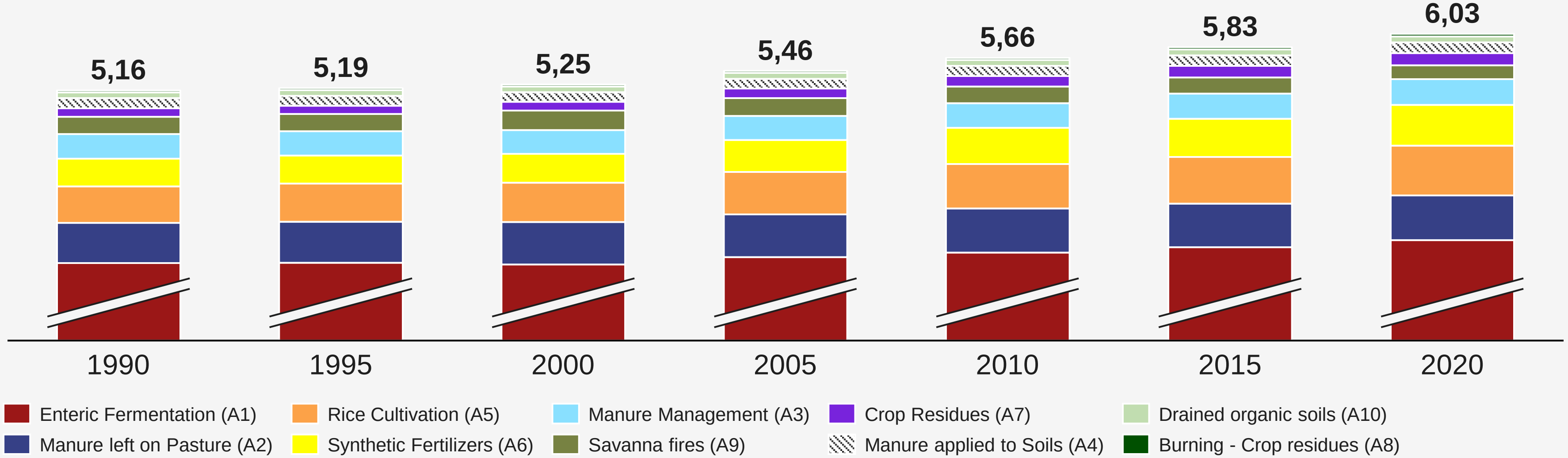
Enteric fermentation, manure practices, and rice cultivation are the major contributors to agriculture GHG emissions

Agriculture as a sector is responsible for non-CO_2 GHG emissions generated within the farm gate by crops and livestock activities.

1.3 Focus on agriculture GHG emissions

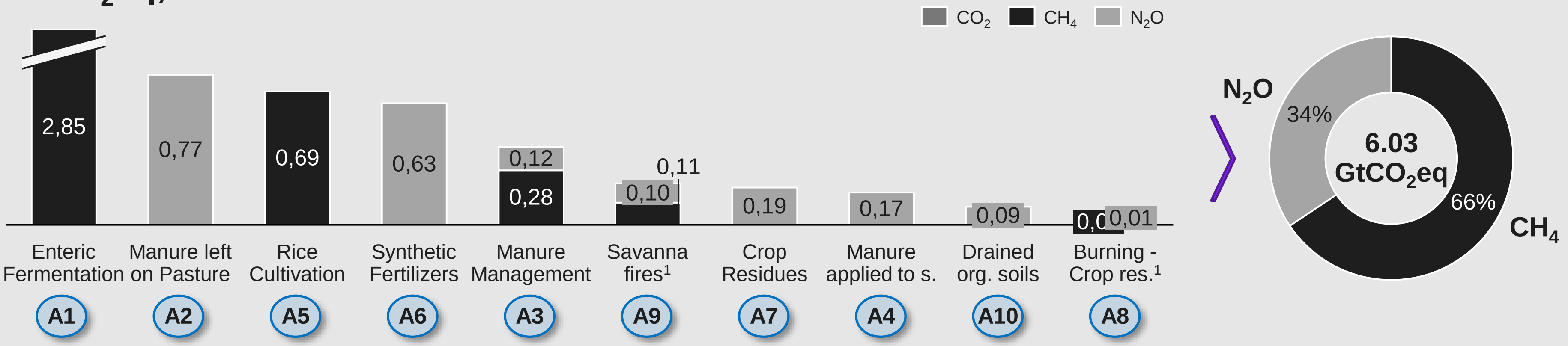
Agriculture global direct emissions trend

$GtCO_2eq$, 1990–2020



Direct emissions by GHG

$GtCO_2eq$, 2020



Note: Data retrieved from FAO, 2021. FAOSTAT Climate Change, Emissions, Emissions Totals (https://www.fao.org/faostat/en/#data/GT)
1. CO_2 emissions from this sources are assumed to be zero in inventories due to its recapture in regrowing vegetation in following agriculture cycles
Sources: FAO; Kearney Energy Transition Institute Analysis

Livestock produces 34% of GHG emissions and is the major emitter of CH_4 through methanogenesis

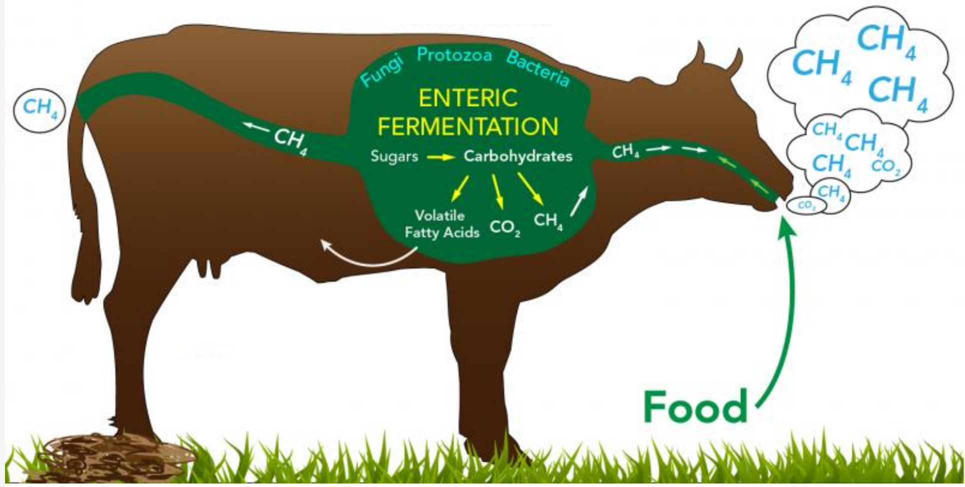
Due to the large population, cattle are the main source of GHG gas emissions associated to enteric fermentation with a total share of ~69%.

XX GHG source

1.3 Focus on agriculture GHG emissions

A1 Enteric fermentation GHG emissions origin

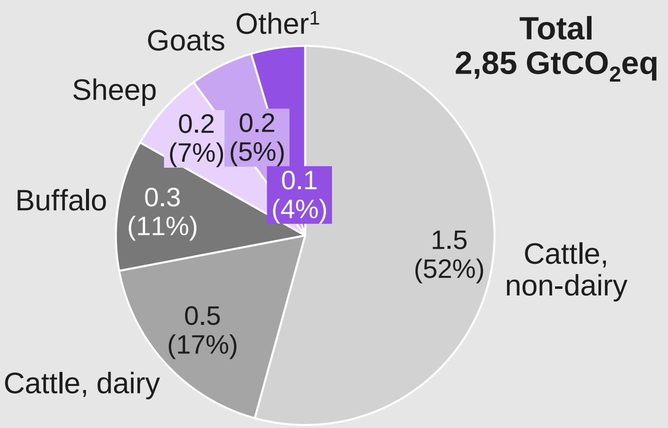
- Enteric fermentation is a natural part of the **digestive process** in ruminant livestock.
  - Fungi, protozoa, and bacteria broken down carbohydrates and **CH_4 is produced as a by-product.**
    - CH_4 production (methanogenesis) is a mechanism in ruminants to **dispose H_2,** which may inhibit carbohydrate fermentation and fiber degradation.
  - CO_2 is produced as well, but its emission is **assumed to be zero in inventories** since it re-enters in the carbon cycle of regrowing vegetation.
- Gaseous waste products (CH_4 and CO_2) are mainly **removed by eructation.**
- CH_4 emission main drivers are **feed quality and quantity, animal age and size**, and **ambient temperature.**



Methanogenesis: $CO_2 + 4H_2 \xrightarrow[\text{Archaea methanogens}]{} CH_4 + 2H_2O$

Global GHG emissions per key livestock type

$GtCO_2eq$, 2020



	Head count (M, 2020)	2020 vs. 2000 head count	kg CH_4/ head-year	kg CO_2eq/ head-year
Sheep	1,263.1	19%	5.5	154.7
Cattle, non-dairy	1,257.8	14%	43.8	1225.3
Goats	1,128.1	49%	5.0	140.0
Swine, market	857.4	6%	1.2	32.3
Cattle, dairy	268.1	22%	67.5	1888.8
Buffalo	203.5	24%	55.0	1540.0
Other	263.8	15%	14.6	407.8

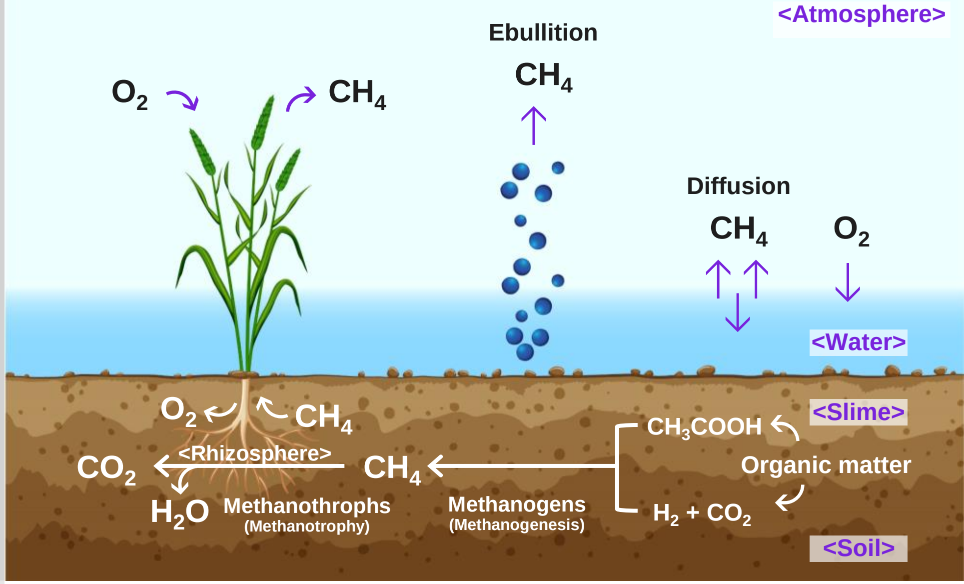
1. Other: camels, horses, swine, asses, llamas, mules, and hinnies
Sources: FAO; IPCC; Kearney Energy Transition Institute analysis

In rice cultivation methane emissions are produced from anaerobic decomposition of organic matter in flooded paddy fields

A5 Rice cultivation GHG emissions origin

- **Methane emissions (CH_4) come from organic matter decomposition** (mainly rice straw residue) under anaerobic conditions in flooded paddy rice.
- Methane is emitted through three main processes:
  - Diffusion across the water interface
  - Ebullition
  - Emissions through rice stems and leaves serving as conduits for methane contained in the ground

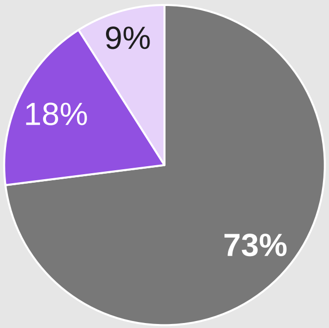
Transport through rice aerenchyma



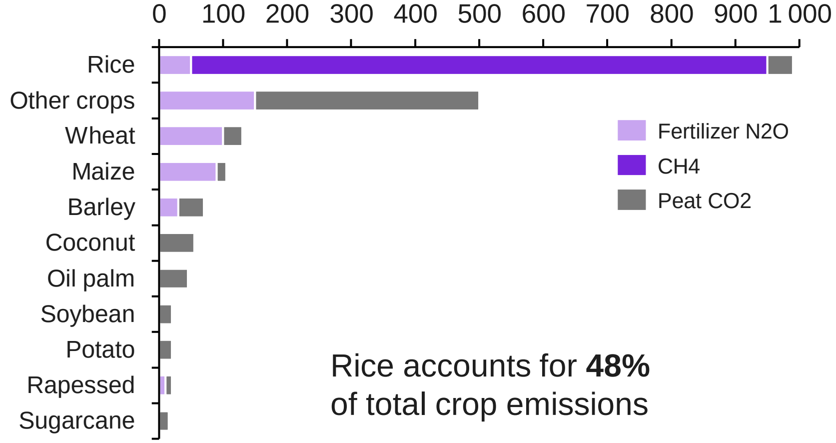
Main emissions drivers from rice cultivation

Emissions are mostly dependent on agricultural practices but also on water management practices, rice variety, harvest number and duration or soil quality, type, and temperature

Typical GHG emissions from rice cultivation[1]



Total crop emissions (Mton CO_2 eq/year)



Rice cultivation is the second biggest source of methane in agriculture GHG emissions.

XX **GHG source**

1.3 Focus on agriculture GHG emissions

1. Rice GHG emissions other than methane may be covered in inventories under other categories such as synthetic fertilizers, crop residues (burning and left on fields), in farm energy.

Sources: Hyo Suk et al., Research Revie of Methane Emissions from Korean Rice Paddies, 2022; Rahman M., Yamamoto A., Methane Cycling in Paddy Field: A Global Warming Issue, 2020; FAO, Rice Landscapes and Climate Change, 2018; Carlson et al., Greenhouse gas emissions intensity of global croplands, 2016; World Bank, Greening the rice we eat, 2022; Kearney Energy Transition Institute analysis

N_2O emissions in agriculture are mainly produced through nitrification and de-nitrification of the soil nitrogen added from crops and livestock practices

Emission drivers include:

- Soil temperature, fertility, pH
- Moisture
- Oxygen amount (O_2) in soil
- Wind conditions

XX **GHG source**

1.3 Focus on agriculture GHG emissions

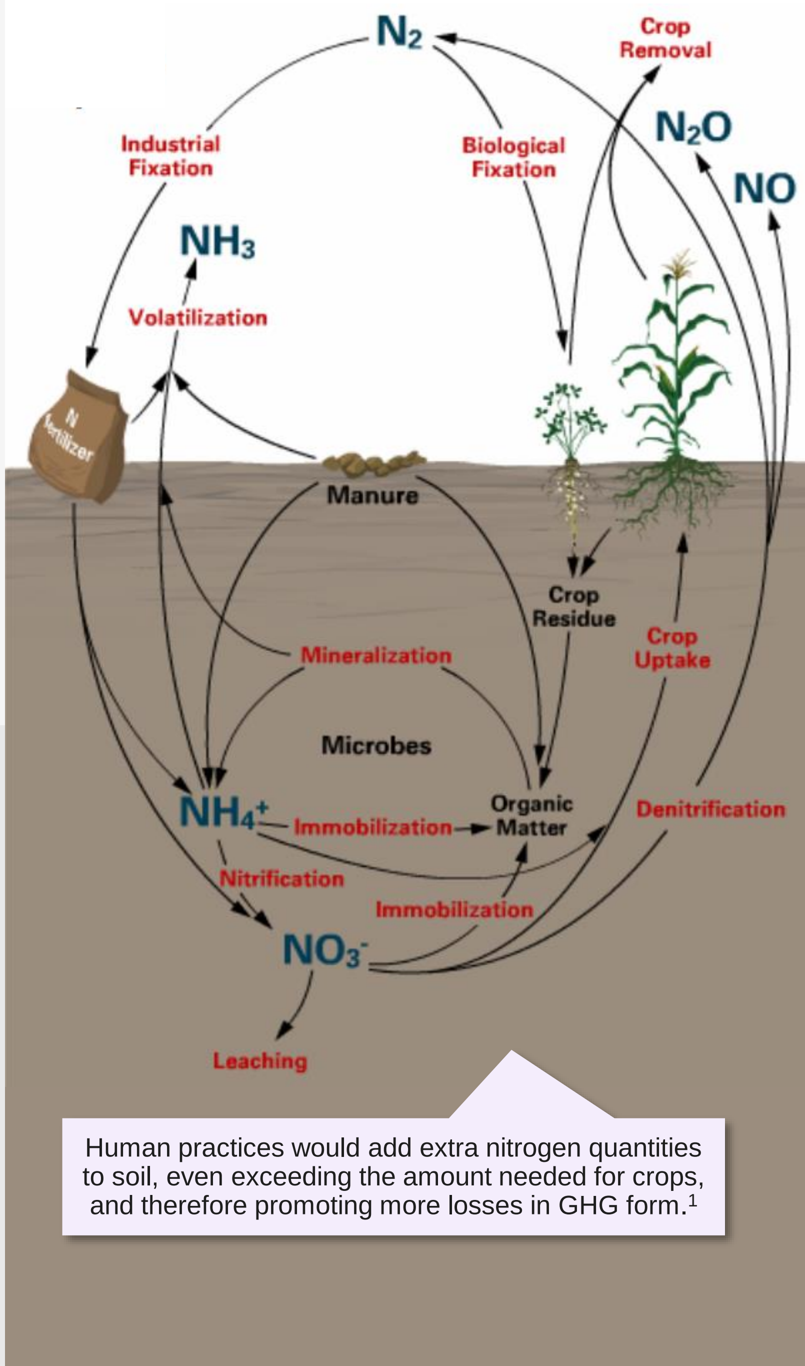
The nitrogen cycle in agriculture

- Nitrogen (N) is an **essential nutrient for development of plants.** Crops uptake N for root and vegetation growth.
- Processes of fixation, mineralization and nitrification **enhance N availability in soils**
  - **Fixation:** Atmospheric N conversion to a plant available form
  - **Mineralization:** Organic N decomposition by microbes
  - **Nitrification:** Ammonium (NH_4^+) conversion to nitrate (NO_3^+)
- Denitrification, volatilization, immobilization, and leaching will result in **permanent or temporary N losses**
  - **Denitrification:** Nitrate (NO_3^+) conversion to gaseous forms of nitrogen (NO, N_2O or N_2)
  - **Volatilization:** Ammonium (NH_4^+) conversion to ammonia gas (NH_3)
  - **Immobilization:** Nitrate and ammonium uptake by soil microorganisms, temporally locking N until organisms' death
  - **Leaching:** Nitrate move with water flows since it is not well retained by soil as both are negatively charged

Agriculture N_2O emission sources

	N source	Emission	Processes involved
Manure practices A2 A3 A4	N in manure from livestock	Direct	Nitrification denitrification
		Indirect	Volatilization
Synthetic fertilizers A6	Atmosphere N	Direct	Industrial fixation + denitrification
		Indirect	Volatilization / leaching / denitrification
Crop residues A7	N in residues organic matter	Direct	Mineralization + nitrification + denitrification
		Indirect	Leaching / denitrification
Drained organic soils A10	N in soil organic matter	Direct	Mineralization + nitrification + denitrification
		Indirect	Denitrification

1. GHG are considered permanent nitrogen (N) losses from soil.
Sources: FAO IPCC; Kearney Energy Transition Institute analysis



Human practices would add extra nitrogen quantities to soil, even exceeding the amount needed for crops, and therefore promoting more losses in GHG form.[1]

Food systems and value chains have the potential to reduce greenhouse gas emissions

Food systems

Food systems correspond to the stakeholders and added-value activities that are along the value chain, which includes production, aggregation, processing, distribution, consumption, and disposal. Sustainable food systems are defined as those systems including the delivery of food security and nutrition through economic, social, and environmental sustainability.

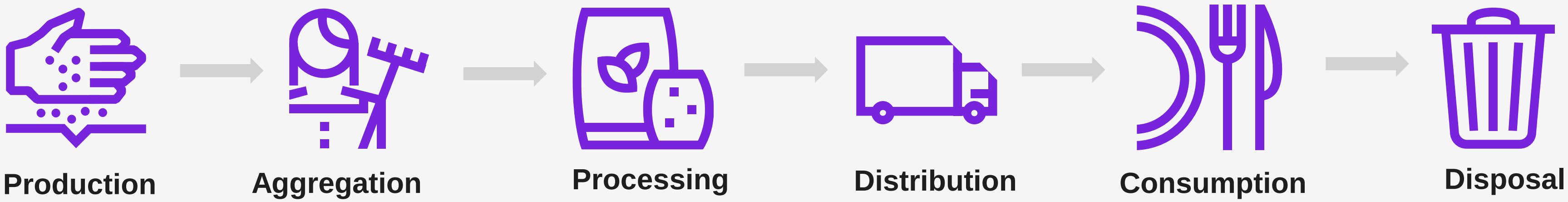
The food system has the potential to reduce emissions and contribute to food system resilience. To expand this potential, activities with the capacity to sequester carbon and reduce emissions in agriculture and modify behavior around food and wood consumption on the demand side are key.

The potential of emissions reductions is dependent on the specificity of measures and countries. Reducing food loss and waste and shifting diets could decrease emissions by 1.8 $GtCO_2eq$ per year.

Solutions for food systems emissions reduction

Solutions	Countries with highest potential
Shifting diets	US, EU, China, Brazil, Argentina, and Russia
Reducing food waste	North America, China, EU, and most emerging economies

Mitigation options in food systems vary greatly from one region to the other based on multiple drivers, including eating habits, food preferences and production systems, urbanization, and infrastructure extent.

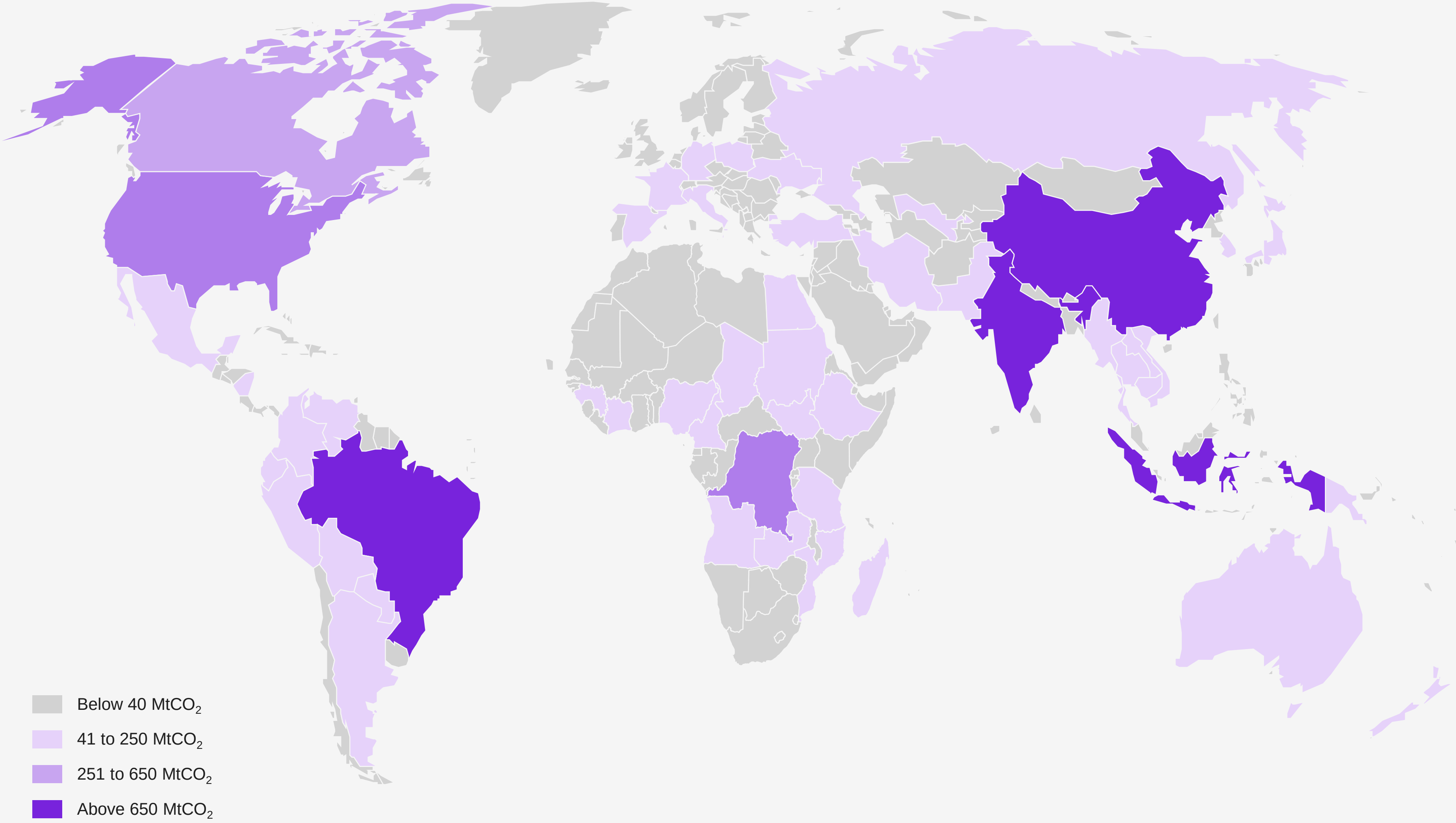


Sources: WWF (2020), Enhancing NDCs for Food Systems Recommendations for decision-makers; Kearney Energy Transition Institute analysis

Great disparities exist between food systems emissions worldwide

Total food system CO_2 emissions by country

Mt CO_2/year



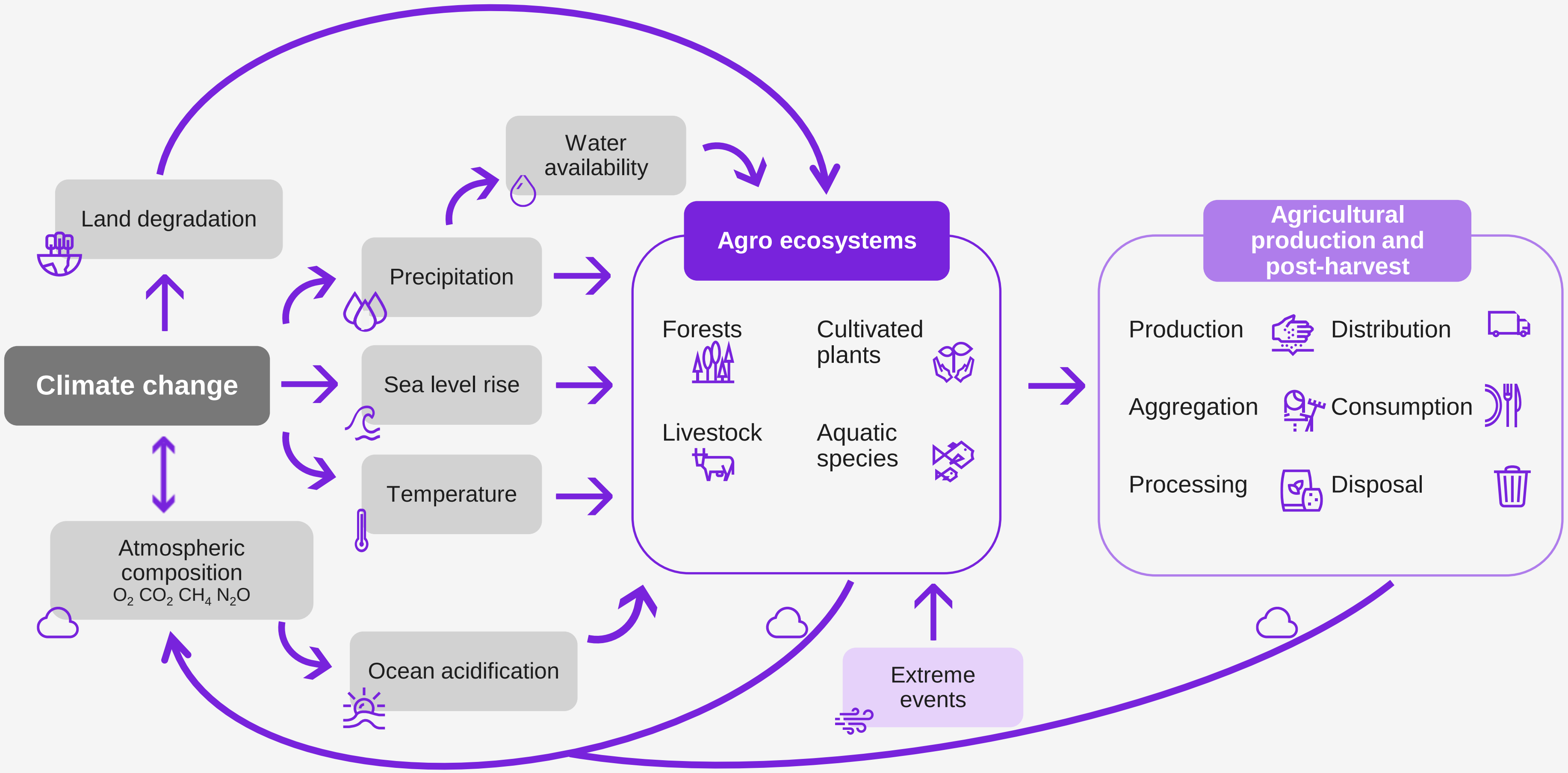
Note: CO_2 emissions from food systems include cropland, livestock, deforestation, and food loss and waste.
Sources: WWF (2020), Enhancing NDCs for Food Systems Recommendations for decision-makers; Kearney analysis

1.3 Focus on agriculture GHG emissions

Food systems are affecting and being affected by climate change

1.3 Focus on agriculture GHG emissions

Interactions between food systems and climate change



The complex interaction between agriculture food systems and climate change impacts food security and nutrition by affecting price and commodity quantity and quality, which in turn is reflected in food availability, access, utilization, and stability.

Sources: FAO (2015), Climate change and food security: risks and responses; Kearney Energy Transition Institute analysis

GHG emissions across the food products value chain are concentrated in the upstream segment

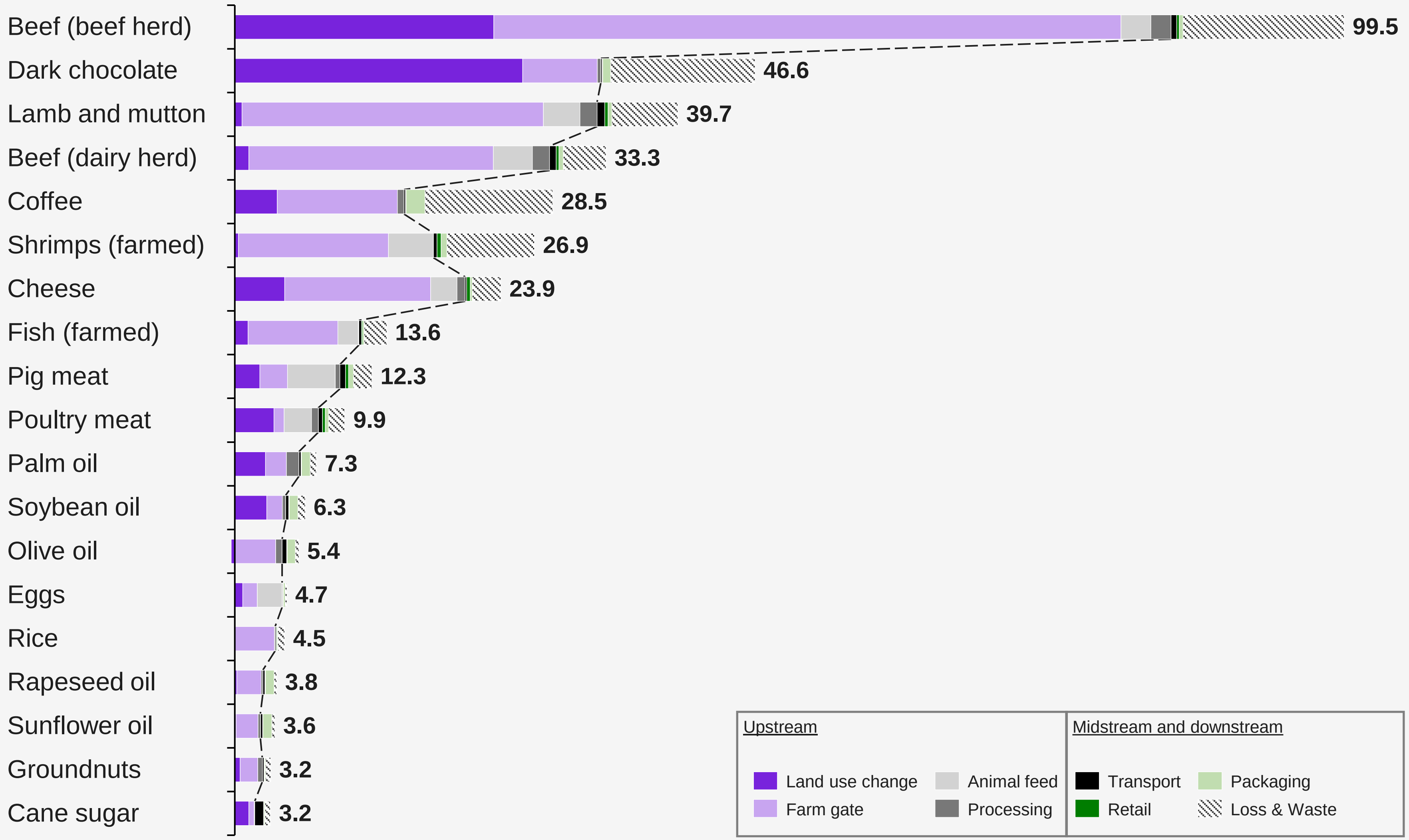
Non-exhaustive

Livestock ruminants related food products have the highest GHG intensity among all largely due to the enteric fermentation process and manure practices.

1.3 Focus on agriculture GHG emissions

GHG of food products per source in the value chain

Kg CO_2eq/kg of food, 2018, Our World in Data



Note: Data retrieved from Our World in Data site, which is based on an article from Science journal (Vol 360, Issue 6392, pp. 987-992).
Sources: Our World in Data; Kearney Energy Transition Institute analysis

Impact assessment of AFOLU requires great effort to understand complex systems, high uncertainties, and closing knowledge gaps

Non-exhaustive

1.4 Uncertainties and challenges of AFOLU emissions

Approaches for GHG inventories estimates

– There are many processes leading to emissions and removals of GHG, which can be **widely dispersed in space and highly variable in time.**

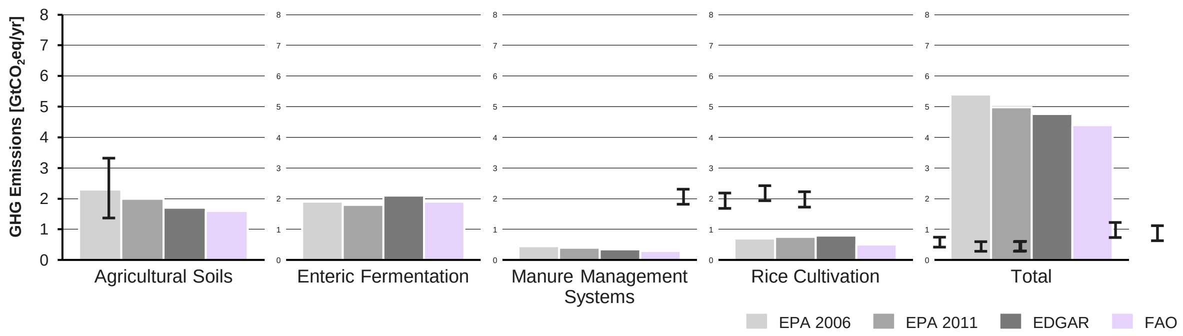
– A better understanding of AFOLU GHG flows requires **monitoring complex variables**. IPCC presents a 3-tier approach for GHG inventories estimation.

	Tier 1	Tier 2	Tier 3
Description	– Use of equations and default parameters	– Use of equations and country-based parameters	– Use of modeling and measurement systems (onsite, geographic)
Data examples	– Default emission and stock change factors – Country activity data from open sources (for example, FAO)	– Country/region emission and stock change factors – Activity data with high temporal and spatial resolution	– Repeated field sampling of specific data of age such as class/production data, soils data, and land-use and management activity data

– Accuracy, complexity, and resources +

GHG uncertainty

Estimations of total amount of GHG emissions from AFOLU **vary depending on the source and present high uncertainties** (over 30% in some cases).



Sources: FAO, IPCC; Kearney Energy Transition Institute analysis

Improvement guidelines for GHG assessment

- Improve global **high-resolution data sets** of
  - Crop production systems
  - Grazing areas
  - Freshwater fisheries and aquaculture
- **Standardize and homogenize** data on soils and forests degradation. Better understand the effects of degradation on carbon balances.
- Better understand the effect of changes in climate parameters, rising CO_2 concentrations, and N deposition on **productivity and carbon stocks** of different types of ecosystems.

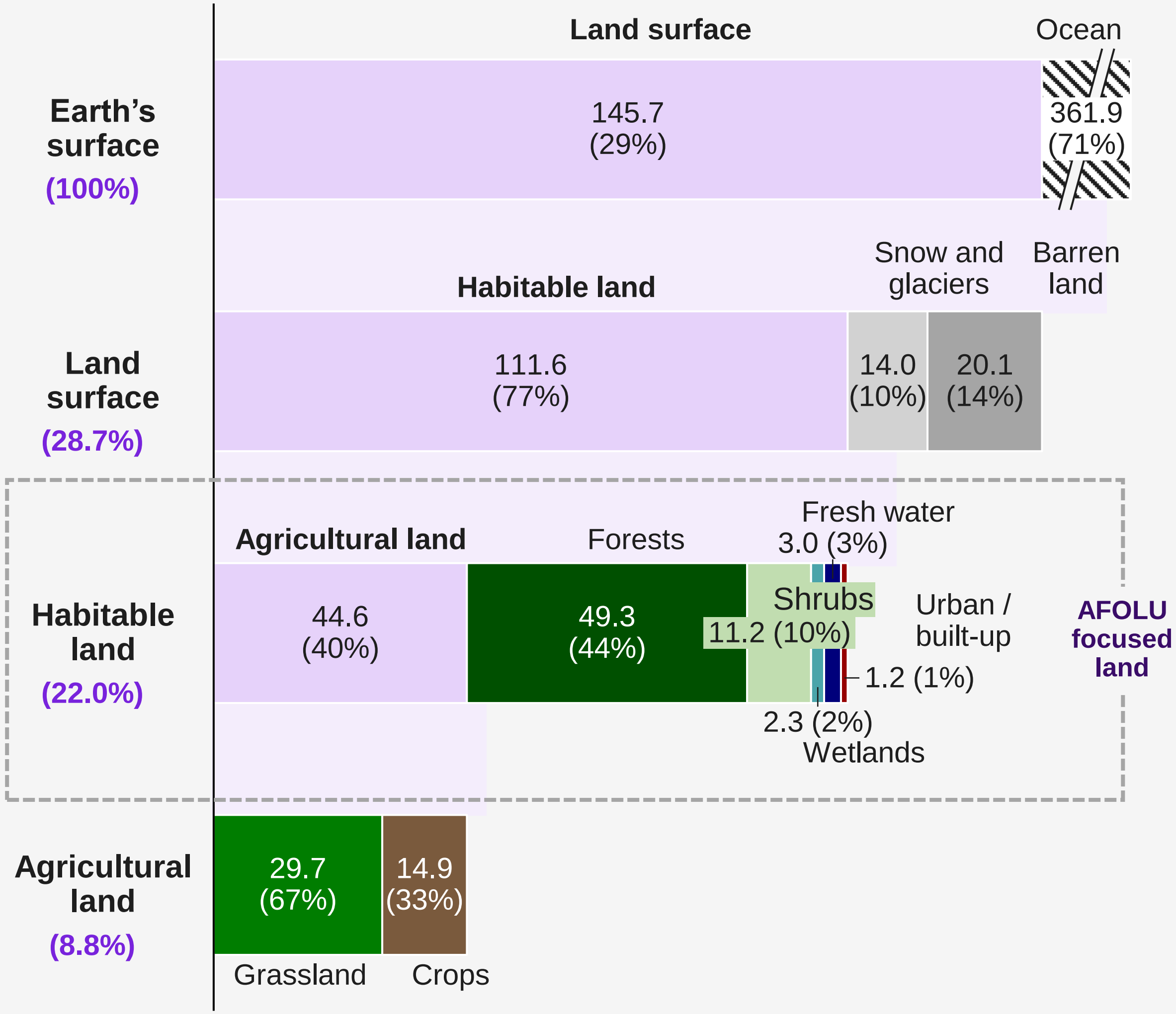
Land is the critical resource for the AFOLU sector, which is limited to the habitable land representing just 22% of the total Earth surface

Driven by increased demand for food as well as land demand for conservation and urbanization, competition for land is expected to intensify.

1.4 Uncertainties and challenges of AFOLU emissions

Global land coverage

Million km², 2019



(XX%) Share in total Earth's surface

Note: Data retrieved from FAO, 2020. FAOSTAT Land, Inputs and Sustainability, Land Cover (fao.org/faostat/en/#data/LC) Copernicus Global Land Service (CGLS) source
Sources: FAO, IPCC; Kearney Energy Transition Institute analysis

Land definitions

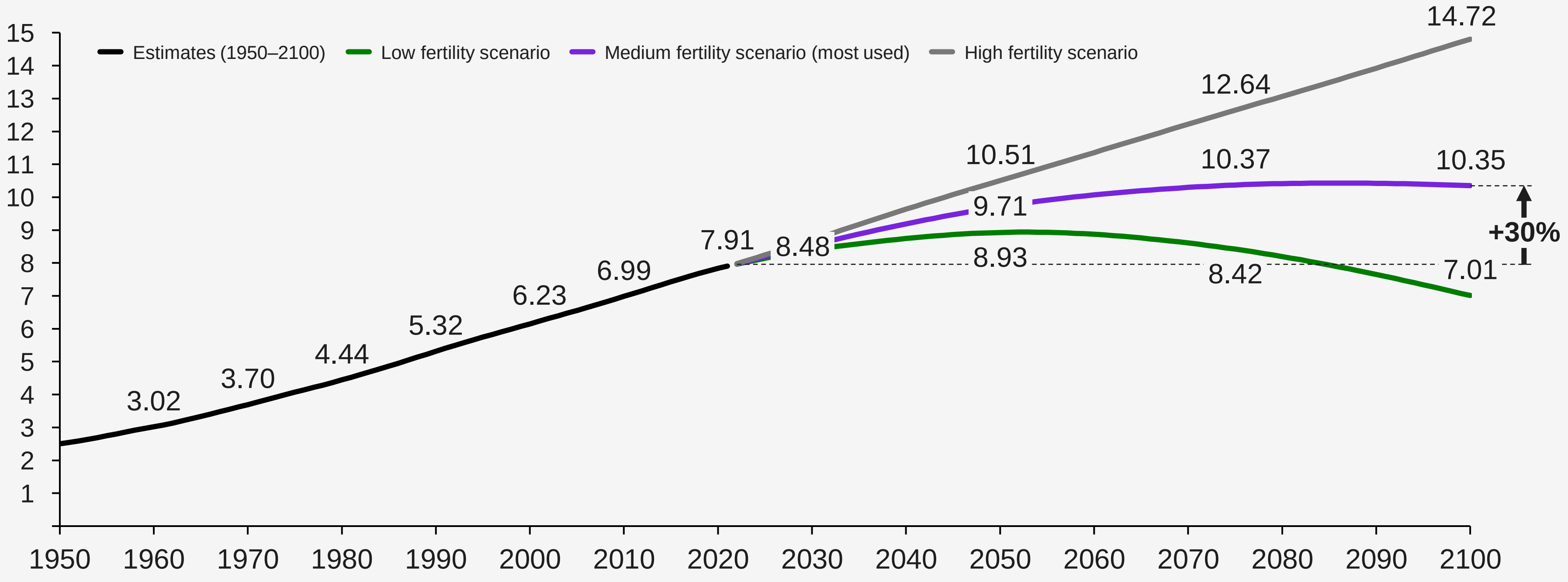
- **Snow and glaciers:** snow or glaciers persistently for 10 months or more
- **Barren land:** natural abiotic surfaces (bare soil, sand, rocks, among others) where the natural vegetation is absent or nearly absent (<2 %)
- **Forest:** natural tree plants with areas planted with trees for afforestation purposes and forest plantations included
- **Shrubs:** natural shrubs having a cover of 10% or more
- **Wetlands:** natural herbaceous vegetation, aquatic or regularly flooded by fresh or brackish water (swamps, marshes, and others)
- **Urban / built-up:** predominant artificial surface. Urban or related feature, industrial areas, waste dump deposit, and extraction sites
- **Grassland:** natural herbaceous plants (grasslands, prairies, steppes, and savannahs) irrespective of different human and/or animal activities
- **Crops:** cultivated herbaceous plants (graminoids or forbs; herbaceous crops used for hay; non-perennial crops that do not last for more than two growing seasons

The projected increase of the global population, at least until 2050, is increasing the pressure on AFOLU

Non-exhaustive

World population prospects

Billion persons, 1950–2100



Challenges for AFOLU

- The evolution of the global population will have a direct impact on the food demand and land use, and therefore on the overall GHG impact of AFOLU.
- Greenhouse gas emissions from the AFOLU sector are driven by both economic and population growth as it will represent an increase in demand for food (both from crops and livestock), bioenergy, land demand for urbanization, and other land-use needs (livelihoods, recreation, tourism, spiritual, and others).
- All United Nations "world population scenarios" project an increase of the global population for the next ~30 years.

Sources: United Nations - Population Division (2022), IPCC; Kearney Energy Transition Institute analysis

Measures to reduce AFOLU GHG emissions are influenced by complex interactions and interdependencies between socioeconomic and natural-induced factors

Non-exhaustive

Land-use competition

- Many mitigation activities in the AFOLU sector affect land use or land cover, influencing (or conflicting with) development objectives of other sectors.
  - Socioeconomic: increased demand for food and bioenergy (expansion of agricultural land), land demand for urbanization, land use rights for social groups (for example, indigenous peoples)
  - Ecological: land demand for biodiversity conservation, water availability, soil quality conservation

Land demand changes feedbacks

- Mitigation options may result in feedbacks such as GHG emissions from land use expansion or agricultural intensification.
  - Afforestation and reforestation may increase agricultural production costs and food prices due to agricultural expansion restrictions.
  - Food supply then needs to be managed with higher yields of food crops and livestock (intensification) or production displacement to other regions (land clearing).

Management challenges

Climate change feedback

- AFOLU activities affect GHG fluxes to and from the atmosphere, which can either reduce or accelerate climate change.
- Climate change reduces mitigation potential of GHG solutions in AFOLU.
  - Rising temperatures, drought, and fires may lead to forests becoming weaker sinks or net carbon sources.
  - CO_2 losses from peatlands are more likely due to droughts and deep burning fires.

Synergies and trade-offs

- Mitigation from ecosystem degradation may yield co-benefits for adaptation by maintaining biodiversity (synergy).
- Plantations (often mono-species stand) that reduce biological diversity may diminish adaptive capacity to climate change (trade-off).
  - Minimizing trade-offs required integrates approaches to meet multiple objectives (for example, adaptive capacity, food security, livelihoods).

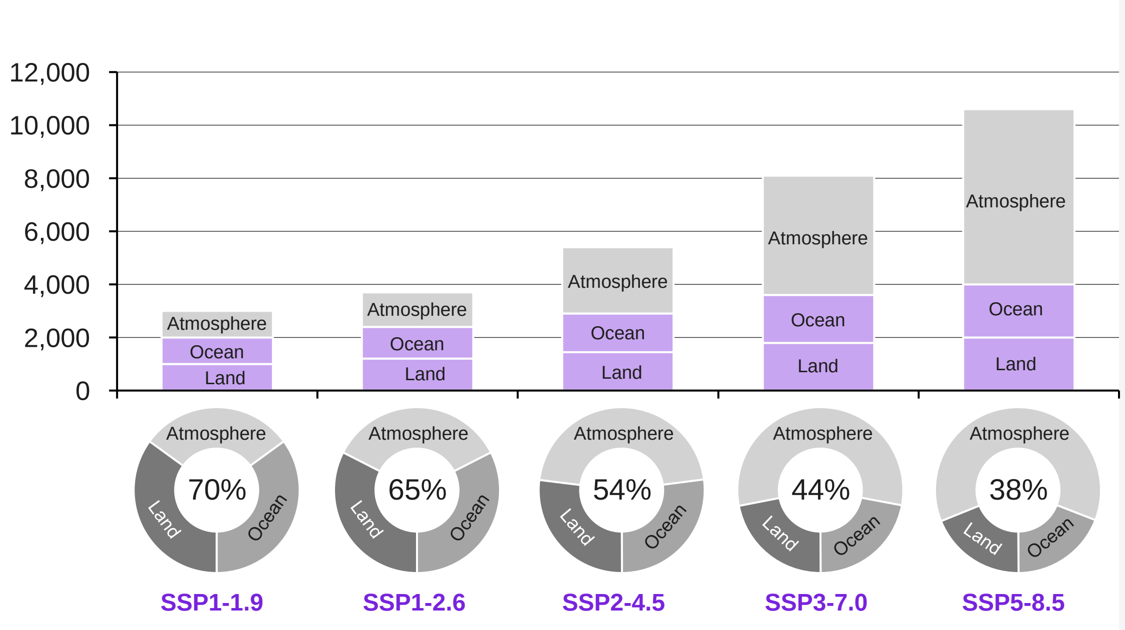
Sources: IPCC – Fifth Assessment Report (AR5): Chapter 11 - Agriculture, Forestry and Other Land Use (AFOLU); Kearney Energy Transition Institute analysis

Unabated emissions and climate change feedback loops threaten the balance of both land and ocean sinks

The magnitude of feedback between climate change and the carbon cycle becomes **larger** but also more **uncertain** in high CO_2 emissions scenarios.

1.4 Uncertainties and challenges of AFOLU emissions

Cumulative anthropogenic CO_2 emissions taken up by land and ocean sinks, 1850–2100[1] (in $GtCO_2$)



– During the historical period (1850–2019) the observed land and ocean sink took up 1,430 $GtCO_2$ (59% of the emissions).

– In higher emission scenarios, the proportion of CO_2 emissions taken up by land and ocean carbon sinks from the atmosphere is smaller despite the continuation of expansion in sink capacities. This implies impaired ability to counteract on atmospheric emission flux.

Beyond 2100

– Land and ocean may transition from being a carbon sink to a source under either very high emissions or net negative emissions scenarios, but for different reasons.

Sinks' responses to warming

– Ocean carbon processes are starting to change in response to the growing ocean sink, and these changes are expected to contribute significantly to future weakening of the ocean sink.

– There will be increased land carbon storage through CO_2 fertilization of photosynthesis and increased water use efficiency

  – However, the overall change in land carbon also depends on land-use change and on the response of vegetation and soil to continued warming and changes in the water cycle.

– The net response of natural CH_4 and N_2O sources to future warming will be increased emissions.

  – Increased CH_4 emissions from wetlands and permafrost thaw

  – Increased soil N_2O emissions in a warmer climate

1. Five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) are simulated from 1850 to 2100 by Coupled Model Intercomparison Project Phase 6 (CMIP6) climate models in the concentration-driven simulations. Land and ocean carbon sinks respond to past, current, and future emissions; therefore, cumulative sinks from 1850 to 2100 are presented here.

Sources: IPCC AR6 (Working Group I, Climate Change 2021: The Physical Science Basis; Working Group II, Climate Change 2022: Impacts, Adaptation and Vulnerability; Working Group III, Climate Change 2022: Mitigation of Climate Change), Kearney Energy Transition Institute analysis

Land's ability to support key functions, including emission mitigation efforts, can be adversely impacted by the feedback loops

Projected climate change, combined with non-climatic drivers, will cause loss and degradation of much of the world's **forests, coral reefs, and low-lying coastal wetlands.**

1.4 Uncertainties and challenges of AFOLU emissions

Observed impacts on emission mitigation

From emission sinks to sources:

- Deforestation, draining, burning or drying of peatlands, and thawing of Arctic permafrost, due to climate change, has already shifted some areas of these ecosystems from carbon sinks to carbon sources.

Loss of carbon sequestration potential:

- Regional increases in the area burned by wildfire (up to double natural levels)
- Drought-induced tree mortality of up to 20%
- Biome shifts of up to 20 km latitudinally and 300 m up-slope tropical, temperate, and boreal ecosystems around the world

Damaged ecological integrity:

- Climate change has degraded the survival of vegetation, habitat for biodiversity, water supplies, and other key aspects of the ecosystems.
- The interaction between fires, land-use change, particularly deforestation, and climate change, is directly impacting forest structure and balance.

Impact on species and biological diversity

- The loss of specialized ecosystems where warming has reduced thermal habitat, as at the poles, at the tops of mountains, and at the equator, results in the hottest ecosystems becoming intolerable for many species.
- Observed responses of species to climate change have altered biodiversity and impacted ecosystem structure and resilience in most regions.

Impact on human health, livelihoods, and well-being

- Climate change is stressing food and forestry systems, with negative consequences for the livelihoods, food security, and nutrition of hundreds of millions of people, especially in low and mid-latitudes.
- Droughts, floods, wildfires, and marine heatwaves contribute to reduced food availability and increased food prices, threatening food security, nutrition, and livelihoods.

Sources: IPCC AR6 (Working Group I, Climate Change 2021: The Physical Science Basis; Working Group II, Climate Change 2022: Impacts, Adaptation and Vulnerability; Working Group III, Climate Change 2022: Mitigation of Climate Change); Kearney Energy Transition Institute analysis

GHG emissions from unmanaged natural ecosystems (Wetlands and Uplands) are not considered in the scope of AFOLU emissions

Non-anthropogenic emissions from unmanaged wetlands and uplands are considered carbon-neutral on the long-term, as they are part of the natural carbon cycle

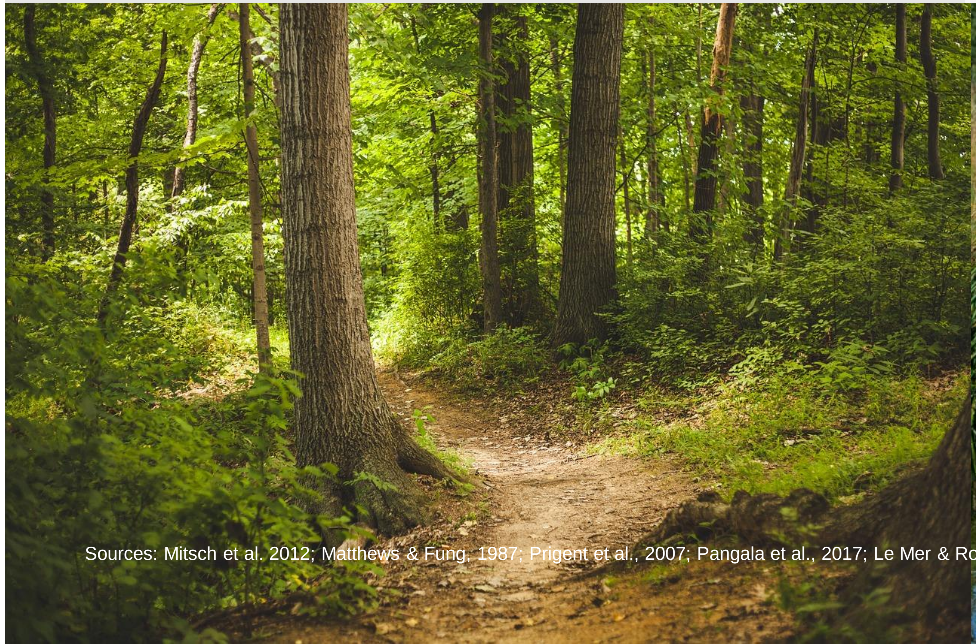
1.5 Non-anthropogenic GHG emissions of natural ecosystems

Uplands

- Uplands ecosystems include **forests, bushlands, tundra, grasslands and desserts**
  - Forests cover about ~31% of the world's total land surface with 46 M km^2. Unmanaged forests account for ~27% of total forest cover
- Upland ecosystems on freely drained soils are **recognized as CH_4 sinks** in global budgets and have been the focus of studies on CH_4 consumption by soils
- Trees and vegetation store carbon from **photosynthesis** and release it through **respiration and decomposition** during natural degradation and death

Wetlands

- Wetlands ecosystems include **marshes, swamps and peatlands**
  - Wetlands cover ~5% of the world's total land surface
  - Forested wetlands are about 60% of total global wetland areas.
- Wetland ecosystems are the **largest natural source of CH_4** globally (20–25% of global methane emissions from **underwater anaerobic decomposition** of organic matter)
- Vegetation stores carbon through **photosynthesis** and acid soil contribute to **peat formation** and long-term carbon storage.



Sources: Mitsch et al. 2012; Matthews & Fung, 1987; Prigent et al., 2007; Pangala et al., 2017; Le Mer & Roger, 2001; Saunois et al., 2016, Megonigal & Guenther, 2008; Kearney Energy Transition Institute

Uplands’ well-drained soil absorbs methane and growing vegetation sequestrates carbon dioxide

Forests are determined both by the presence of trees and the absence of other predominant land uses.

Land with a tree canopy cover of more than 10 percent and area of more than 0.5 hectares.

Tundra are vast, flat, and treeless and located in the Arctic region of Europe, Asia, and North America in which the subsoil is permanently frozen with discontinued vegetation.

Bushlands are dry or semi-humid land covered with shrubby vegetation and bushes.

Forests can be boreal, tropical, or temperate depending on their location.

Grasslands are land covered with grass or herbage and grazed by or suitable for grazing by livestock.

Deserts are arid land with usually sparse vegetation.

Sources: IUCN issues brief; Mitsch et al., 2013; US Environmental Protection Agency; Britannia; National Geographic; Kearney Energy Transition Institute analysis

1.5 Non-anthropogenic GHG emissions of natural ecosystems

Wetlands are characterized by vegetation growing on water-saturated soil, capturing carbon and emitting methane

Wetlands also provide many ecosystem services in addition to carbon sequestration, such as water quality improvement, flood mitigation, biodiversity reservoir, and coastal and storm protection.

1.5 Non-anthropogenic GHG emissions of natural ecosystems

Marshes

Wetlands are frequently or continually inundated with water (fresh or saline), characterized by emergent soft-stemmed vegetation adapted to saturated soil conditions.

– Tidal marshes can be found along a coastline.

– Non-tidal marshes occur along streams in poorly drained depressions and in the shallow water along the boundaries of lakes, ponds, and rivers.

Swamps

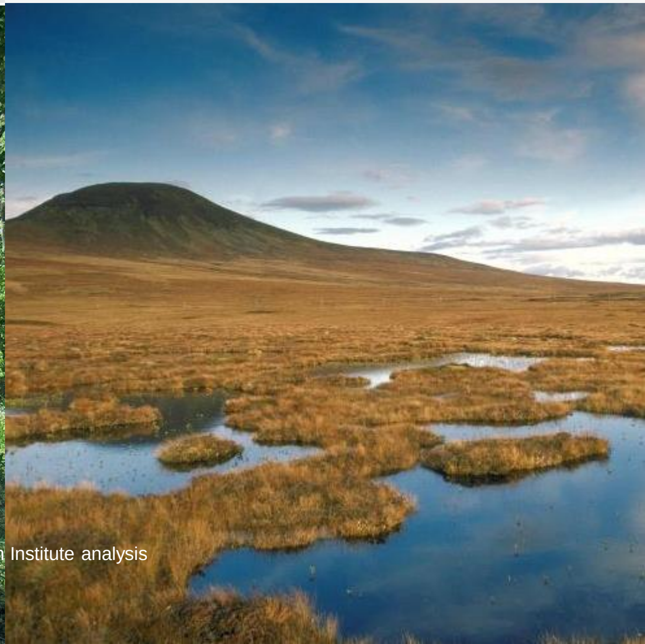
A swamp is any wetland dominated by woody plants.

– Forested swamps are often inundated with floodwater from nearby rivers and streams.

– Shrub swamps are similar to forested swamps except that they contain shrubby vegetation and bushes.

Peatlands

Peatlands are terrestrial wetland ecosystems in which waterlogged conditions prevent plant material from fully decomposing (bogs and fens). Consequently, the production of organic matter exceeds its decomposition, which results in a net accumulation of peat and sedimented carbon sequestration in soil.



Sources: IUCN issues brief; Mitsch et al., 2013; US Environmental Protection Agency; Britannia; National Geographic; Kearney Energy Transition Institute analysis

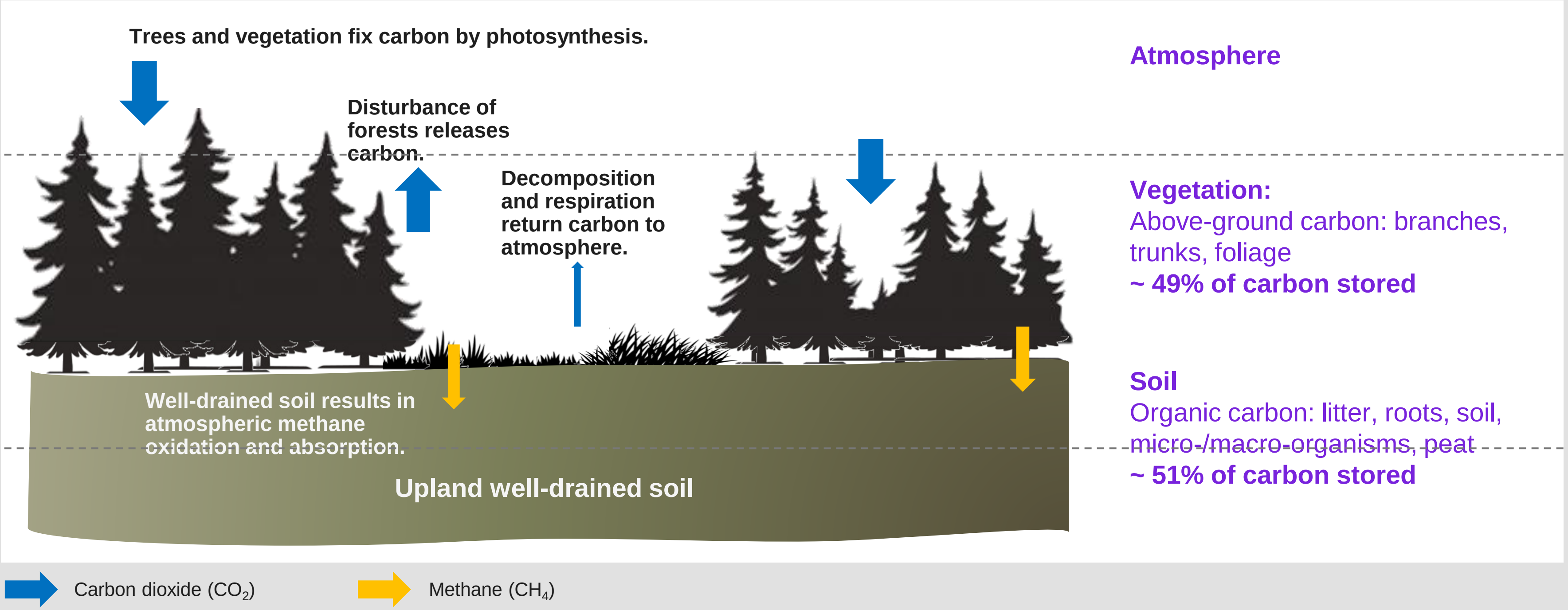
Upland forests and vegetation strengthen their carbon sink potential with additional soil absorption of methane

Uplands contribution to GHG fluxes

Upland forests and vegetation store carbon from the atmosphere by photosynthesis. This storage is temporary and conditioned by the forest management. In fact, burning or natural decomposition of the organic matter returns the stored carbon to the atmosphere.

Forests can be managed to maintain or enhance carbon storage by adjusting harvest frequency and intensity.

Additionally, well-drained soil contains methanotrophs, oxidizing methane into carbon dioxide under aerobic conditions and accounting for about 10% of the global methane sink.



Sources: Board of Water and Soil Resources; Whiting et al., 2016, Goudrian & al.; Topp & Pattey, 1997; Kearney Energy Transition Institute analysis

1.5 Non-anthropogenic GHG emissions of natural ecosystems

Upland terrestrial biosphere[1] absorb methane in their well-drained soil, which contributes to enhancing their carbon storage

Uplands and forests are radiative sinks. If we consider a shorter time horizon, such as 2050, sink capacity of uplands and forest will appear larger.

1.5 Non-anthropogenic GHG emissions of natural ecosystems

Uplands soil methane absorption combined with carbon sequestration

Methane absorption in drylands soil induces reinforced upland biosphere (such as conventional forests) carbon sink capacity.

– According to the Global Methane Budget, **soil yearly absorbs between 30 and 38 $TgCH_4$.**[2]

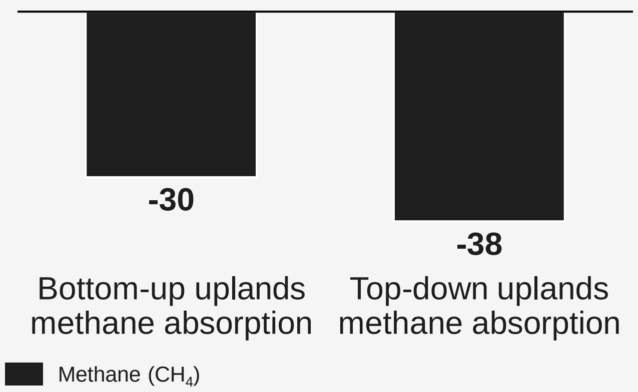
Sink capacity rise highly depends on the metric taken to compare methane and CO_2 global warming potential. Methane is a more potent GHG than CO_2 but has a shorter atmospheric lifespan.[3]

– The equivalence factor between methane and carbon dioxide is in the range of 20 to 80 gCO_2eq/gCH_4 (Balcombe & al. 2018), thus **soil methane absorption could represent between 0.8 and 3.2 Gt of CO_2eq per year.**

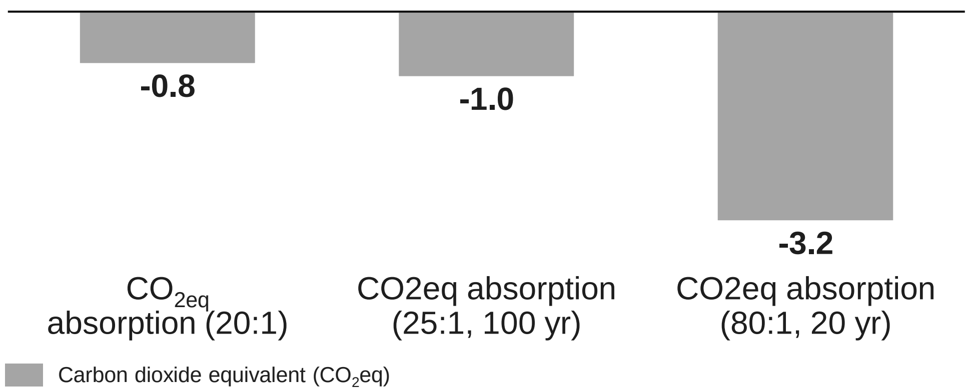
– According to Mitsch & al. 2012, considering the factor used by IPCC to compare methane and carbon dioxide (25:1 over 100 years) **soil methane absorption yearly represents about 1GtCO_2eq.**

The upland forests carbon sink potential is strengthened by methane absorption, due to oxidation of atmospheric methane into carbon dioxide by well-drained soils.

CH_4 uplands absorption
$TgCH_4$/year, global, 2008–2017



Top-down uplands CH_4 absorption converted into CO_2eq
$GtCO_2$eq/year, global, 2008–2017



1. Upland terrestrial biosphere covers non-water saturated lands and forests.
2. Top-down approach, average emission 2008–2017
3. Methane has a perturbation life of only 12.4 years, whereas CO_2 lasts in the atmosphere for much longer; 50% of an emission is removed from the atmosphere within 37 years, while 22% of the emission effectively remains indefinitely (Balcombe et al. 2018).

Sources: Global Carbon Budget; Global Methane Budget; Balcombe & al., 2018; Mitsch & al., 2012; Kearney Energy Transition Institute analysis

The impact of wetlands carbon storage is balanced with their CH_4 emissions

Wetlands are fragile ecosystems, and anthropogenic or climate disturbance of soil or hydrology disturb their carbon sink effect.

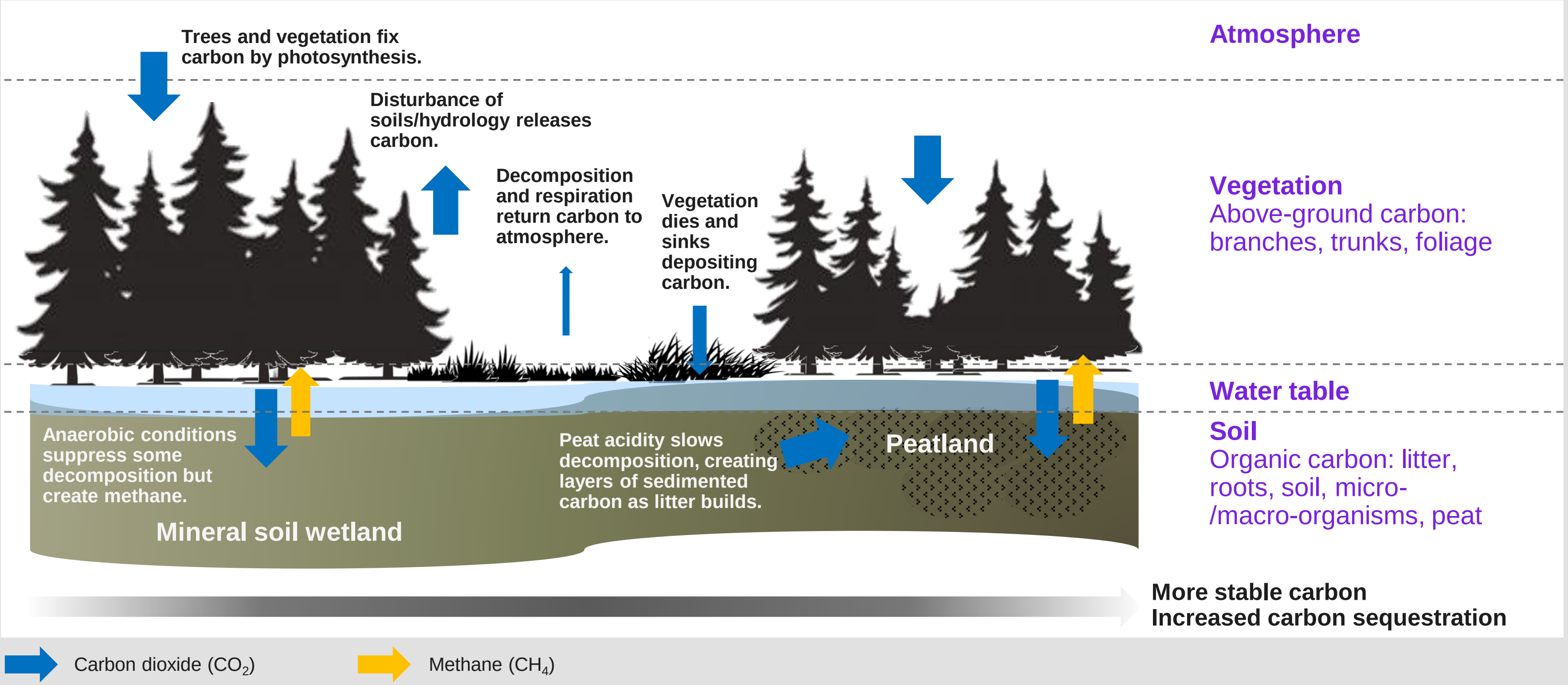
1.5 Non-anthropogenic GHG emissions of natural ecosystems

Wetlands contribution to GHG fluxes

Carbon fixation under wetland anaerobic soil conditions provides unique conditions for **long-term storage of carbon into soil**.

However, this carbon sequestration process is intimately linked to **methane emission from wetlands** produced by methanogens under anaerobic conditions.

The potential contribution of this emitted methane to the greenhouse effect can be mitigated **by the removal of atmospheric CO_2 and storage into peat**. The balance of CH_4 and CO_2 exchange can provide an index of a wetland's greenhouse gas (carbon) contribution to the atmosphere.



Sources: Board of Water and Soil Resources, Whiting et al., 2016; Kearney Energy Transition Institute analysis

Wetlands release methane through underwater anaerobic decomposition of organic matter

Most wetlands are carbon sinks but not necessarily radiative sinks. If we consider a shorter time horizon such as 2050, wetlands will appear as global radiative sources.

1.5 Non-anthropogenic GHG emissions of natural ecosystems

Wetlands' methane emissions balanced with carbon sequestration[1]

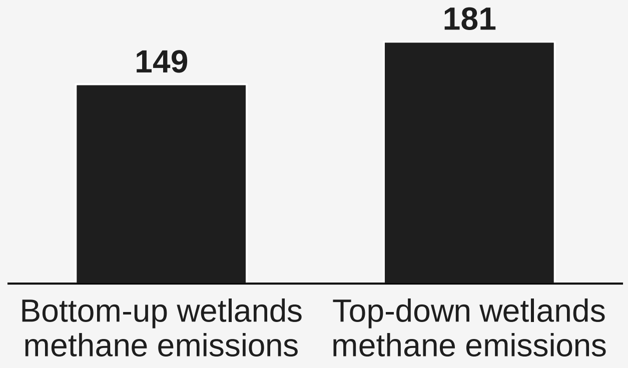
In saline water, fermentation is inhibited so wetlands do not emit CH_4.

Methane emissions from wetlands induce an antagonist effect, offsetting their carbon sink capacity.
- According to the Global Methane Budget, **wetlands yearly emit between 149 and 181 $TgCH_4$.**
- According to Mitsch et al. 2012, **wetlands yearly absorbs 1,280 Tg-C of carbon dioxide, which represents 4.7 Gt CO_2.**

Wetlands' sink capacity reduction highly depends on the metric taken to compare methane and CO_2 global warming potential. Methane is a more potent GHG than CO_2 but has a shorter atmospheric lifespan.[2]
- The equivalence factor between methane and carbon dioxide is in the range of 20 to 80 gCO_2 eq/gCH_4 (Balcombe & al. 2018), thus **biosphere methane emissions could represent between 3.6 and 14.4 Gt of CO_2 eq per year.**
- Considering the factor used by IPCC to compare methane and carbon dioxide (25:1 over 100 years) **wetlands' yearly methane emissions represent 4.5GtCO_2 eq.**

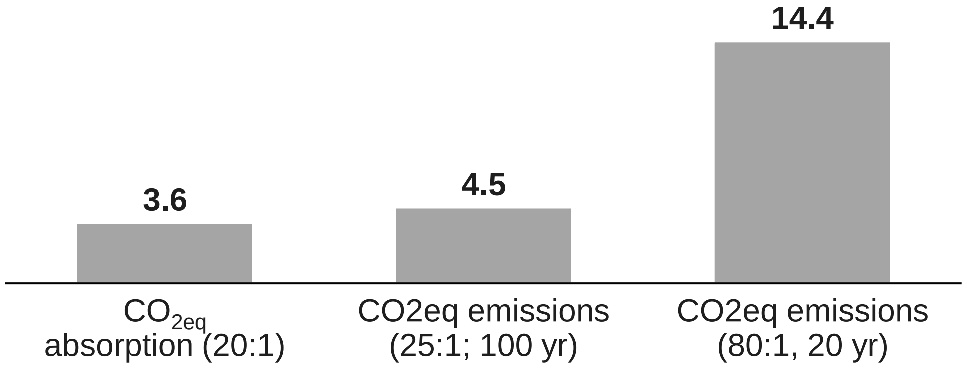
The wetlands' radiative sink potential is reduced by methane emissions, less if you consider a long-time scale and more if you consider a short one (<100 years).

CH_4 wetlands emissions
$TgCH_4$/year, global, 2008–2017



Methane (CH_4)

Top-down wetlands CH_4 emissions converted into CO_2 eq
$GtCO_2$ eq/year, global, 2008–2017



Carbon dioxide equivalent (CO_2eq)

1. Top-down approach, average emission 2008–2017
2. Methane has a perturbation life of only 12.4 years, whereas CO_2 lasts in the atmosphere for much longer; 50% of an emission is removed from the atmosphere within 37 years, while 22% of the emission effectively remains indefinitely (Balcombe et al. 2018).

Sources: Global Carbon Budget; Global Methane Budget; Balcombe & al., 2018; Mitsch & al. 2012; Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention, K. D. Kroeger 2017; Kearney Energy Transition Institute analysis

Balancing carbon sequestration with methane emissions shows that wetlands are carbon sinks but are debatable radiative sinks

This can have negative consequences (some of them irreversible such as permafrost thaw, etc.) in the coming years. Hence, it is imperative to comprehensively analyze the impact of methane over the short term.

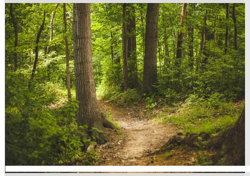
1.5 Non-anthropogenic GHG emissions of natural ecosystems

GHG balance on a 20-year time horizon
$GtCO_2eq$/year, global, 2008–2017

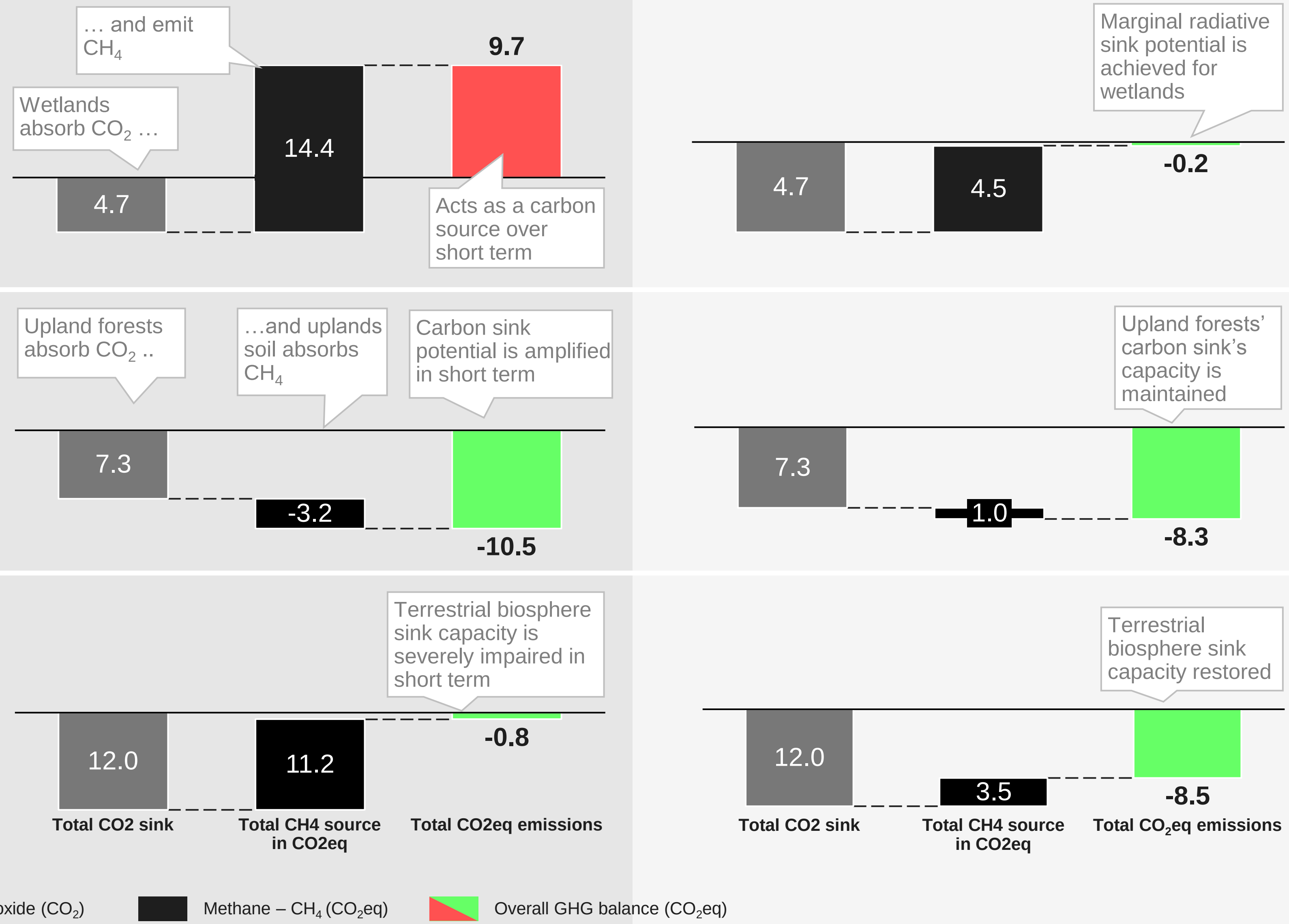
GHG balance on a 100-year time horizon
$GtCO_2eq$/year, global, 2008–2017

Wetlands

Uplands



Total
∑



Sources: Global Carbon Budget; Global Methane Budget; Balcombe & al., 2018; Mitsch & al., 2012; Kearney Energy Transition Institute analysis

2. Carbon emissions mitigation solutions in AFOLU

AFOLU sector offers a substantial opportunity to reduce GHG emissions as well as enrich biodiversity and human well-being

AFOLU sector mitigation potential. Global AFOLU emission mitigation potential is approximately 14 $GtCO_2eq$/year (with carbon prices up to USD100/tCO_2eq) with measures targeting forests and ecosystems and agriculture accounting for most of the mitigation potential. Regionally, the mitigation potential is highest in tropical countries in Asia and developing Pacific, Latin America and the Caribbean, and Africa and the Middle East from reducing deforestation whereas carbon sequestration in agricultural land and demand-side measures are critical in developed countries.

Classification of mitigation measures. Measures are broadly categorized either as supply-side (targeting forest and other ecosystems, agriculture, and bioenergy and BECCS) or demand-side (for example, interventions that require a change in consumer behavior such as reduced waste, shift to sustainable diets, and others).

- **Forests and other ecosystems.** Protection, improved management, and restoration of forests, peatlands, coastal wetlands, savannas, and grasslands offer highest mitigation potential.
- **Agriculture.** Agriculture-based measures such as cropland and grassland soil carbon management, agroforestry, use of biochar, improved rice cultivation, and livestock and nutrient management account for the second largest share of the mitigation potential.
- **Bioenergy and BECCS.** This area represents an important share of the total mitigation potential.
- **Demand-side measures.** These include reducing food waste, shifting to sustainable healthy diets, and improved use of wood products.

Each measure is characterized by its own set of benefits, risks, and challenges in implementation.

Co-benefits and risks. In general, the mitigation measures in the AFOLU sector also deliver co-benefits but depending on the specific context, their impact should be carefully evaluated on the environmental and societal dimensions as negative consequences can be substantial in case of inappropriate selection and implementation. Natural ecosystem protection, carbon sequestration in agriculture, sustainable healthy diets, and reduced food waste provide high co-benefits with efficiency.

Most of the mitigation options are available and ready to deploy. Many mitigation solutions offer a significant near-term mitigation potential at relatively low cost. Measures targeting emissions reductions can be implemented relatively quickly, whereas CDR (carbon dioxide removal) needs upfront investment and time. Mitigation measures should be evaluated not only on their potential but resilience to costs and likelihood of impact given the barriers to implementation. At the same time, new innovative solutions such as CH_4 vaccines, inhibitors, and breeding of low-emission livestock are being developed.

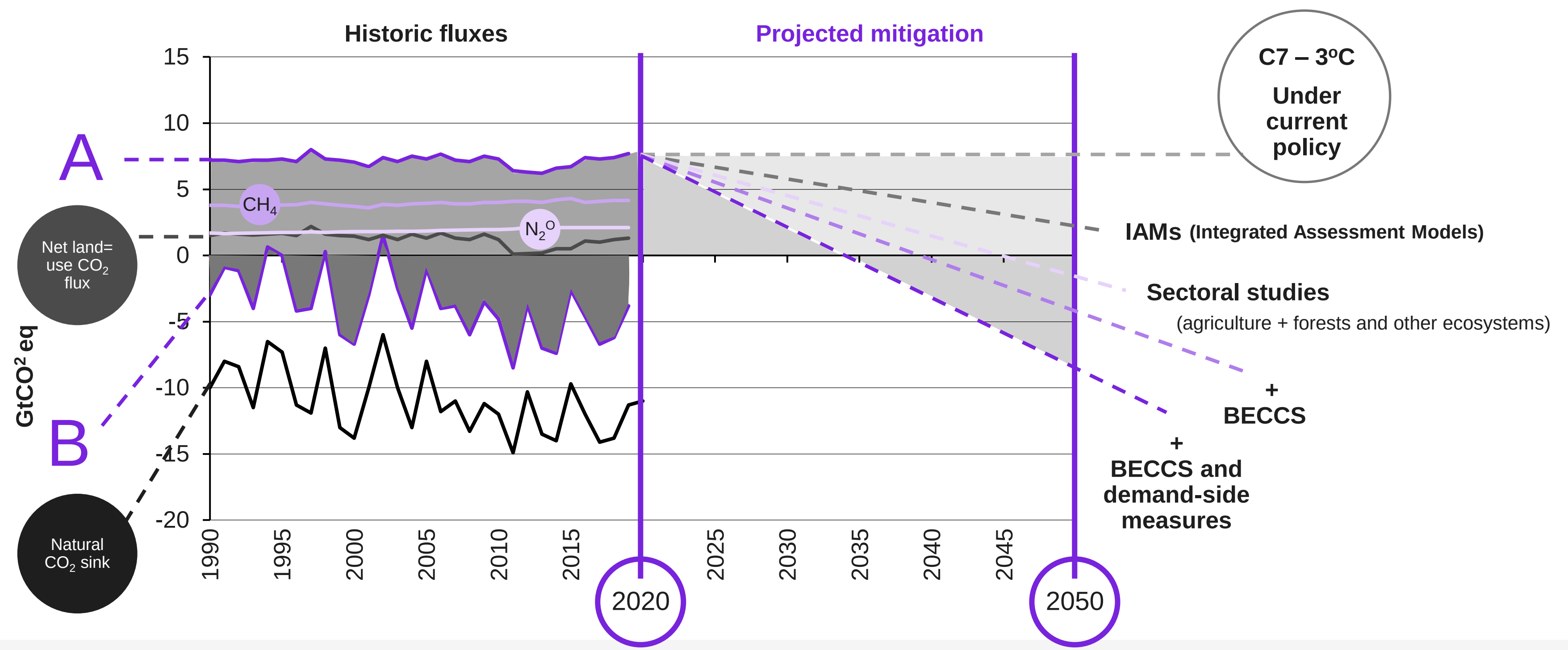
Role in achieving net zero through carbon removal. Carbon removal solutions are essential in offsetting hard-to-abate emissions to reach a net zero emissions state in the future. AFOLU mitigation solutions can help support carbon removal but the mitigation potential estimates are characterized by uncertainties and often the realized potential is dependent on the costs.

AFOLU offers substantial global emission mitigation potential through multiple solutions to address climate change

Significant near-term mitigation potential can be realized at relatively low cost.

2.1 Mitigation potential

Historic land-sector GHG flux estimates and illustrative AFOLU mitigation pathways



A = Net AFOLU (anthropogenic) emissions B = Net AFOLU (anthropogenic) emissions and the natural land CO_2 sink

How to read:

- **A** depicts total anthropogenic GHG emissions from AFOLU while **B** outlines variations in net GHG flux AFOLU taking into account land sink fluctuations (per Friedlingstein et al. 2020).
- Projected AFOLU GHG emissions in 2050 according to a scenario of current policy (C7 - Above 3C - Model: GCAM 5.3) is referenced.
- Projected mitigation potentials are mapped per sectoral studies and integrated assessment models.

Sources: IPCC AR6 (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7, Link); Kearney Energy Transition Institute analysis

AFOLU mitigation comprises a series of improvement measures to mitigate climate change and preserve ecosystems

Mitigation measures under forests and other ecosystems, agriculture, and bioenergy are often referred as supply-side measures (for example, land management interventions) vs. demand-side measures (for example, interventions that require a change in consumer behavior).

2.2 Classification of key mitigation solutions

Classification of the key mitigation measures to address AFOLU GHG emissions

Mitigation measures[1]

- **Forest and other ecosystems**
  - **Protect**
    - Reduce deforestation
    - Conserve coastal wetlands
    - Conserve peatlands
    - Conserve grasslands/ savanna
  - **Manage**
    - Improve forest management
    - Improve fire management
  - **Restore**
    - Restore forests – afforestation/ reforestation
    - Restore coastal wetlands
    - Restore peatlands
- **Agriculture**
  - **Sequester carbon**
    - Manage soil carbon in croplands
    - Manage soil carbon in grasslands
    - Encourage agroforestry
    - Encourage biochar
  - **Reduce emissions**
    - Manage enteric fermentation
    - Improve manure management
    - Improve crop nutrient management
    - Improve rice cultivation management
- **Bioenergy**
  - **Remove carbon**
    - Encourage bioenergy and BECCS
- **Demand-side measures**
  - **Modify behavior**
    - Reduce food loss/waste
    - Shift to sustainable diets
    - Improve use of wood products

Supply-side measures | Demand-side measures

1. Individual mitigation measures are expanded in the following slides.
Sources: : IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7); Kearney Energy Transition Institute analysis

Forest and other ecosystems and agriculture-based measures account for most of the mitigation potential

Max

Average

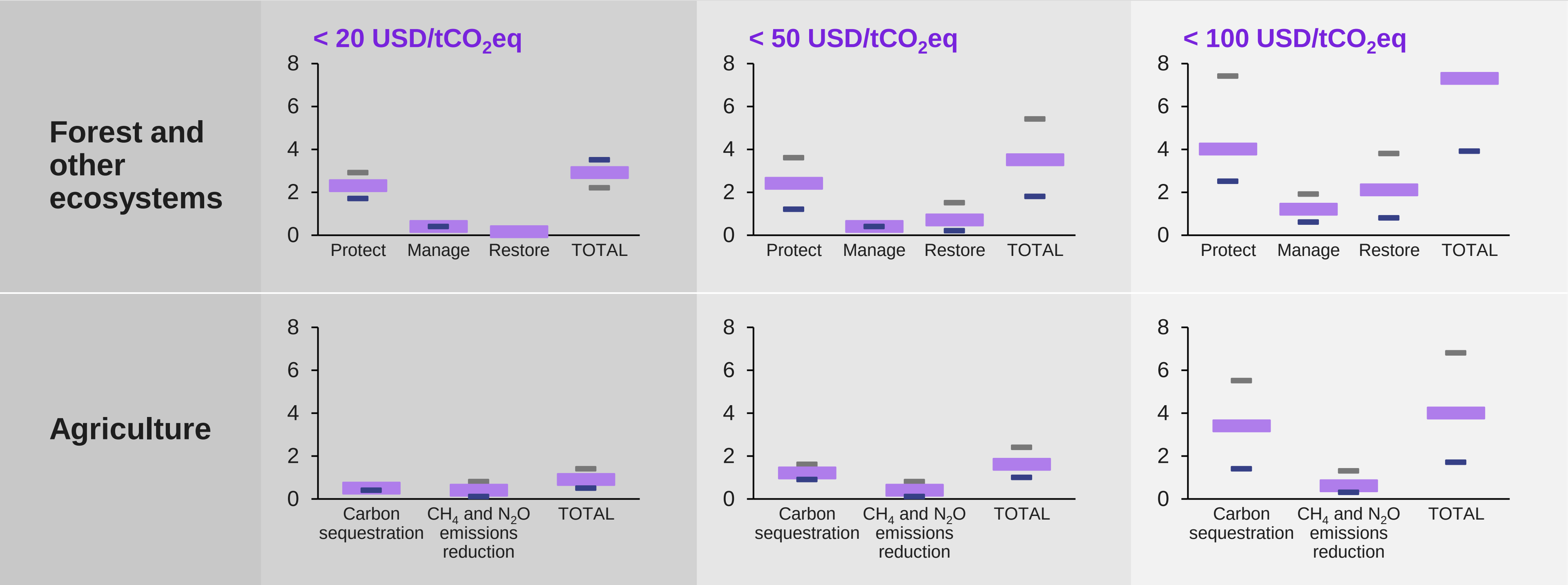
Min

Based on sectoral studies, the likely global AFOLU[1] emission mitigation potential is approximately **14 $GtCO_2eq$/year** (with carbon prices up to 100 USD/tCO_2eq), and a technical potential up to 65 $GtCO_2eq$/year.

2.2 Classification of key mitigation solutions

Estimated annual mitigation potential of AFOLU mitigation options by carbon price

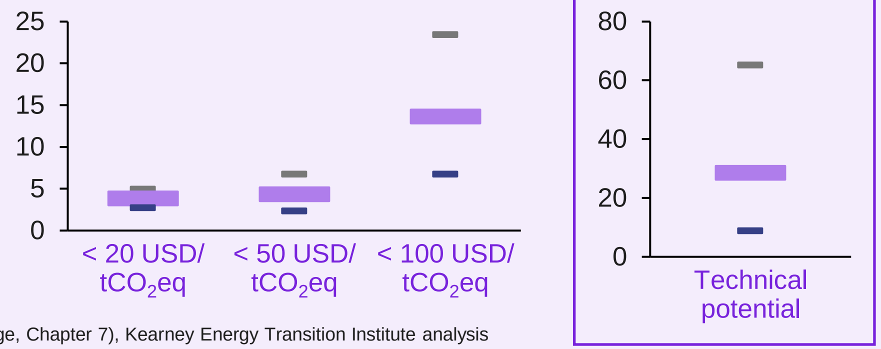
2020–2050, $GtCO_2eq$/year



Other mitigation measures

Only for < 100 USD/tCO_2eq

Total AFOLU[1]



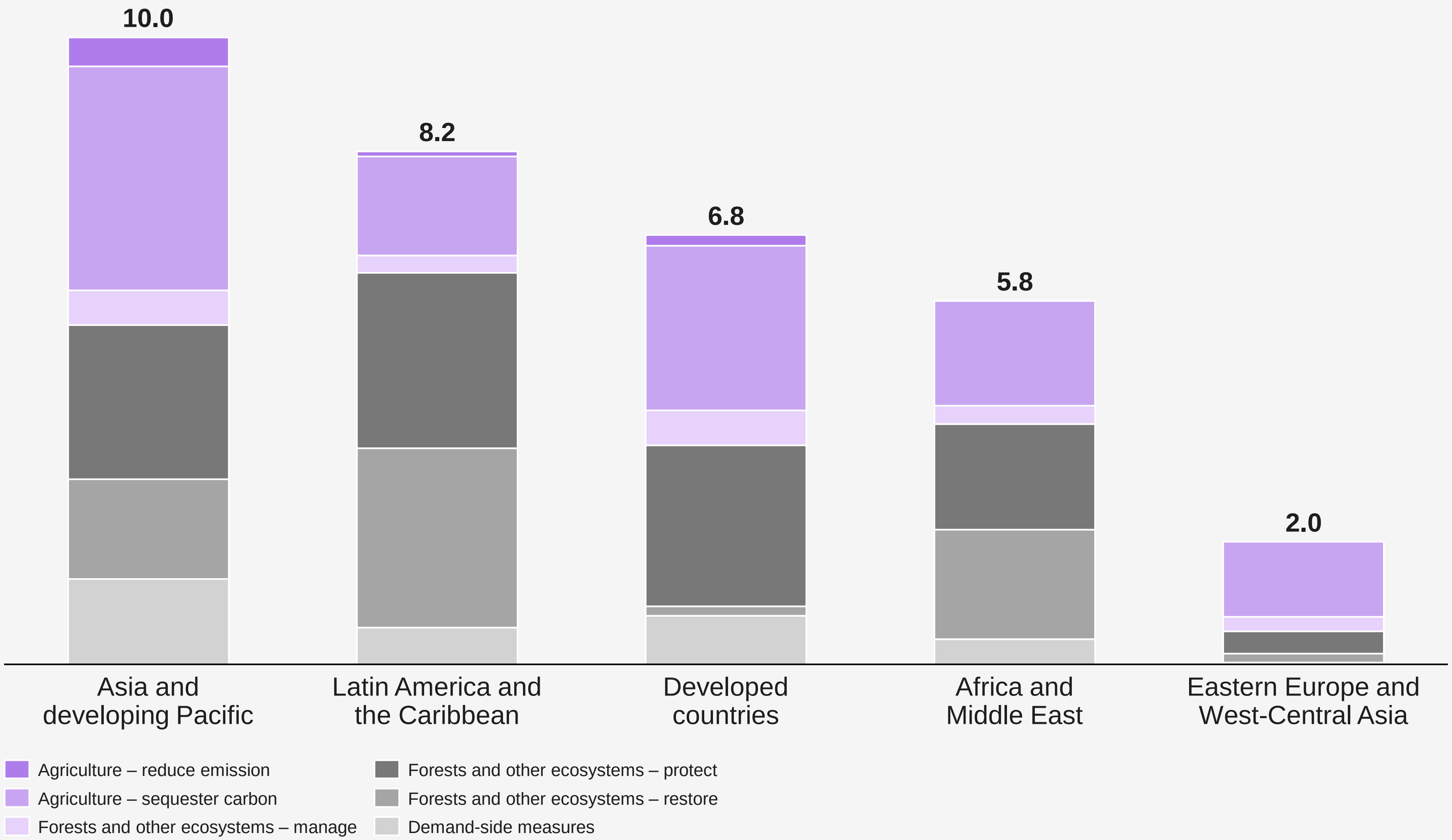
1. Cumulative of all mitigation measures excluding BECCS

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Asia, followed by LATAM, offers the biggest mitigation potential, primarily driven by protecting forests and other ecosystems and sequestering carbon in agriculture

Regional technical mitigation potential[1,2]

2020–2050, $GtCO_2eq$/year

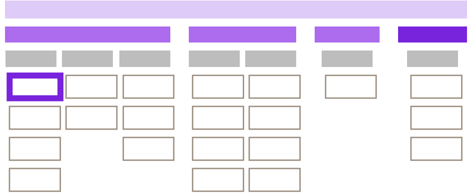


1. Technical mitigation potential; BECCS not evaluated
2. Mitigation measures under forests and other ecosystems, agriculture, and bioenergy are often referred as supply-side measures (for example, land management interventions) vs. demand-side measures (for example, interventions that require a change in consumer behavior).

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Reducing deforestation and forest degradation represents one of the most effective options for climate change mitigation

1



Fact card: reduce deforestation and degradation

2.3 Factcards of the key solutions/technologies

Description

- Existing carbon pools in forest vegetation and soil are conserved by avoiding tree cover loss and disturbance.
- Protecting forests involves controlling the drivers of deforestation (such as commercial and subsistence agriculture, mining, urban expansion) and forest degradation (such as overharvesting, including fuelwood collection, poor harvesting practices, overgrazing, pest outbreaks, and extreme wildfires.

Current status and opportunities

- Reduced deforestation is a significant piece of the NDCs in the Paris Agreement and over the past decade, hundreds of subnational initiatives that aim to reduce deforestation related emissions have been implemented across the tropics.
- Tropical forests continue to account for the highest rates of deforestation and associated GHG emissions.
- Tropical forests and savannas in Latin America provide the largest share of mitigation potential followed by Southeast Asia and Africa.

Challenges

- Unclear land tenure and insecure land rights especially in countries with high deforestation rates
- Weak environmental governance
- Insufficient capital
- Increasing pressures associated to agriculture conversion, resource exploitation, and infrastructure development

Benefits

- Preserving biodiversity and ecosystem at better efficiency and lower costs than afforestation/reforestation

Risks

- Reduced potential for agricultural and industrial activities
- Restricting the rights and access of local people to forest resources

Global technical mitigation potential (in $GtCO_2eq$/year)	4.5 (2.3 - 7)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Reduce degradation and conversion of coastal wetlands

2

Fact card: reduce degradation and conversion of coastal wetlands

2.3 Factcards of the key solutions/technologies

Description

– Reducing conversion of coastal wetlands, including mangroves, marshes, and seagrass ecosystems, avoids emissions from above- and below-ground biomass and soil carbon.
– The main drivers of conversion include intensive aquaculture, agriculture, salt ponds, urbanization and infrastructure development, the extensive use of fertilizers, and extraction of water resources.

Current status and opportunities

– Loss rates of coastal wetlands have been estimated at 0.2–3% per year, depending on the vegetation type and location. Recent loss rates of mangroves are 0.16–0.39% per year and are highest in Southeast Asia.
– Regional estimates show that about 85% of mitigation potential for avoided mangrove conversion is in Southeast Asia and developing Pacific.

Challenges

– Preservation of coastal wetlands also conflicts with other land use in the coastal zone, including aquaculture, agriculture, and human development; financial incentives are needed to prioritize wetland preservation over more profitable short-term land use.

Benefits

– Additional benefits include biodiversity conservation, fisheries production, soil stabilization, water flow and water quality regulation, flooding and storm surge prevention, and increased resilience to cyclones.

Risks

– Uncertain permanence under future climate scenarios, including the effects of coastal squeeze, where coastal wetland area may be lost if upland area is not available for migration as sea levels rise

Global technical mitigation potential (in $GtCO_2eq$/year)	0.8 (0.06–5.4)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Reduce degradation and conversion of peatlands

3

Fact card: reduce degradation and conversion of peatlands

2.3 Factcards of the key solutions/technologies

Description

- Peatlands are carbon-rich wetland ecosystems with organic soil horizons in which soil organic matter concentration exceeds 30% (dry weight) and soil carbon concentrations can exceed 50%.
- Reducing the conversion of peatlands avoids emissions of above- and below-ground biomass and soil carbon due to vegetation clearing, fires, and peat decomposition from drainage.

Current status and opportunities

- Tropical peatlands account for only ~10% of peatland area and about 20% of peatland carbon stock but about 80% of peatland carbon emissions mainly from peatland conversion in Indonesia.
- 90% of tropical peatland carbon stocks are vulnerable to emission during conversion and may not be recoverable through restoration.
- In northern peatlands, climate change (in other words, warming) is the major driver of peatland degradation (for example, through permafrost thaw).

Challenges

- The feasibility of reducing peatland conversion is dependent on countries' governance, financial capacity, and political will.

Benefits

- High per hectare mitigation potential and high rate of co-benefits particularly in tropical countries

Risks

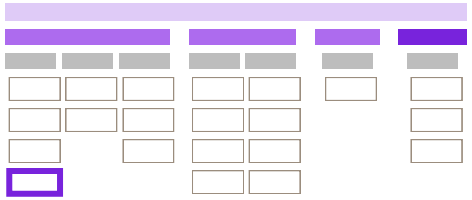
- Uncertainties in peatland extent and the magnitude of existing carbon stocks
- Peatlands are sensitive to climate change impacting their potential as carbon sink in future.

Global technical mitigation potential (in $GtCO_2eq/year$)	0.86 (0.43–2.02)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Reduce degradation and conversion of grasslands and savannas

4



Fact card: reduce degradation and conversion of grasslands and savannas

2.3 Factcards of the key solutions/technologies

Description

- Reducing the conversion of grasslands and savannas to croplands prevents soil carbon losses by oxidation, and to a smaller extent, biomass carbon loss due to vegetation clearing.
- Most of the carbon sequestration potential is in below-ground biomass and soil organic matter.

Current status and opportunities

- In comparison to tropical rainforest regions that have been the primary target for mitigation policies associated to natural ecosystems, grasslands and savannas have received less national and international attention, despite growing evidence of concentrated cropland expansion into these areas with impacts of carbon losses.

Challenges

- Annual operating costs, and opportunity costs of income foregone by undertaking the activities needed for avoiding conversion of grasslands

Benefits

- Conservation of grasslands presents significant benefits for desertification control, especially in arid areas.
- Additional socioeconomic, biodiversity, water cycle, and other environmental benefits

Risks

- Benefit/potential estimates are based on few studies and vary according to the levels of soil carbon and ecosystem productivity.

Global technical mitigation potential (in $GtCO_2eq/year$)	0.2 (0.1–0.4)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Improve forest management

5

Fact card: improve forest management

2.3 Factcards of the key solutions/technologies

Description

- Key measures consist of one or combination of longer rotations, less intensive harvests, continuous-cover forestry, mixed stands, more adapted species, selected provenances, and high-quality wood assortments.
- However, strategies aimed at increasing the biomass stock may have adverse side effects, such as decreasing the stand-level structural complexity, large emphasis on pure fast-growing stands, risks for biodiversity, and resilience to natural disasters.

Current status and opportunities

- The area of forest under management plans has increased in all regions since 2000 by 233 Mha.
- Adoption of the “climate smart forestry” concept which considers the whole value chain from forest to wood products and energy, illustrating that a wide range of measures can be applied to provide positive incentives for more firmly integrating climate objectives into the forest and forest sector framework

Challenges

- The measure requires carbon price incentives and policy support, knowledge, institutions, skilled labor, good access, etc.
- Net benefits are difficult to assess development.

Benefits

- Improved sustainable forest management of already managed forests can lead to higher forest carbon stocks and better quality of produced wood, and continuously produce wood while maintaining and enhancing the forest carbon stock.

Risks

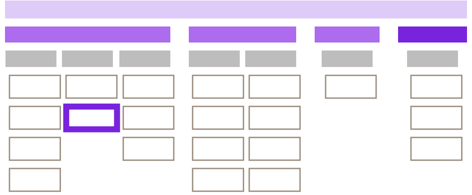
- Leakage can arise from efforts to change management for carbon sequestration.
- Efforts might be counteracted by higher harvesting pressures elsewhere.

Global technical mitigation potential (in $GtCO_2eq/year$)	1.7 (1–2.1)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Improve fire management (forest and grassland/ savanna fires)

6



Fact card: improve fire management (forest and grassland/savanna fires)

Description

- Fire management objectives include safeguarding life, property, and resources through the prevention, detection, control, restriction, and management of fire for diverse purposes in natural ecosystems.
- Controlled burning is an effective economic method of reducing fire danger and stimulating natural regeneration.

Current status and opportunities

- Savanna fires contributed 62% of gross global mean fire emissions between 1997 and 2016. Regrowth from vegetation postfire sequesters the CO_2 released into the atmosphere, but not the CH_4 and N_2O emissions.
- In Australia, savanna burning emissions abatement has exceeded 15 $MtCO_2eq$ mainly through the management of low-intensity early dry season fire.

Challenges

- Legal and policy issues, equity and rights concerns, governance, and capacity are some of the key issues.

Benefits

- Reduced air pollution compared to much larger, uncontrolled fires, prevention of soil erosion and land degradation, biodiversity conservation, and improvement of forage quality

Risks

- The benefits for the management of carbon stocks are unclear in the long term.

Global technical mitigation potential (in $GtCO_2eq$/year)	0.1 (0.09–0.1)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Restore forests – afforestation/ reforestation (A/R)

7

Fact card: restore forests – afforestation/reforestation (A/R)

2.3 Factcards of the key solutions/technologies

Description

- Reforestation is on land that has previously contained forests, while afforestation is on land that historically has not been forested.
- Forest restoration refers to a form of reforestation that gives more priority to ecological integrity as well, even though it can still be a managed forest.

Current status and opportunities

- Initiatives launched: UN Decade on Restoration announced in 2019, the Bonn challenge on 150 million ha of restored forest in 2020, and the trillion-tree campaign launched by the World Economic Forum in 2020
- However, there's a polarization on the scale, effectiveness, and pitfalls of A/R and tree planting for climate mitigation.

Challenges

- Climate change will affect the mitigation potential of reforestation due to impacts in forest growth and composition, as well as changes in disturbances including fire.
- Implementation costs may be higher if albedo is considered in North America, Russia, and Africa.

Benefits

- Enhance climate resilience and biodiversity, and provide a variety of ecosystem services
- Can help address land degradation and desertification

Risks

- May change the surface albedo and evapotranspiration regimes
- Very large-scale implementation of A/R may negatively affect food security

Global technical mitigation potential (in $GtCO_2eq/year$)	3.9 (0.5–10.1)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Restore coastal wetlands

8

Fact card: restore coastal wetlands

2.3 Factcards of the key solutions/technologies

Description

- Coastal wetland restoration involves restoring degraded or damaged coastal wetlands including mangroves, salt marshes, and seagrass ecosystems, leading to sequestration of “blue carbon” in wetland vegetation and soil.
- Recent studies of rehabilitated mangroves also indicate that annual carbon sequestration rates in biomass and soils can return to natural levels within decades of restoration.

Current status and opportunities

- Successful approaches to wetland restoration include: (1) passive restoration, the removal of anthropogenic activities that are causing degradation or preventing recovery; and (2) active restoration, purposeful manipulations to the environment in order to achieve recovery to a naturally functioning system.
- Major successes in both active and passive restoration of seagrasses have been documented in North America and Europe.

Challenges

- Many coastal wetland restoration efforts do not succeed due to failure to address the drivers of degradation.

Benefits

- Conservation of grasslands presents significant benefits for desertification control, especially in arid areas.

Risks

- High site-specific variation in carbon sequestration rates and uncertainties regarding the response to future climate change
- 30% of mangrove soil carbon stocks and 50–70% of marsh and seagrass carbon stocks are unlikely to recover even within 30 years of restoration hence its pertinent to preserve coastal wetlands.

Global technical mitigation potential (in $GtCO_2eq/year$)	0.3 (0.04–0.84)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Restore peatlands

9

Fact card: restore peatlands

2.3 Factcards of the key solutions/technologies

Description

– Peatland restoration involves restoring degraded and damaged peatlands, for example through rewetting and revegetation, which both increases carbon accumulation in vegetation and soils and avoids ongoing CO_2 emissions.

Current status and opportunities

– Peatlands only account for about 3% of the terrestrial surface, predominantly occurring in boreal ecosystems (78%), with a smaller proportion in tropical regions (13%), but may store about 600 Gt carbon or 21% of the global total soil organic carbon stock of about 3,000 Gt.
– Large areas (0.51 Mkm^2) of global peatlands are degraded of which 0.2 Mkm^2 are tropical peatlands.

Challenges

– Large-scale implementation of tropical peatland restoration will likely be limited by costs and other demands for these tropical lands.
– Adequate resources for implementing restoration policies are key to engage local communities and maintain livelihoods.

Benefits

– Enriched biodiversity, regulated water flow, and downstream flooding prevention, while still allowing for extensive management such as paludiculture
– Rewetting of peatlands also reduces the risk of fire.

Risks

– Displacement of food production and damage food supply locally
– Peatlands are highly sensitive to climate change, and this induces uncertainty in potential estimates.
– Although rewetting of drained peatlands increases CH_4 emissions, this effect is often outweighed by decreases in CO_2 and N_2O emissions but depends very much on local circumstances

Global technical mitigation potential (in $GtCO_2eq$/year)	**0.79 (0.49–1.3)**

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Manage soil carbon in croplands and grasslands

10 11

Fact card: manage soil carbon in croplands and grasslands

2.3 Factcards of the key solutions/technologies

Description

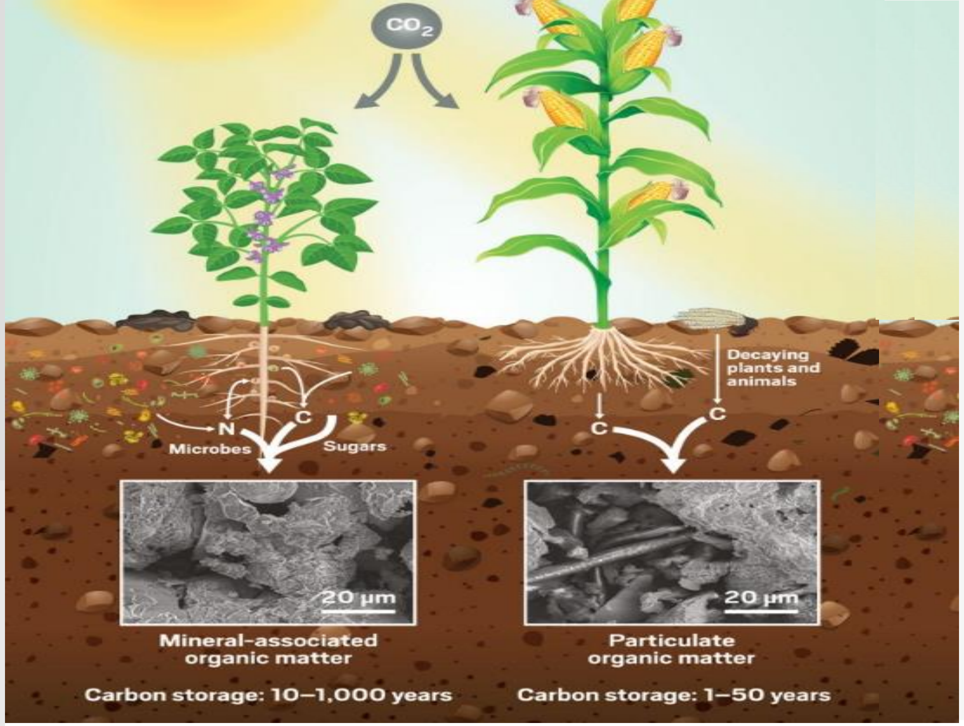
– Increasing soil organic matter in croplands is achieved through agricultural management practices such as 1) crop management, 2) nutrient management, 3) reduced tillage intensity and residue retention, and 4) improved water management.
– Measures to increase soil organic matter in grasslands include 1) management of vegetation, 2) livestock management, and 3) fire management.
– However, for well managed grasslands, soil carbon stocks are already high and the potential for additional carbon storage is low.

Current status and opportunities

– Already well deployed globally as it is a low-cost option at a high level of technology readiness with low sociocultural and institutional barriers.

Challenges

– Issues impacting implementation include regional capacity for monitoring and verification (especially in developing countries).
– Concerns exist over saturation and permanence of this mitigation solution.



Benefits

– Additional benefits are realized for livelihoods, biodiversity, water provision, and food security.

Risks

– Effectiveness can be limited in very dry regions.

Global technical mitigation potential (in $GtCO_2eq$/year)	2.9 (0.6-9.4)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Encourage agroforestry

12

Fact card: encourage agroforestry

2.3 Factcards of the key solutions/technologies

Description

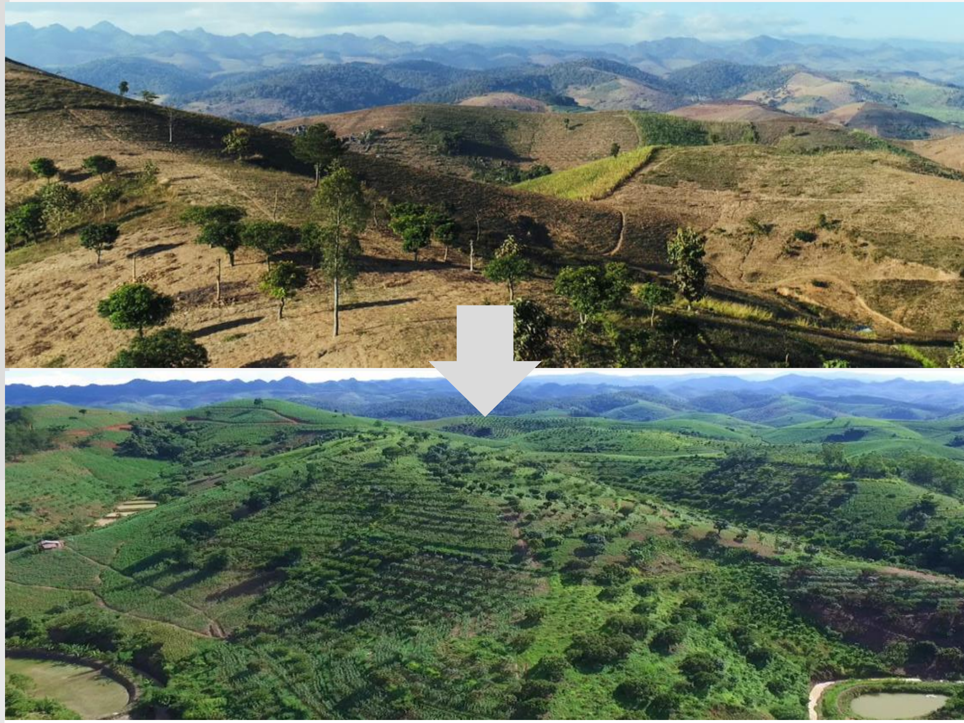
- Agroforestry is a set of diverse land management systems that integrate trees and shrubs with crops and/or livestock in space and/or time.
- Agroforestry options differ significantly by geography: multi-strata shaded coffee and cacao are successful in the humid tropics, silvopastoral systems are prevalent in Latin America, while agrosilvopastoral systems, shelterbelts, hedgerows, and windbreaks are common in Europe.

Current status and opportunities

- Highest regional economic (up to USD100 tCO_2-1) mitigation potential for the period 2020–2050 are estimated to be in Asia and the developing Pacific (368.4 $MtCO_{2eq}$ yr-1) followed by developed countries (264.7 $MtCO_{2eq}$ yr-1).

Challenges

- Water availability, soil fertility, seed and germplasm access, land policies and tenure systems affecting farmer agency, access to credit and to information regarding the optimum species for a given location



Benefits

- Increased land productivity, diversified livelihoods, reduced soil erosion, improved water quality, and more hospitable regional climates

Risks

- Incorporation of trees and shrubs in agricultural systems, however, can affect food production, biodiversity, and local hydrology and contribute to social inequality.

Global technical mitigation potential (in $GtCO_2eq$/year)	4.1 (0.3-9.4)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Encourage biochar[1]

13

Fact card: encourage biochar

2.3 Factcards of the key solutions/technologies

Description

- Biochar is produced by heating organic matter in oxygen-limited environments (pyrolysis and gasification). Feedstocks include forestry and sawmill residues, straw, manure, and biosolids.
- When applied to soils, biochar is estimated to persist from decades to thousands of years depending upon feedstock and production conditions.
- Offers significant mitigation potential through CDR and emissions reduction.

Current status and opportunities

- A recent assessment finds greatest economic potential (up to USD100 tCO_2-1) between 2020 and 2050 to be in Asia and the developing Pacific (793 $MtCO_2$ 16 yr-1) followed by developed countries (447 $MtCO_2$ yr-1).
- Biochar properties vary with feedstock, production conditions, and post-production treatments, so mitigation and agronomic benefits are maximized when biochars are chosen to suit the application context.

Challenges

- Insufficient investment, limited large-scale production facilities; high production costs at small scale; lack of agreed approach to monitoring, reporting, and verification; and limited knowledge, standardization, and quality control, restricting user confidence

Benefits

- Improves soil properties, enhancing productivity and resilience to climate change
- Reduced GHG and ammonia emissions from compost and manure
- Improved crop water use efficiency

Risks

- Uncertainty in the availability of sustainably-sourced biomass for biochar production

Global technical mitigation potential (in $GtCO_2eq/year$)	2.6 (0.2–6.6)

1. For a more detailed discussion on bioenergy, please refer to Kearney Energy Transition Institute's factbook "Negative emission technologies."
Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Manage enteric fermentation

14

Fact card: manage enteric fermentation

2.3 Factcards of the key solutions/technologies

Description

- Mitigating measures can be direct (for example, targeting ruminal methanogenesis and emissions per animal or unit of feed consumed) or indirect, by increasing production efficiency (for example, reducing emission intensity per unit of product).
- They can be further classified into (1) feeding; (2) supplements, additives, and vaccines; and (3) livestock breeding and wider husbandry.

Current status and opportunities

- Approaches differ regionally, with more focus on direct, technical options in developed countries, and improved efficiency in developing countries.
- The highest mitigation potential is in Asia and the developing Pacific followed by developed countries.
- Continuing research on inhibitors/feeds containing inhibitory compounds, such as macroalga or seaweed, CH_4 vaccines, breeding of low emitting animals, and others.

Challenges

- Feeding/administration constraints
- Legal restrictions on emerging technologies
- Mitigation persistence and public acceptance
- Concerns around palatability, toxicity, environmental impacts, and the development of industrial-scale supply chains of inhibitors/feeds containing inhibitory compounds

Benefits

- Enhanced climate change adaptation and increased food security associated with improved livestock breeding

Risks

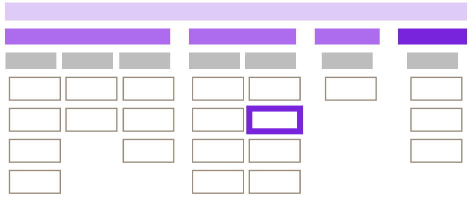
- Ecological impacts associated with improving feed quality especially in developing countries
- Potential toxicity and animal welfare issues concerning feed additives
- Potential land-use change and greater emissions associated with production of concentrates

Global technical mitigation potential (in $GtCO_2eq/year$)	**0.8 (0.2–1.2)**

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Improve manure management

15



Fact card: improve manure management

2.3 Factcards of the key solutions/technologies

Description

- The aim is to mitigate CH_4 and N_2O emissions from manure storage and deposition.
- Measures include (1) anaerobic digestion, (2) applying nitrification or urease inhibitors to stored manure or urine patches, (3) composting, (4) improved storage and application practices, (5) grazing practices, and (6) alteration of livestock diets to reduce nitrogen excretion.

Current status and opportunities

- The highest mitigation potential is estimated in developed countries in more intensive and confined production systems.

Challenges

- The potential antagonistic relationship between GHG and ammonia mitigation implies the need for appropriate management.

Benefits

- Enhances system resilience, sustainability, and food security and helps prevent land degradation
- Local environmental benefits, for example, water quality

Risks

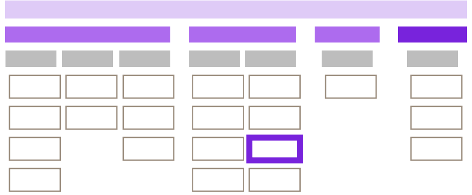
- Increased N_2O emission from the application of manure to poorly drained or wet soils
- Trade-offs between N_2O and ammonia emissions and potential eco-toxicity associated with some of the measures

Global technical mitigation potential (in $GtCO_2eq/year$)	0.3 (0.1-0.5)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Improve crop nutrient management

16



Fact card: improve crop nutrient management

2.3 Factcards of the key solutions/technologies

Description

– Practices such as optimizing fertilizer application delivery, rates and timing, utilizing different fertilizer types (for example, organic manures, composts, and synthetic forms), and using slow or controlled-released fertilizers or nitrification inhibitors when combined with crop rotations can help reduce N_2O emissions from cropland soils while enhancing nutrient uptake.

Current status and opportunities

– Effectiveness is context dependent (for example, sub-Saharan Africa has one of the lowest global fertilizer consumption rates.
– Given their high shares of global nitrogen fertilizer use, Asia and developing Pacific and developed countries represent the highest mitigation potential.

Challenges

– Significant regional imbalances, with some regions experiencing nutrient surpluses from over fertilization and others, nutrient shortages and chronic deficiencies
– Depending on the context, some mitigation practices may be inaccessible, expensive, or require expertise to implement.

Benefits

– Enhanced soil quality (notably when manure, crop residues, or compost is utilized), carbon sequestration in soils and biomass, water holding capacity, adaptation capacity, farm incomes, water quality (from reduced nitrate leaching and eutrophication), air quality (from reduced ammonia emissions)

Risks

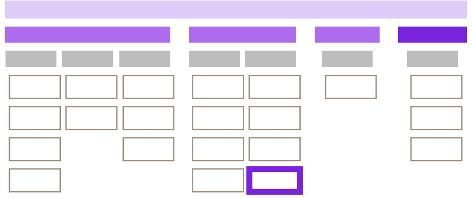
– Yield reduction concerns

Global technical mitigation potential (in $GtCO_2eq$/year)	**0.3 (0.06–0.7)**

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Improve rice cultivation management

17



Fact card: improve rice cultivation management

2.3 Factcards of the key solutions/technologies

Description

- Anaerobic conditions (CH_4) and nitrification and denitrification processes (N_2O) are the main sources of GHG emissions from rice cultivation.
- Key mitigation measures include (1) improved water management (for example, single drainage and multiple drainage practices), (2) improved residue management, (3) improved fertilizer application (for example, using slow-release fertilizer and nutrient specific application), and (4) soil amendments.

Current status and opportunities

- Intensity of emissions show considerable spatial and temporal variations.
- Alternative wetting and drying (AWD) with irrigation management can reduce CH_4 emissions by 20–30% and water use by 25.7%, though this resulted in a slight yield reduction (5.4%).
- The highest mitigation potential between 2020 and 2050 is estimated to be in Asia and the developing Pacific followed by Latin America and the Caribbean.

Challenges

- Barriers to adoption may include site-specific limitations regarding soil type, percolation and seepage rates or fluctuations in precipitation, water canal or irrigation infrastructure, paddy surface level, and rice field size.
- Social factors including farmer perceptions, pump ownership, and water management

Benefits

- Enhanced drought adaptation and system resilience, improved yield, increased farm income, and others
- Improved production sustainability in terms of resource utilization including water consumption and fertilizer application

Risks

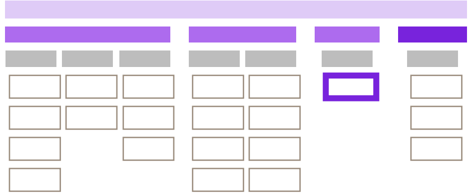
- Emission reductions show high variability and are dependent on site-specific conditions and cultivation practices.

Global technical mitigation potential (in $GtCO_2eq$/year)	0.3 (0.1-0.8)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Encourage bioenergy and BECCS[1]

18



Fact card: encourage bioenergy and BECCS

2.3 Factcards of the key solutions/technologies

Description

– In addition to replacing more emission-intensive energy sources, BECCS (bioenergy with carbon capture and storage) may provide CDR (carbon dioxide removal) by durably storing biogenic carbon in geological, terrestrial, or ocean reservoirs, or in products, contributing to enhanced emission mitigation.

Current status and opportunities

– Strategies to enhance benefits include management practices that protect carbon stocks and the productive and adaptive capacity of lands, as well as their environmental and social functions.
– BECCS' potential depends on investments in and the rollout of advanced bioenergy technologies currently not widely available.

Challenges

– Governance has a critical influence on outcome and larger-scale and higher expansion rate generally translates into higher risk for negative outcomes for GHG emissions, biodiversity, food security, and a range of other sustainability criteria.

Benefits

– Closely intertwined with other AFOLU mitigation options, for example deployment of energy crops, agroforestry, A/R, anaerobic digestion of manure and wastewater, and others

Risks

– Faulty deployment of energy crops can also cause land carbon losses
– Increased biomass demand for energy could hamper other mitigation measures such as reduced deforestation and degradation

Global technical mitigation potential (in $GtCO_2eq/year$)	5.9 (0.5-11.3)

1. For a more detailed discussion on bioenergy, please refer to Kearney Energy Transition Institute's factbooks "Biomass to energy: developing carbon circularity" and "Negative emission technologies."
Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Reduce food loss and waste

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Fact card: reduce food loss and waste

2.3 Factcards of the key solutions/technologies

Description

– Food loss and waste refer to the edible parts of plants and animals produced for human consumption that are not ultimately consumed.
– Food loss occurs through spoilage, spilling, or other unintended consequences due to limitations in agricultural infrastructure, storage, and packaging while food waste typically takes place at the distribution (retail and food service) and consumption stages in the food supply chain.

Current status and opportunities

– Investing in harvesting and post-harvesting technologies in developing countries, taxing and other incentives to reduce business and consumer-level waste in developed countries, mandatory reporting and reduction targets for large food businesses, and regulation of unfair trading practices are some of the key measures.

Challenges

– Infrastructural and capacity limitations, institutional regulations, financial resources, constraining resources (for example, energy), information gaps (for example, with retailers), and consumers' behavior are some of the main barriers.

Benefits

– Multiple benefits beyond GHG mitigation are realized, including reducing environmental stress (for example, water and land competition, land degradation, desertification), safeguarding food security, and reducing poverty.

Risks

– Potential needs to be understood in a wider and changing sociocultural context that determines nutrition

Global technical mitigation potential (in $GtCO_2eq/year$)	**2.1 (0.1–5.8)**

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Shift to sustainable healthy diets

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Fact card: shift to sustainable healthy diets

2.3 Factcards of the key solutions/technologies

Description

– Sustainable healthy diets refers to dietary patterns that promote all dimensions of individuals’ health and well-being; have low environmental pressure and impact; are accessible, affordable, safe, and equitable; and are culturally acceptable.

Current status and opportunities

– Global studies continue to find high mitigation potential from reducing animal-source foods and increasing proportions of plant-rich foods in diets.
– Regionally, mitigation potentials for shifting toward sustainable healthy diets vary across regions but the highest economic (up to USD100 tCO_2-1) potential is estimated for 2020–2050 in Asia and the developing Pacific (609 $MtCO_{2eq}$ yr-1) followed by developed countries (322 $MtCO_{2e}$qeq/year).

Challenges

– Potential varies across regions as diets are location- and community-specific, and thus may be influenced by local production practices, technical and financial barriers and associated livelihoods, everyday life, and behavioral and cultural norms around food consumption.

Benefits

– Less pressure on forests and land used for feed supports the preservation of biodiversity and planetary health
– Preventing forms of malnutrition in developing countries
– Lower mortality rates through mitigation of cardiovascular diseases, type 2 diabetes, and others

Risks

– Potential for adverse impacts on the economic stability of the agricultural sector, especially animal food-based sub sectors

Global technical mitigation potential (in $GtCO_2$eq/year)	3.6 (0.3-8.0)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Improve use of wood products

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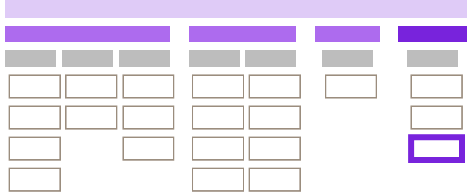


Fact card: improve use of wood products

2.3 Factcards of the key solutions/technologies

Description

– Wood products impact the carbon cycle through two distinctly different components, carbon storage in wood products and material substitution.
– Carbon storage in wood products can be increased through enhancing the inflow of products in use.
– Material substitution involves the use of wood for applications instead of other more emission-intensive materials (for example, concrete, steel) to avoid or reduce emissions.

Current status and opportunities

– There is strong evidence at the product level that wood products from sustainably managed forests are associated with less greenhouse emissions in their production, use, and disposal over their lifetime compared to products made from emission-intensive and non-renewable materials.

Challenges

– Variation in the forest system considered, the type of wood products that are produced and substituted and the assumed production technologies and conversion efficiencies of these products

Benefits

– Closely tied to sustainable forest management

Risks

– Decreasing carbon storage in forest biomass when not done sustainably
– Environmental impacts associated with the processing, manufacturing, use, and disposal of wood products

Global technical mitigation potential (in $GtCO_2eq/year$)	1.0 (0.04–3.7)

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Mitigation measures, especially land-based interventions, should be evaluated for their impact on environmental and societal dimensions (1 of 2)

Co-benefits and risks

Protection of natural ecosystems provides high co-benefits and cost efficiency.

Category	Mitigation measures	Bio-diversity	Water	Soil	Air quality	Resilience	Livelihood	Food security
Forest and other ecosystem – protect	Reduce deforestation	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Conserve coastal wetlands	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Conserve peatlands	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Conserve grasslands and savanna	🟢	🟢	🟢	🟢	🟢	🟠	🟠
Forest and other ecosystem – manage	Improve forest management	🟠	🟢	🟢	🟢	🟢	🟠	🟠
	Improve fire management	🟠	🟢	🟢	🟢	🟢	🟢	🟢
Forest and other ecosystem – restore	Restore forests – afforestation/ reforestation	🟠	🟠	🟢	🟢	🟠	🟠	🟠
	Restore coastal wetlands	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Restore peatlands	🟢	🟢	🟢	🟢	🟢	🟠	🟠

🟢 Potential co-benefit only
🟠 Potential co-benefit and risks
🔴 Potential risks only

Mitigation measures' efficacy and scale of benefit/risk largely depends on the type of activity undertaken, deployment strategy (for example, scale, method), and context (for example, soil, biome, climate, food system, land ownership) that vary geographically and over time. Hence, each mitigation measure should be carefully studied for its wider impact as negative consequences can be substantial in case of inappropriate implementation.

2.4 Environmental impacts and feasibility

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Mitigation measures, especially land-based interventions, should be evaluated for their impact on environmental and societal dimensions (2 of 2)

Co-benefits and risks

Bioenergy, when implemented at a large scale, translates to higher rates of negative outcomes.

Category	Mitigation measures	Bio-diversity	Water	Soil	Air quality	Resilience	Livelihood	Food security
Agriculture – sequester carbon	Manage soil carbon – cropland	🟢	🟢	🟢	🟢	🟢	🟢	🟠
	Manage soil carbon – grassland	🟢	🟢	🟢	🟢	🟢	🟢	🟠
	Encourage agroforestry	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Encourage biochar	🟠	🟢	🟢	🟢	🟢	🟠	🟢
Agriculture – reduce emissions	Manage enteric fermentation	NA	NA	NA	🟢	NA	🟠	🟠
	Improve manure management	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Improve crop nutrient management	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Improve rice cultivation management	🟢	🟢	🟢	🟢	🟢	🟠	🟠
Bioenergy	Encourage bioenergy and BECCS	🟠	🟠	🟠	🟠	🟠	🟠	🔴
Demand-side measures	Reduce food loss and waste	🟢	🟢	🟢	🟢	🟢	🟢	🟢
	Shift to sustainable healthy diets	🟢	🟢	🟢	🟢	🟢	🟠	🟠
	Improve use of wood products	🟠	🟠	🟢	🟢	🟠	🟠	🟠

🟢 Potential co-benefit only

🟠 Potential co-benefit and risks

🔴 Potential risks only

2.4 Environmental impacts and feasibility

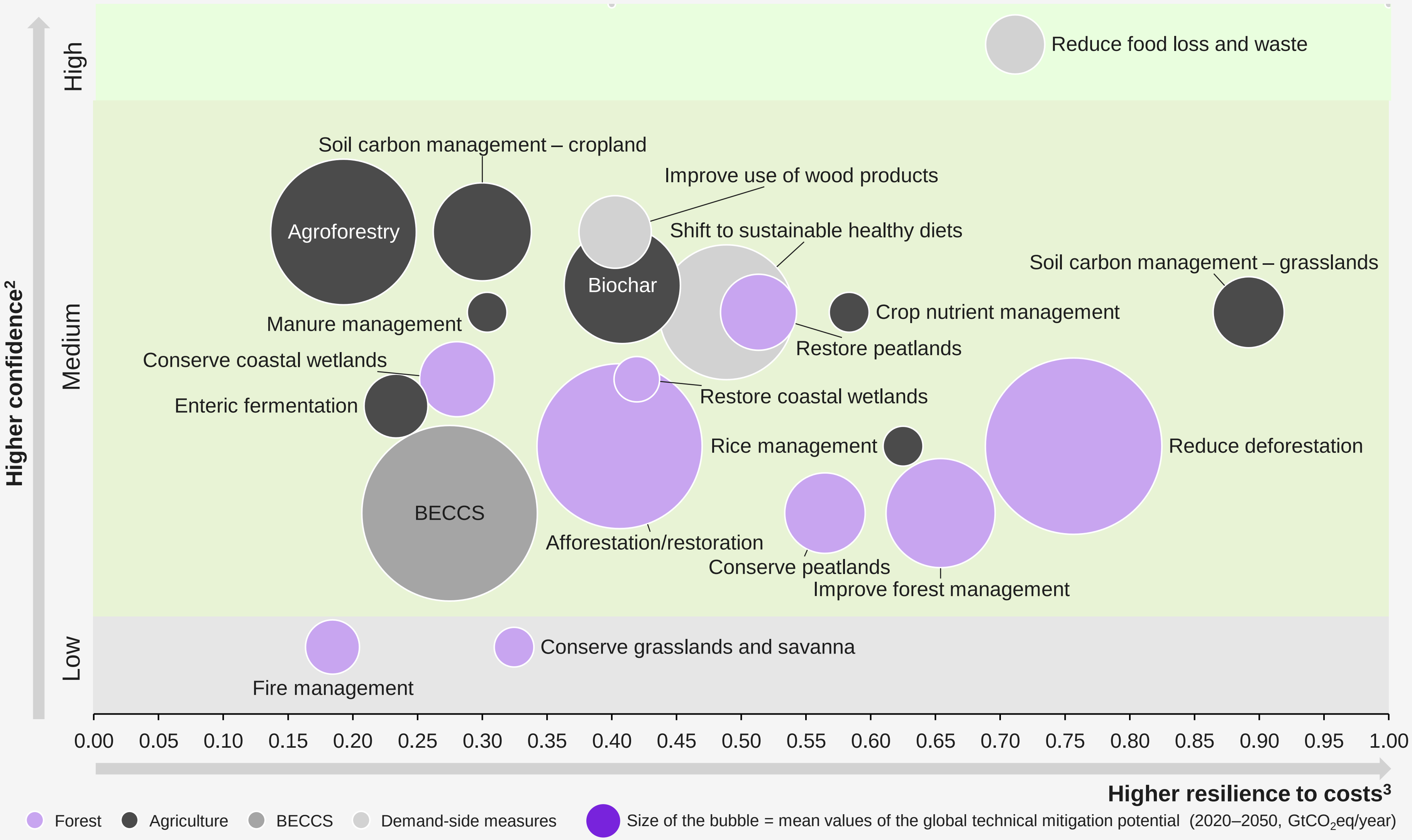
Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

In addition to accuracy in potential benefits' estimates, the mitigation measures should be evaluated on cost impacts too

Indicative

In addition to agriculture-based measures, the demand-side measures may be also be able to deliver non-CO_2 emissions reductions cost efficiently

High confidence and resilience is indicative of a mitigation measure's feasibility and sustainability over longer terms[1]



1. The analysis presented is based on global averages. However, there can be a significant variation in costs/benefits across the regions
2. The feasibility of implementing AFOLU mitigation measures taking into account economic, technological, institutional, sociocultural, environmental, and geophysical barriers
3. Estimated by the ratio of economic potential (potential constrained by costs, for example at carbon price of \$100/tCO_{2eq}) to technical potential

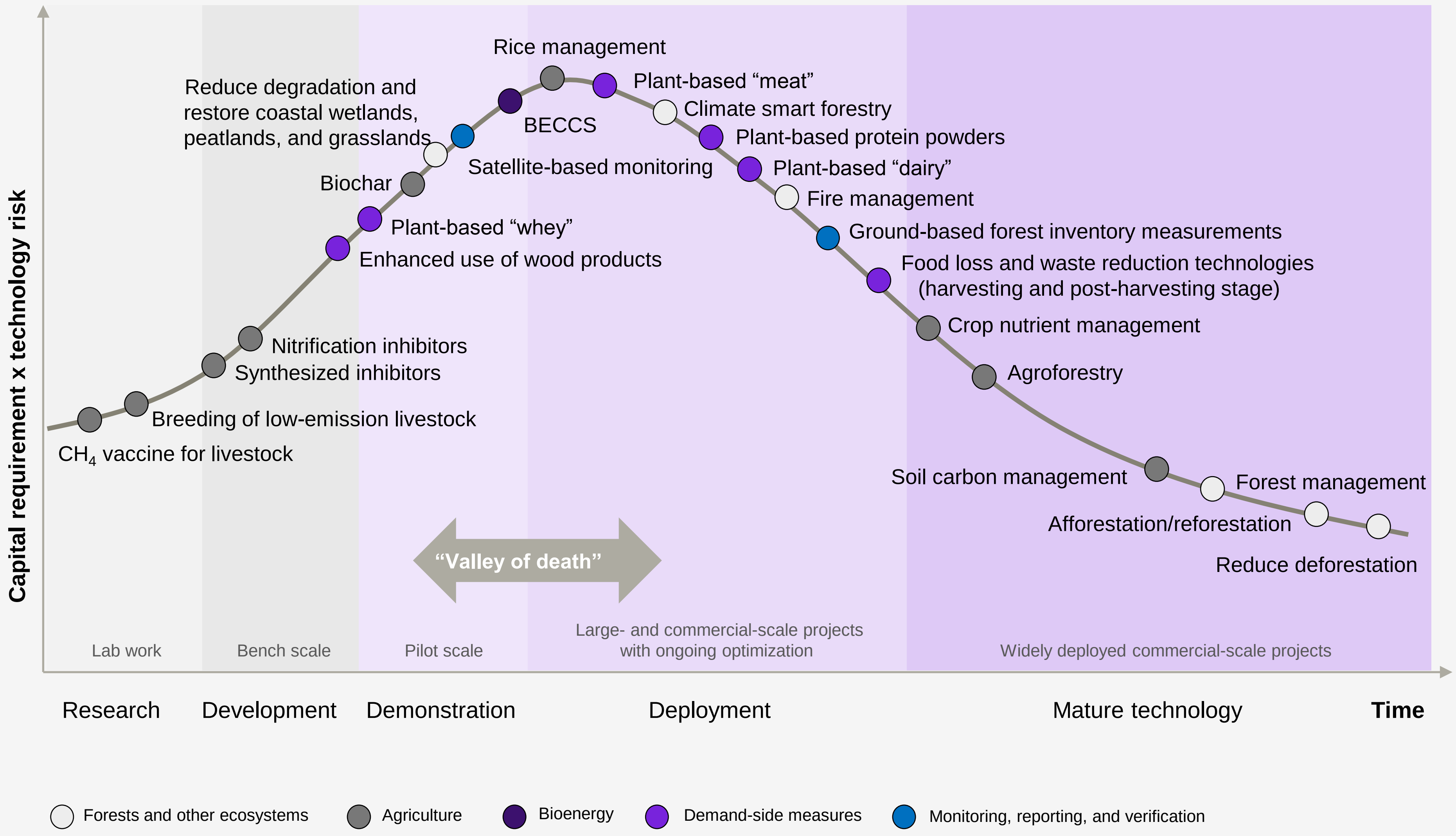
Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

Multiple new innovative solutions are being developed to complement traditional solutions

Most of the mitigation options are available and ready to deploy.

2.5 Technology maturity curve

Technology maturity curve



Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

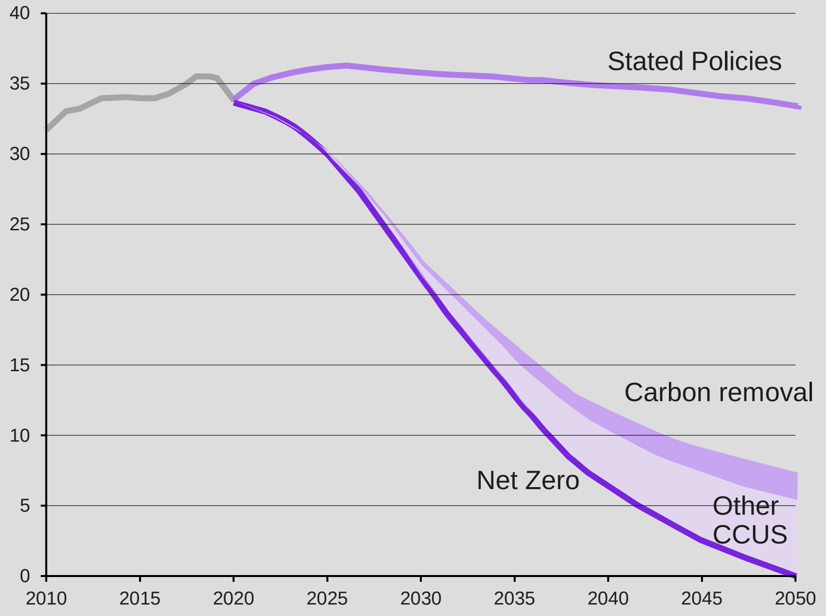
Carbon removal technologies will play a key role in energy transition

Net zero targets inherently recognize that some form of carbon removal will be required.[1]

2.6 Role in achieving net zero through carbon removal

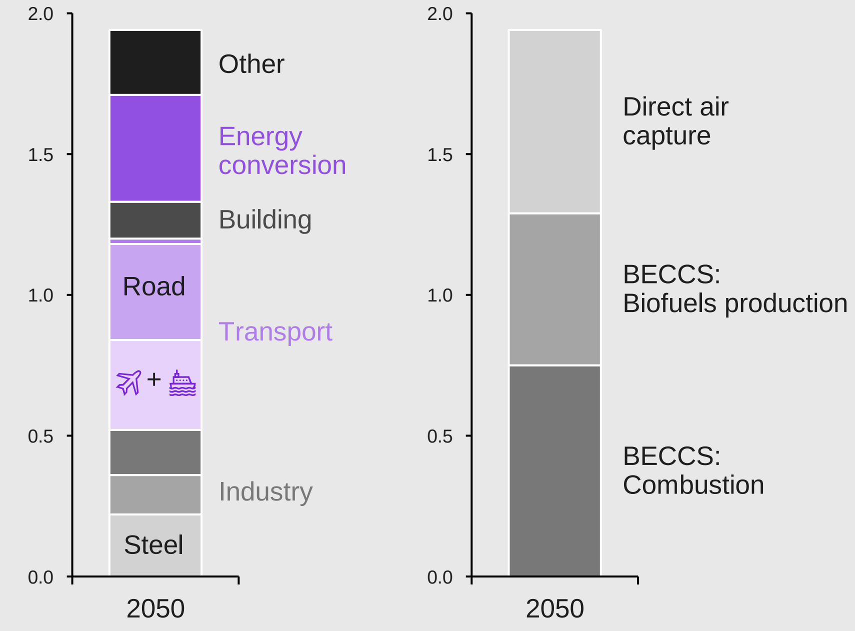
Global energy CO_2 emissions in STEPS and NZE

In $GtCO_2$



Residual CO_2 emissions and removal in NZE

In $GtCO_2$



- Carbon removal (BECCS and DACCS) accounts for **5% of cumulative energy-related CO_2 emissions reduction** between STEPS and NZE.

- Most of the residual emissions are from **hard-to-abate applications** and carbon removal technologies can help offset these emissions.
- Carbon removal technologies are instrumental to offset almost **2 Gt of residual CO_2 emissions in 2050.**
- Carbon removal technologies are part of **CCUS industrial cluster.**

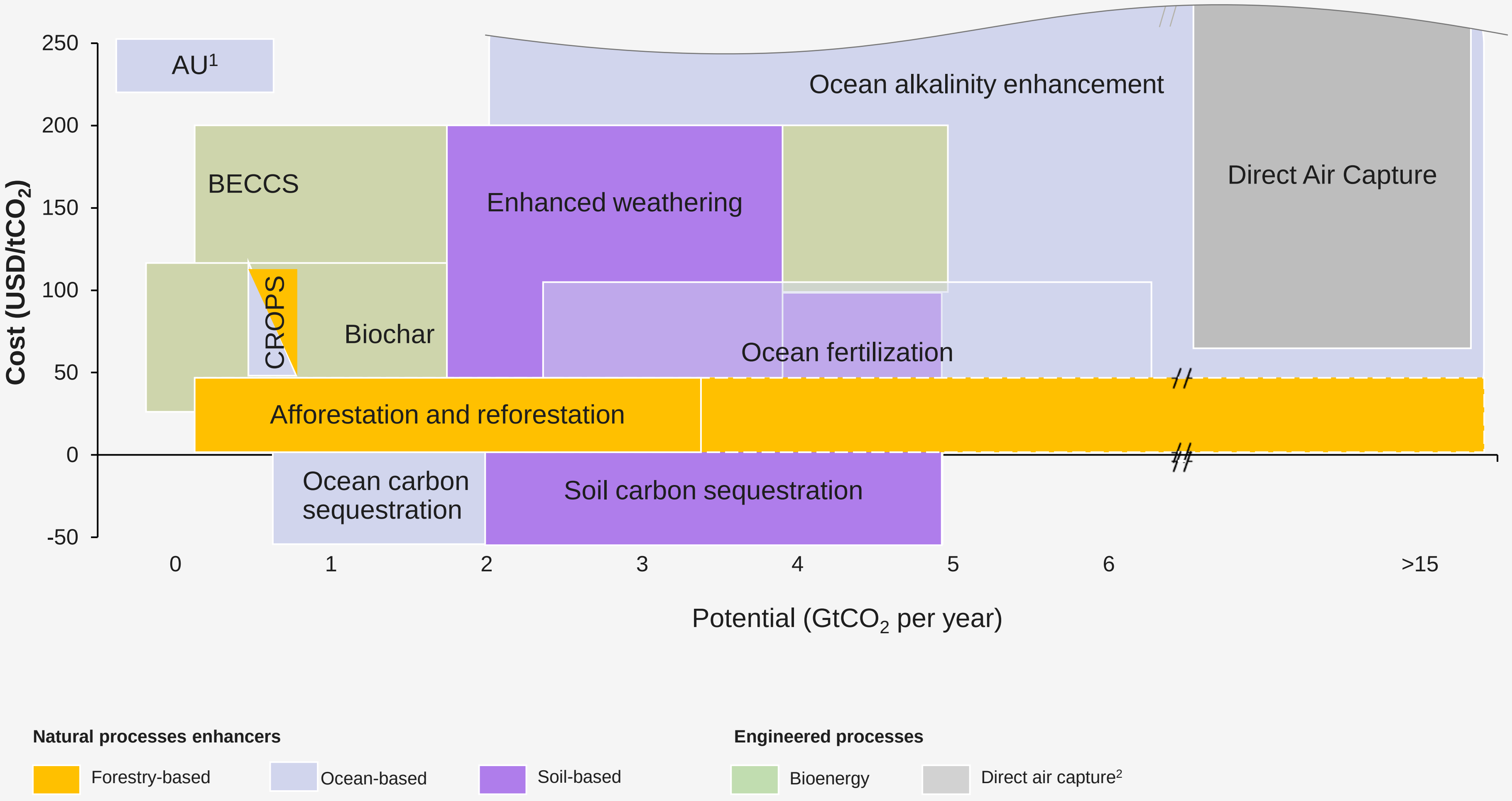
1. As per projected scenarios and models published by both IPCC and IEA. IEA scenarios are abbreviated as STEPS (Stated Policies Scenario) and NZE (Net Zero Emissions by 2050 Scenario).
Sources: IEA, “Role of carbon removal in IEA Net Zero roadmap” (2022); Kearney Energy Transition Institute analysis

AFOLU mitigation solutions can help support carbon removal efforts at scale

AFOLU mitigation solutions are part of a wider set of solutions classified as **negative emission technologies.**[3]

2.6 Role in achieving net zero through carbon removal

Negative emission technologies ranges for cost and potential



1. Cost for artificial upwelling (AU) is not available.
2. Costs for direct air capture technologies are based on projections by each firm for future large-scale projects.
3. For a more detailed discussion, please refer to Kearney Energy Transition Institute's factbook "Negative emission technologies."

Sources: IPCC "SR5 – chapter 3" (2018); UNEP (2017); Smith et al. (2015); Griscom et al. (2017); University of Michigan; E. Strand et al. (2009); G. Keil et al. (2010); Oschlies, A. et al. (2010); Bauman, S.J. et al. (2014); direct air capture companies' claims; Kearney Energy Transition Institute analysis

Kearney XX/ID

The goal is to enhance biological production and storage on land (in vegetation, soils, or geologic formations)

Summary of AFOLU mitigation solutions' characteristics
From carbon removal perspective

Solution	Status (TRL)	Cost (USD /tCO_2)	Mitigation potential (GtCO_2 /year)	Nature of CO_2 removal process/storage	Time scale of carbon storage (factors that affect carbon storage time scale)
Afforestation, reforestation, and forest management	8–9	0–240	0.5–10	Store carbon in trees and soils by planting, restoring, or managing forests	Decades to centuries (disturbances, such as fires, pests; extreme weather)
Soil carbon sequestration	8–9	45–100	0.6–9.3	Use agricultural management practices to improve soil carbon storage	Decades to centuries (soil and crop management)
Biochar	6–7	10–345	0.3–6.6	Burn biomass at high temperature under anoxic conditions to form biochar and add to soils	Decades to centuries (fire)
Peatland restoration	8–9	Lack of data	0.5–2.1	Store carbon in soil by creating or restoring peatlands	Decades to centuries (peatland drainage, fire, drought, land-use change)
Bioenergy with carbon capture and storage (BECCS)	5–6	15–400	0.5–11	Production of energy from plant biomass combined with carbon capture and storage	Potentially permanent—analogous to direct air carbon capture with carbon (leakage)
Restoration of vegetated coastal ecosystems (blue carbon)	8–9	Lack of data	0.5–2.1	Manage coastal ecosystems to increase net primary production and store carbon in sediments	Decades to centuries if functional integrity of ecosystem maintained (land-use change of coastal ecosystems; extreme weather (for example, heatwaves); sea level change)

Sources: ICEF "Blue Carbon Roadmap, Carbon Captured by the World's Coastal and Ocean Ecosystems" (2022); Kearney Energy Transition Institute analysis

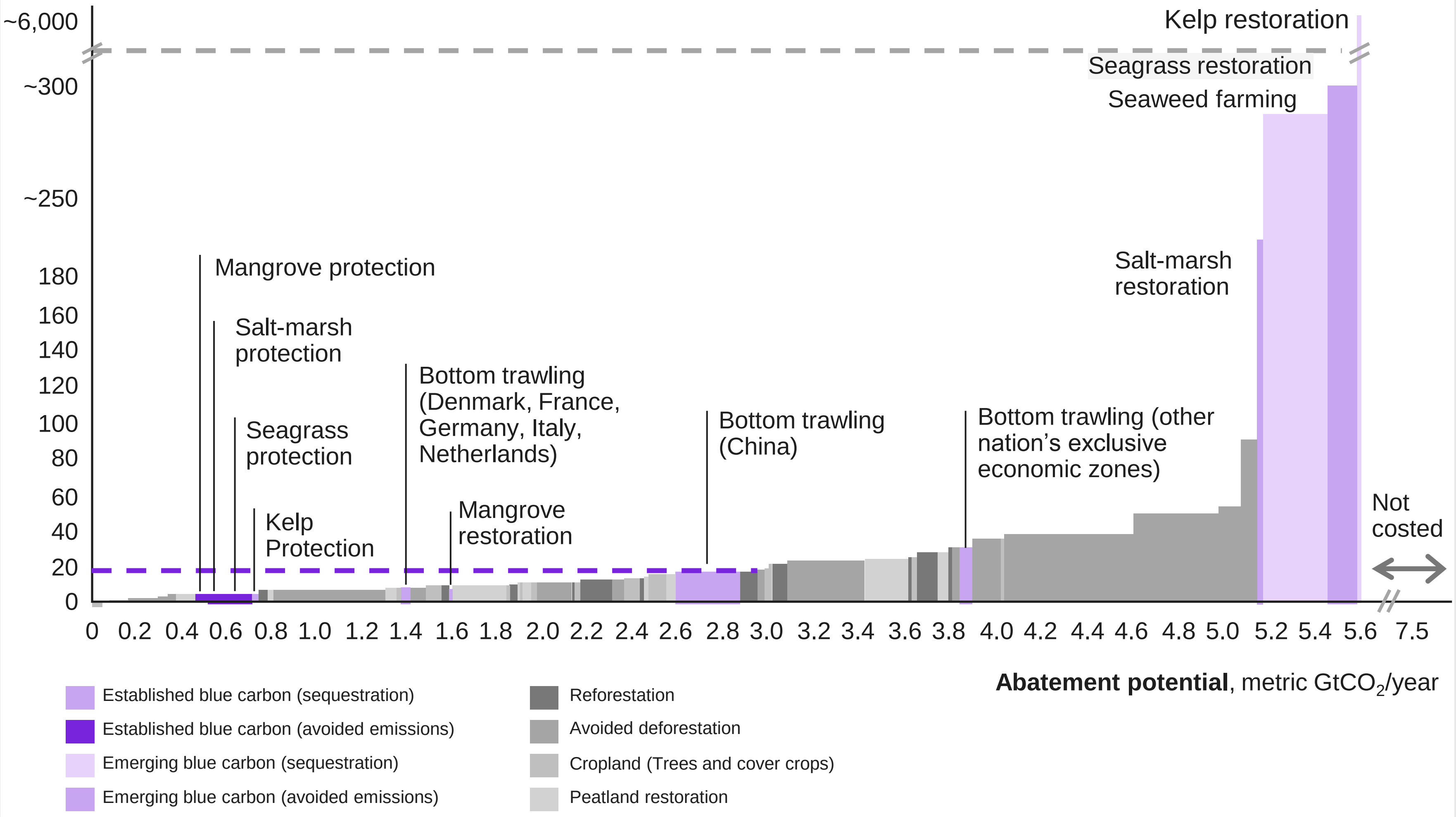
However, there are uncertainties around the mitigation potential and… (1/2)

Around one-third of the total abatement potential would be viable below USD 18 per tCO_2.

2.6 Role in achieving net zero through carbon removal

Abatement cost curve, nature-based solutions

USD per metric ton of carbon dioxide



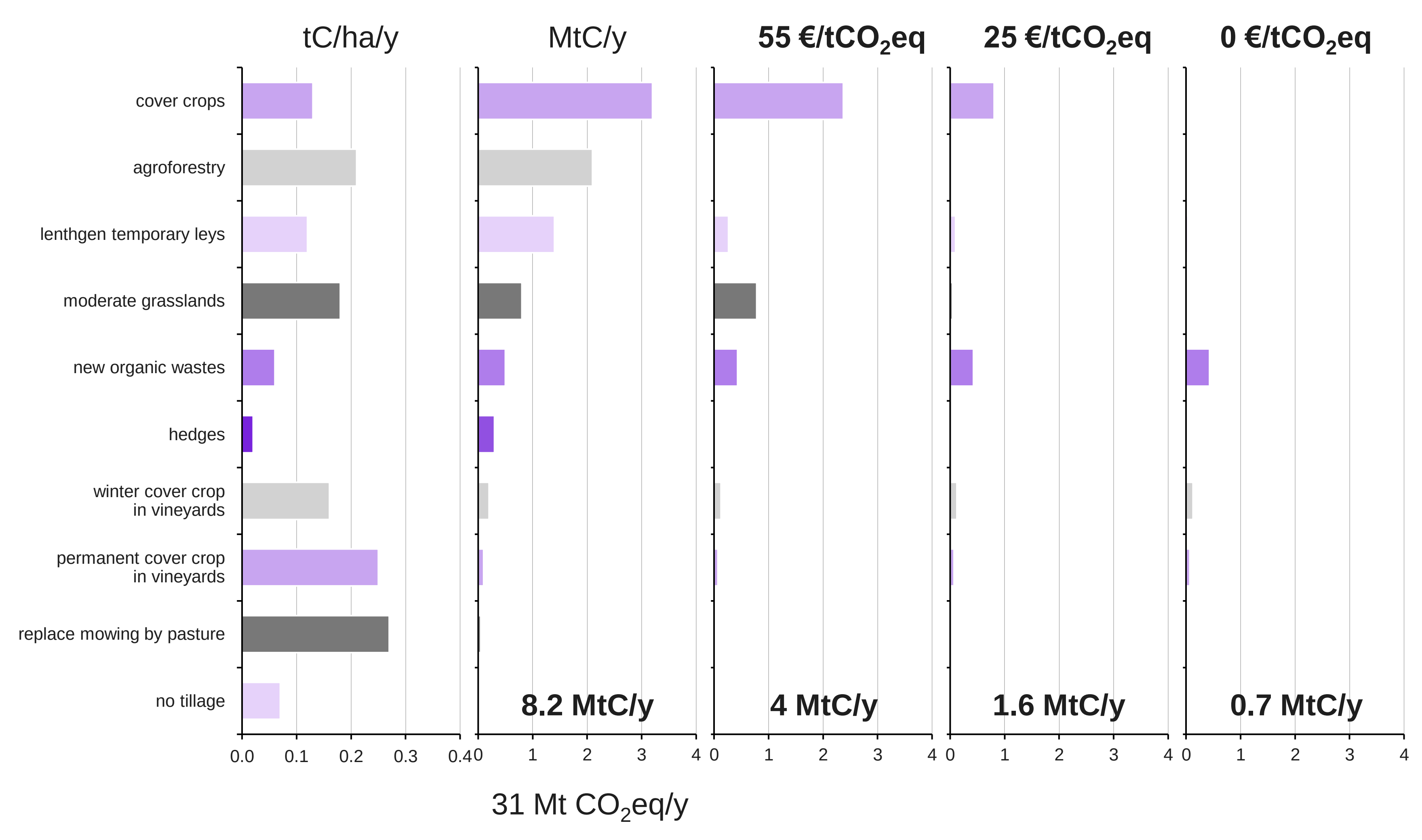
Sources: ICEF "Blue Carbon Roadmap, Carbon Captured by the World's Coastal and Ocean Ecosystems" (2022); Kearney analysis

… the realized potential is a function of costs (2/2)

Around one-half of the total abatement potential would be viable at €55 per tCO_2eq.

2.6 Role in achieving net zero through carbon removal

Soil organic carbon storage potential – technical vs. economic
Mainland France



Sources: Pellerin et al., 2019, 2020; Bamière et al., 2021; INRAE 4p1000 assessment (https://www.inrae.fr/en/news/storing-4-1000-carbon-soils-potential-france)

3. Regulatory and policy scan

Global regulatory and policy efforts to mitigate AFOLU emissions continue to gather momentum

Multiple international initiatives and national policy instruments are in force. UNFCC has been at the forefront of the policy development on the AFOLU sector's emission mitigation since the early 1990s. Various initiatives such as deforestation and conservation pledges, financing, carbon market development etc. have been announced in the recent COP summits to address emissions from AFOLU. Many countries now include mitigating AFOLU emissions in their updated NDCs.

A wide variety of policy tools are leveraged to mitigate AFOLU emissions. Financial incentives such as low interest loans, subsidy programs, Payment for Ecosystem Services (PES), emission trading schemes and carbon offsets, have been utilized to encourage mitigation efforts at global, national, and sub-national levels. Whereas regulations imply direct controls on how land is used, zoning sets legal limits on converting land from one use to another to realize emission mitigation aims such as conserving forest resources and safeguarding protected land resources, among others.

REDD+, Reducing Emissions from Deforestation and Forest Degradation. A climate change mitigation approach designed to incentivize developing countries to reduce carbon emissions from deforestation and forest has been developed under the UNFCCC umbrella. Developing countries that meet the requirements receive results-based payments for verified emissions reductions and this creates an incentive to reduce emissions from forests and invest in low-carbon paths to sustainable development. Countries implementing REDD+ activities must provide information on how social and environmental safeguards are being addressed and respected and develop a national forest monitoring system and national REDD+ strategy or action plan. 60+ developing countries have implemented or are implementing REDD+ activities under the UNFCCC guidance.

Mitigating the impact of LULUCF emissions is a focus area in key geographies. Brazil and Indonesia prioritize large-scale measures targeting land-use change and forests to lower emissions. Brazil instituted the Action Plan to Prevent and Control Deforestation in the Amazon (PPCDAm) in 2004 while Indonesia launched its plan, comprised of 23 mitigation activities, for the LULUCF sector in 2010. Both these countries have participated in REDD+ projects to conserve their forests. Afforestation is a key measure globally with many countries announcing specific targets such as The Middle East Green Initiative (MGI), which is a regional effort to plant 50 billion trees. Development of agricultural biogas, agro-ecology projects, promotion of innovative and sustainable agricultural practices, among others are key tools to address emissions from the agriculture sector.

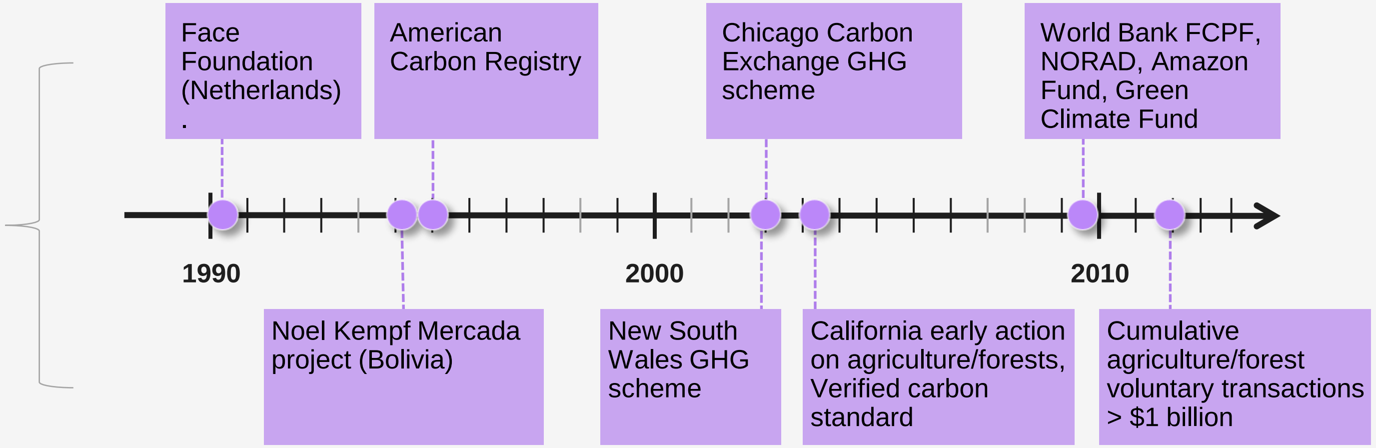
Various emissions trading markets and financing schemes have evolved to address the capital requirements for mitigation efforts. Capital flows toward AFOLU emissions mitigation have also gathered pace with USD 8 billion in investments pledged by 140 countries in climate-smart agriculture and food systems, and targeted methane abatement finance in AFOLU projects hit USD 4.2 billion in 2019–2020, making it the second largest tracked sector behind waste. However, the AFOLU sector still doesn't feature in most of the national emission trading schemes and emission abatement targets are sometimes not specific.

The past three decades have seen a constant push to formulate policies to facilitate and encourage GHG mitigation within AFOLU

Milestones in policy development for AFOLU measures

Timeline	1992	1997	2007	2012	2015	2022
International agreements	UNFCC – GHG inventory/comprehensive coverage of LULUCF and non-CO_2 emissions in agriculture	COP3, KYOTO protocol – GHG inventory/comprehensive coverage of LULUCF and non-CO_2 emissions in agriculture – Clean development mechanism	COP13, REDD+ – Avoided deforestation levels – Result-based payments (reducing emissions from deforestation and forest degradation, for example REDD+)	COP18 – Nationally appropriate mitigation actions (NAMA) which may cover AFOLU emissions	COP21, PARIS Agreement – Nationally determined contributions (NDC) which may cover AFOLU emissions	COP27 Launch of the Forest and Climate Leaders' Partnership (FCLP), following announcements made at COP26 (Glasgow), which aims to unite concrete action by governments, businesses, and community leaders.

Compliance and voluntary market and financing schemes



3.1 Milestones and timelines

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

A wide variety of policy tools are utilized to encourage mitigation of AFOLU emissions

Not exhaustive

Types of policy tools

1

Financial incentives	Description
Emissions trading/carbon taxes	Emissions trading programs have been developed across the globe, but forest and agriculture have not been included as part of the cap in any of the existing systems. However, offsets from forestry and agriculture have been included in several of the trading programs (for example, California, South Korea).
REDD+/payment for ecosystem services (PES)	REDD+ emerged in the early 2000s and is a widely recognized example of PES program focused on conservation of tropical forests. Measuring, monitoring, and verification systems have been developed and deployed, REDD readiness programs have improved capacity to implement REDD+ on the ground in more than 50 countries, and several countries now have received results-based payments.
Agro-environmental subsidy programs	Agriculture is one of the most subsidized sectors globally, especially in the European Union and the United States. While subsidy payments over the past 20 years have shifted modestly to programs designed to reduce the environmental impact of the agricultural sector, only 15–20% of the more than USD 700 billion spent globally on subsidies are green payments.

2

Regulations	Description
Legal frameworks that influence agricultural and forest management	Include direct controls on how land is used, zoning, or legally set limits on converting land from one use to another. However, regulatory approaches face challenges in part because environmental issues are a lower priority than many other socioeconomic issues in the least developed and developing countries.
Set asides and protected areas	A widely utilized approach for conservation, and accordingly, 726 Mha (18%) of forests are in protected areas globally.
Community forest management (CFM)	Provides property rights to communities, allowing less intensive use of forest resources, while at the same time providing carbon benefits by protecting forest cover.

Sources: IPCC Sixth Assessment Report (Working Group III, Climate Change 2022: Mitigation of Climate Change, Chapter 7), Kearney Energy Transition Institute analysis

REDD+ is a climate change mitigation solution developed by parties to the United Nations Framework Convention on Climate Change

REDD+ stands for "Reducing Emissions from Deforestation and Forest Degradation."

History

A REDD+ web platform was established, after COP 13, with the purpose of making available information relating to REDD+, including activities on capacity building, demonstration activities, addressing drivers of deforestation, and mobilization of resources.

– The requirements and mechanisms were further refined in the subsequent years (for example, three-phase progression to qualify for REDD+ in COP 16, Warsaw Framework adoption in COP 19).

– The Paris Climate Agreement recognizes REDD+ and the central role of forests in Article 5.

Map of REDD+ activities

Key aim

REDD+ aims to incentivize developing countries to contribute to climate change mitigation actions in the forest sector by:

– Reducing carbon emissions from deforestation

– Reducing carbon emissions from forest degradation

– Conservation of forest carbon stocks

– Sustainable management of forests

– Enhancement of forest carbon stock

Sources: press search, UNFCC REDD+; Kearney Energy Transition Institute analysis

Tracking of results

In COP 19, it was decided to establish the Lima REDD+ Information Hub to publish information on the results of REDD+ activities and corresponding results-based payments.

– Example: Brazil has bilateral agreements with the governments of Norway and Germany for REDD+ results-based payments to the Amazon Fund.

– Example: The 2019 Indonesia–Norway REDD+ deal was unsuccessful due to lack of payments but the countries signed another REDD+ deal in September 2022.

Developing countries that meet UNFCCC REDD+ will receive results-based payments for verified emissions reductions

Since 2008, the UN-REDD Programme (UNEP, FAO, and UNDP) has been supporting 65 partner countries in their nationally led efforts to become “REDD+ ready” and qualify for results-based payments.

3.2 Policy instruments

Three phases of REDD+

NFMS – National forest monitoring system

FREL – Forest reference emission levels

SIS – Safeguards and safeguards information systems

NS/AP – National strategies/action plans

Phase 1 – **Readiness**
Warsaw framework – Development of national strategies, action plans, and capacity building

Phase 2 – **Implementation**
Implementation of national strategies, action plans, deployment of NFMS, capacity building, and results-based demonstration activities

Phase 3 – **Payments for results**
Results-based actions are fully measured, reported, and verified

REDD+ enabling environment
Governance (policy and legal framework, tenure, and others) and stakeholder engagement (including indigenous groups)

Global impact

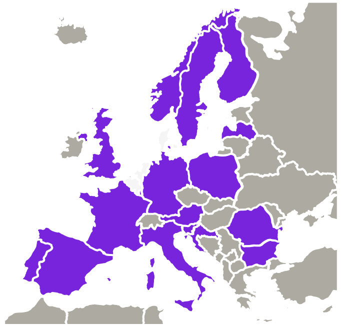
- UN-REDD countries have submitted forest emissions reductions equal to taking 150 million cars off the road for a year.
- More than USD 1 billion have been mobilized and channeled since the inception of UN-REDD.

Sources: press search, UNFCC REDD+; Kearney Energy Transition Institute analysis

Emission reduction targets for non-ETS sectors such as AFOLU are not outlined individually but cumulatively in the EU

Focus on the European Union

Non-exhaustive



3.3 Focus on geographies

Policy focus areas

Climate and energy framework	**Effort sharing decision (ESD) mechanism** – Non-ETS sectors (of which AFOLU is a part) cumulatively to cut emissions by 30% (compared to 2005 levels) through effort sharing regulation which sets national targets. **LULUCF regulation** – Target for net carbon removals by natural sinks to 310 million tonnes of CO_2 equivalent by 2030 **European Green Deal** – Farm to fork strategy, which aims to reduce the environmental and climate footprint of the EU food system and ensure food security.
Common Agricultural Policy (CAP) and Carbon Farming Initiative	CAP provides financial support through its two pillars: **Green direct payments** conditional on following eco-friendly practices **Rural Development Programme (RDP)'s Priority 5** addresses "resource efficiency and shift to low carbon and climate resilient economy" in the AFOLU and food sectors The EU has also launched a **Carbon Farming Initiative**, which aims to promote carbon sequestration and soil health in agricultural practices.

Examples of country specific initiatives

Ireland

Emissions by agriculture account for 32.7% of total emissions compared to 10% share of emissions in the EU.

- Climate action plan: specific targets for reducing emissions from AFOLU are set for 2021–2030.
- Ag-climatize: road map aims to translate the targets set for the AFOLU sector in the Climate Action Plan into more detailed actions and targets, such as i) enhancing soil fertility and nutrient efficiency, ii) promoting the use of protected nitrogen products, iii) developing enhanced dairy and breeding programs, and iv) developing a charter with animal feed manufacturers on the crude protein content of livestock.
- The Targeted Agricultural Modernisation Schemes (TAMS II) is an RDP-funded measure supporting the emission reduction target for agriculture pledged in the Climate Action Plan.

France

France set a target to reduce agricultural emissions by 12% by the end of its third carbon budget period in 2028 (compared to 2013) and by 24% by 2050 (compared to 1990).

- The agricultural emissions targets will be achieved primarily through the implementation of the agro-ecology project.
- Six strategies cover sustainable forest management, and in particular the National Forest and Wood Programme 2016–2026 provides a policy framework for LULUCF.

Germany

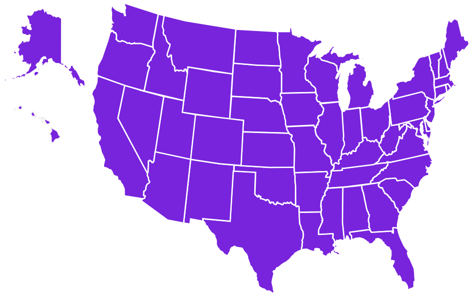
Targets a 31–34% annual reduction in agricultural emissions by 2030, compared to 1990 levels, in its Climate Action Plan 2050.

Sources: OECD – "A survey of GHG mitigation policies for the agriculture, forestry, and other land-use sectors" (2020); Kearney Energy Transition Institute analysis

Many programs under federal and state governments have been implemented to target AFOULU emissions in the United States

Focus on the United States

Non-exhaustive



Policy focus areas

Agri-environmental programs	The federal government funds a number of agri-environmental programs in the United States. : **Financial funding** For the conversion of environmentally fragile cropland to approved conservation uses, including long-term retirement (Conservation Reserve Program) Reward crop and livestock farmers for the implementation of conservation practices that reduce environmental pressures such as cover crops and prescribed grazing Funding for all major national conservation programs in agriculture is being continued under the current farm law, the Agriculture Improvement Act.
AgSTAR program	This program by the US EPA promotes the use of biogas recovery systems to reduce methane emissions from livestock waste. It offers technical, financial, and policy resources to farmers and industry for the deployment of anaerobic digester and biogas recovery systems for manure management.

Other initiatives

Agriculture Resilience Act

In 2019, the Agriculture Resilience Act was introduced in the US Congress. The bill includes several provisions aimed at reducing greenhouse gas emissions from agriculture, including funding for research into sustainable agriculture practices, incentives for farmers to adopt climate-friendly practices, and support for the development of renewable energy on farms.

Research programs

National Resources Conservation Service (NRCS) Conservation Innovation Grants program encourages voluntary demonstration projects across the country to stimulate the development and adoption of innovative conservation programs and technologies, some of which focus on agricultural GHG emissions reduction and soil carbon.

- Sustainable Agriculture Research and Education program by the USDA is a decentralized competitive grants program that funds farmers, researchers, educators, and students to advance sustainable agricultural practices.

Industry initiatives

The Alliance for Sustainable Agriculture is a collaboration by stakeholders across the agricultural supply chain working to advance the sustainability of US commodity crop production.

Sources: OECD – "A survey of GHG mitigation policies for the agriculture, forestry, and other land-use sectors" (2020); Kearney Energy Transition Institute analysis

Currently, agriculture and land-use sector is not part of the National Emissions Trading Scheme in China

Focus on China

Non-exhaustive

Policy focus areas

National Emissions Trading Scheme	The main policy mechanism being considered to mitigate national emissions is a nationwide emissions trading scheme, which was launched in December 2017, that will build on existing pilot schemes. – Initially the scheme covers the power sector only – Depending on the findings from this initial phase, the scheme could be expanded to include other sectors, including agriculture. – However, there is no specific timeline for the inclusion of other sectors.
Agricultural biogas	Agricultural biogas production from the treatment of livestock and poultry manure, straw, and agricultural processing waste can reduce manure-based CH_4 emissions. The Agricultural Biogas Development Plan (2017) aims to reduce China's GHG emissions by 46 $MtCO_2eq/yr$ by 2020 by increasing agricultural biogas and digestate fertilizer production. Support for agricultural biogas production tends to take the form of subsidies for the construction of biogas digesters or plants.

Other initiatives

Agriculture

In 2020, China released a new Agricultural Green Development Plan, which aims to reduce the carbon footprint of the agricultural sector. The plan includes several policy tools, such as promoting the use of green fertilizers and pesticides, encouraging the adoption of precision agriculture techniques (such as intermittent irrigation for rice crop), and supporting the development of renewable energy in rural areas.

LULUCF

A number of forestry programs, primarily involving increased afforestation and improved forest management, support GHG emission reductions in the LULUCF sector. China's Grain-for-Green Program (GFGP) is described as the world's largest reforestation scheme.

The National Afforestation Plan (2016–2020) and the Forest Management Plan (2016–2050) will also help reduce deforestation-related emissions.

China has implemented a Forest Carbon Sequestration Program to encourage afforestation and reforestation in areas with low vegetation cover. The program provides financial incentives for planting trees and sequestering carbon, and it also supports the development of forest-based carbon offset markets.

Research programs

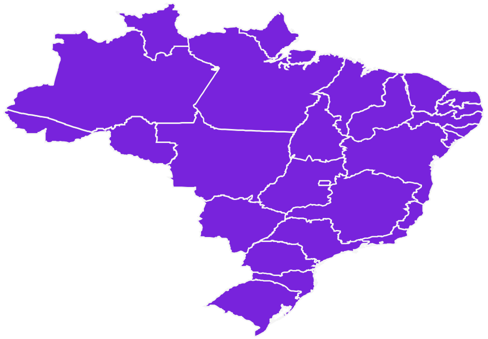
In 2018, China launched two major research projects on GHG emissions mitigation from livestock as part of a research collaboration among Chinese agencies, the Research Program on Climate Change, Agriculture, and Food Security (CCAFS), the Sino-Dutch Dairy Development Centre (SDDDC), Wageningen University & Research, GRA, and the private sector.

Sources: OECD – "A survey of GHG mitigation policies for the agriculture, forestry, and other land-use sectors (2020); Kearney Energy Transition Institute analysis

Brazil prioritizes large-scale measures targeting land-use change and forests to lower emissions

Focus on Brazil

Non-exhaustive



3.3 Focus on geographies

Policy focus areas

Adaptation and Low Carbon Emission Agriculture (ABC) Plan	Launched in 2010, the ABC Plan integrates the sectoral plans and targets set by Brazil in its NAMAs and its NPCC. **Main objective** – Promote sustainable development, reduce CO_2, CH_4, and N_2O emissions, increase carbon removals from agriculture, and increase the resilience and adaptive capacity of agricultural systems **Key levers** – Low-interest loans to farmers who want to implement sustainable agricultural practices
The Action Plan to Prevent and Control Deforestation in the Amazon (PPCDAm)	The plan was launched in 2004, when deforestation rates in the Amazon forest were growing significantly. The program helped curb deforestation in the Amazon biome. **Main objective** – Reduce deforestation and enable the transition to a sustainable development model in the Amazon **Key levers** – i) Land use, tenure, and settlement planning; ii) environmental monitoring and control; and iii) promotion of sustainable production activities

Other initiatives

The Action Plan to Prevent and Control Deforestation and Fire in the Brazilian Cerrado (PPCerrado)

The Cerrado biome has experienced an extremely high rate of land conversion in recent decades, with deforestation rates surpassing those in the Amazon. By 2009, the biome had already lost 48% of its forest cover.

- Launched in 2010, the PPCerrado targets a sustained reduction in the deforestation rate and a reduction in the occurrence of forest fires and burning in the Cerrado.
- In 2019, deforestation reached 6,483 km² in the biome, which is marginally lower than the 6,634 km² recorded in 2018 and was 35% lower than in 2010 when the plan was implemented.

The Forest Code

Created in 1934, and revised in 2012, the Forest Code is considered the main environmental law in Brazil. It regulates land-use and conservation to native vegetation on private properties and has prioritized the mapping and identification of individual land holdings in forested areas, enrolling them in the national Cadastro Ambiental Rural (Rural Environmental Registry) system.

Reducing emissions from deforestation and forest degradation (REDD+)

An international climate change mitigation mechanism developed by the UNFCCC which creates a financial value for the carbon stored in forests by offering incentives for developing countries to reduce emissions from forest land and invest in low-carbon paths to sustainable development. The developing countries are incentivized to maintain their forests by offering results-based payments for actions to reduce or remove forest carbon emissions.

Sources: OECD – "A survey of GHG mitigation policies for the agriculture, forestry, and other land-use sectors (2020); Kearney Energy Transition Institute analysis

LULUCF is the policy focus area in Indonesia for GHG emission reduction

Focus on Indonesia

Non-exhaustive

Policy focus areas

National Action Plan to reduce GHG emissions (RAN-GRK)	Launched in 2010, the plan outlined 23 mitigation actions for the LULUCF sector and seven for the agricultural sector and included a number of quantitative targets to be achieved by 2020. All provincial governments also have their own local mitigation plan. **Key mitigation areas** – Management of lowland rice, promotion of organic fertilizer, and the utilization of livestock manure and agricultural waste for biogas production
Forestry sector (as forests cover 63% of Indonesian territory and have world's largest area of tropical peatland)	These forest stocks have been under threat due to conversion to oil palm concessions, pulp and paper plantation, and other commercial uses. However, the destruction rates have come down significantly due to government policies: – Forest Moratorium which prohibits conversion of primary forests and peatlands and promotes sustainable forest management – Government Regulation No. 57 of 2016 halts issuance of new licenses on peatlands permanently. – In 2016, a Peat Restoration Agency was established.

Other initiatives

Initiatives focused on the forests

- Forest and land rehabilitation projects: Classification of forests and lands as critical and allocating budget for rehabilitating them. However, previous budgets were insufficient and could achieve only partial targets
- Forest and land fire control: Establishment of a national program for forest and land fire control. This is supported by key measures such as early warning detection systems, capacity building, stronger enforcement, and international co-operation.

International initiatives

Indonesia has actively engaged in REDD+ negotiations and development since 2007.

Research programs

The Sustainable Intensification of Dairy Production Indonesia (SIDPI) project supports GHG mitigation in the AFOLU sector.

Sources: OECD – "A survey of GHG mitigation policies for the agriculture, forestry, and other land-use sectors (2020); Kearney Energy Transition Institute analysis

The Middle East Green Initiative (MGI) is a regional effort led by Saudi Arabia to mitigate the impact of climate change on the region

Focus on Middle East

Non-exhaustive

3.3 Focus on geographies

Policy focus areas

Afforestation	A target of planting 50 billion trees across the Middle East has been set. A fifth (10 billion) trees will be planted within Saudi Arabia's borders, with the remaining 40 billion being planted across the region in the coming decades. **Scale of this afforestation initiative:** – This is equivalent to restoring 200 million hectares of degraded land and 5% of the global afforestation target.
Saudi Green Initiative	In addition to the afforestation targets, Saudi Arabia is committed to protecting 30% of its terrestrial and marine area. The protected areas cover a variety of geographies, including deserts, forests, mountains, and coastal areas. **Key initiatives** – Conserve and restore vegetation cover in rangelands, nature reserves, national parks, and others – Vegetation cover development and combating desertification – Sustainable forest management and development – Sustainable management and conservation of coastal area environments

Other initiatives

Carbon markets and Financing

- In October 2022, 1.4 million tons of carbon credit offset certificates were sold to 15 Saudi and regional entities in 1st regional Voluntary Carbon Market in MENA i.e. Middle east and North Africa (set up by Saudi Arabia's Public Investment Fund)
- At COP27, The Arab Coordination Group (ACG) members pledged USD 24 billion in financing by 2030 in multiple sectors including agriculture

Agriculture Innovation Mission for Climate (AIM4C)

This is a global initiative led by the UAE and the US, with the support of more than 140 government and non-government partners, to target USD 8 billion in investments in climate-smart agriculture and food systems by 2025.

Conservation of blue carbon ecosystems

The UAE is among the few countries that have proactively expanded their mangrove forest cover as it has implemented a range of restoration and conservation efforts since the 1970s.

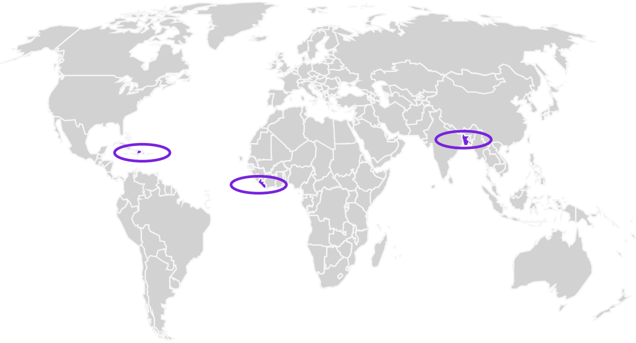
- During COP26, the UAE announced its ambition to plant 100 million mangrove seedlings by 2030, significantly increasing the target of 30 million seedlings set in 2020.
- The emirate of Abu Dhabi targets the inclusion of a minimum of 20% marine blue carbon habitats within protected areas.
- The UAE is working on the Mangrove Alliance for Climate (MAC) that seeks to leverage expertise and resources to scale up and accelerate mangrove conservation, restoration, and resilience.

Agriculture 4.0 initiative

This initiative, by the government of UAE, seeks to upgrade traditional farms with technology-enabled operating models that optimize production while abiding by the water budget set by the UAE Water Strategy 2036.

Sources: OECD – "A survey of GHG mitigation policies for the agriculture, forestry, and other land-use sectors (2020), press search, country NDC on UNFCC; Kearney Energy Transition Institute analysis

For the food systems, mitigation and adaptation measures are included in NDCs, mainly through measures at agriculture production level



Bangladesh

Plans to reduce methane emissions from rice cultivation have been defined:

- Aim to shift 50,000 ha to an alternate wetting and drying (AWD) irrigation method have been included. Additional 100,000 ha using AWD are planned based on international finance support.
- Variety of rice change and improving fertilizer management are also considered to reduce emissions.

Dominican Republic

Specific quantitative and qualitative food systems measures have been included for agroforestry and sustainable livestock among others:

- Plans to reduce emissions by 5 $MMtCO_2eq$ from the conversion into low carbon coffee production of 75,102 ha by 2035.
- Additional reductions are aimed at cocoa production with a potential of 2.2 $MMtCO_2eq$ across 146,600 ha over a 10-year period.

Liberia

Pledged 40% GHG reduction of agricultural emissions ($13GgCO_2eq$) by 2030.
The measures to promote low-emission rice cultivation include:

- No/low tillage
- Multi-cropping
- Organic fertilizers
- Crop rotation
- Others

Additional measures address food waste and dietary guidelines to support climate-resilient food security.

3.3 Focus on geographies

Sources: WWF, Unlocking and Scaling Climate Solutions in food systems, 2022; Kearney Energy Transition Institute analysis

Key initiatives have been launched at the recent COP summits ….

Non-exhaustive

Out of all new/updated NDCs (Nationally Determined Contributions), 95% also include mitigation in the agriculture and/or land use, land use change, and forestry (LULUCF) sectors compared to previous NDCs (82%).

3.4 UN climate change conferences and AFOLU

COP26

Declaration of forests and land use

The leaders of more than 140 countries, **accounting for 90% of the world's forests**, signed a declaration in which, among other things, commitment to conserve forests and other terrestrial ecosystems and accelerate their restoration was highlighted.

- However, this declaration is less specific than the previous ones such as the New York Declaration (2014) on forests, signed by a smaller number of stakeholders.

Global forest finance pledge

Intention to collectively provide **US$ 12 billion for forest-related climate finance between 2021 and 2025** which will be used for financing the protection, restoration, and sustainable management of forests

Global action agenda for innovation in agriculture

It aims to close the "innovation gap" limiting the ability to adapt to and mitigate climate change, while accelerating efforts toward greater food security around the world.

- Between US$ 50-70 billion is spent on agricultural innovation every year in low- and middle-income countries
- But **less than 7% of that expenditure** seeks to improve the environment or limit climate change and its impacts

Global methane pledge

Although not specifically aimed at AFOLU emissions, it commits more than 100 countries, representing nearly 50% of global anthropogenic methane emissions and more than two-thirds of global GDP, **to reduce human-caused methane emissions by 30% this decade from 2020 levels**, which would avert at least 0.2°C in global warming by 2050.

- Targeted methane abatement finance in AFOLU projects reached US$ 4.2 billion in 2019–2020, making it **the second largest tracked sector behind waste**

Sources: Press search, UKCOP26; Kearney Energy Transition Institute analysis

… targeting AFOLU emissions

Non-exhaustive

Koronivia Joint Work for Agriculture, the only formal UNFCCC workstream for food, was renewed to advance the discussions on agriculture and climate change linkages (including reducing emissions and increasing resilience).

3.4 UN climate change conferences and AFOLU

COP27

Deforestation and conservation pledges

Several new multi-country initiatives for tackling deforestation and restoring carbon-rich ecosystems were unveiled

– **Forest and Climate Leaders' Partnership:**, a group of 26 countries – representing a third of the world's forests – will meet twice yearly to track commitments on efforts to halt and reverse forest loss by 2030

– **Positive conservation partnerships:** an initiative launched by France to protect areas high in carbon stores and biodiversity, such as ancient forests, peat bogs or mangroves

Strategic alliance on rainforests

Brazil, Indonesia and the Democratic Republic of the Congo, which account for more than half of the world's tropical forests, launched an alliance for rainforest conservation

– Other countries, esp. in the Amazon basin, can be included in the alliance in the future

– Colombia and Venezuela proposed relaunching the 1978 Amazon Cooperation Treaty Organisation

Financing

Multiple funding initiatives were announced

– **Bezos Earth Fund** has pledged to invest USD 1 billion by 2030 for the conservation of the most important carbon and biodiversity stores

– US, EU, Norway, Germany and the Netherlands announced an **additional USD 135m of funding for fertiliser and soil-health programmes** in sub-Saharan Africa and in key middle-income countries climate

Carbon market development

Progress was made in defining the functioning of Article 6 (which governs carbon trading and other cooperative approaches to cutting emissions) including the use of **Internationally Transferred Mitigation Outcomes (ITMOs)**

– **African Carbon Markets Initiative** which aims to expand Africa's participation in voluntary carbon markets

– Switzerland and Ghana have completed the first ever voluntary sale of ITMOs under Article 6.2 (sustainable rice farming in Ghana will help Switzerland lower its national emissions)

Sources: Press search; Kearney Energy Transition Institute analysis

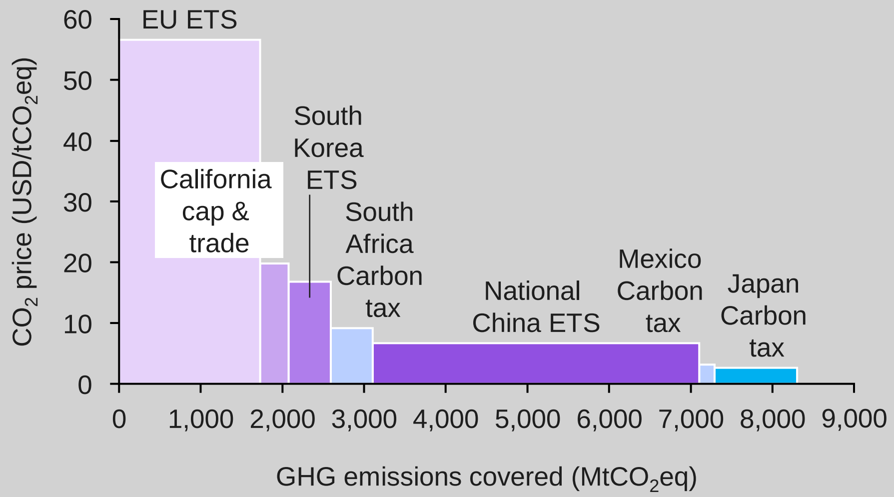
4. Voluntary markets

Carbon regulations are globally strengthening, providing further support to low-carbon solutions

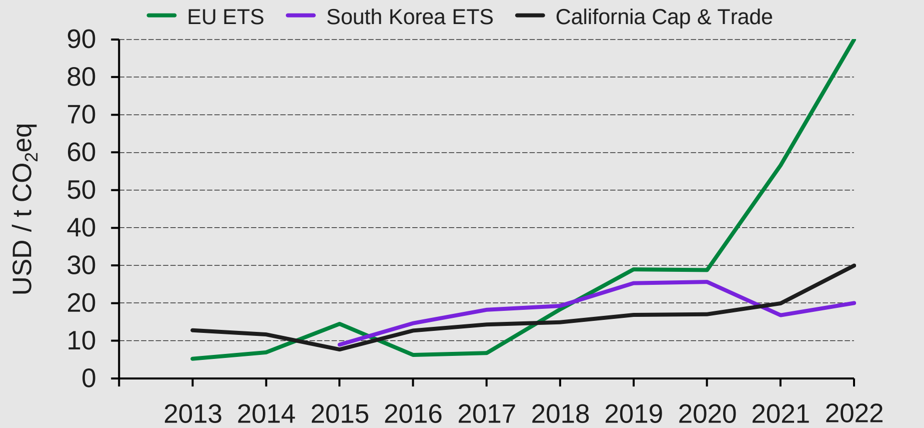
About 22% of global GHG emissions are covered by current mechanisms (11.65 $GtCO_2eq$), but level of pressure varies per geography.

4.1 Overview of carbon pricing mechanisms

Largest carbon-pricing systems by emissions covered (2021)

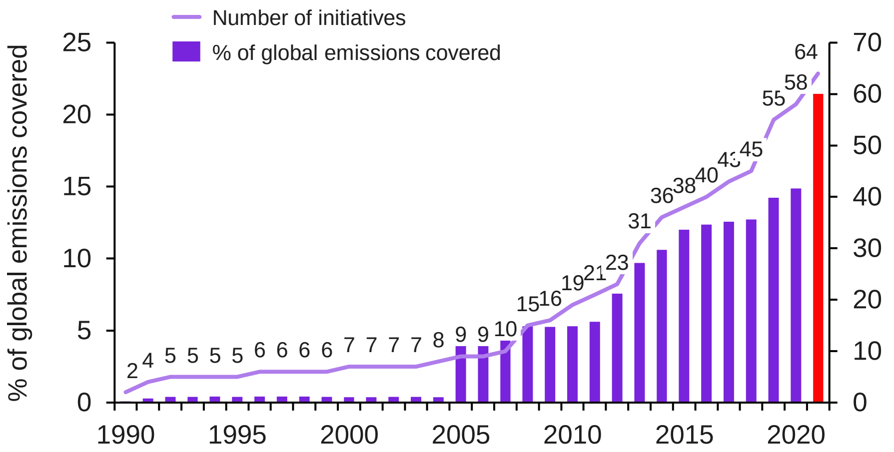


Carbon price in key ETS/cap and trade markets (annual average, USD/tCO_2eq)



Sources: ICAP (https://icapcarbonaction.com/en/ets-prices); Kearney Energy Transition Institute analysis

Global carbon pricing initiatives



Kearney XX/ID

Carbon pricing mechanisms that put a price on greenhouse gas emissions include carbon taxes, emission trading systems (ETS), and carbon crediting

Categories of carbon markets

Regulated		Usually not regulated
1 Carbon tax	2 Compliance carbon markets	3 Voluntary carbon markets
Explicit rate on GHG emissions incentivizing emissions reduction	**Market for carbon credits created by the need to comply with a regulatory act** (carbon allowances)	**Corporations, governments, and individuals volunteer to offset their emissions by purchasing credits** (carbon offsets)
Carbon taxes – A carbon tax **directly sets a price on carbon** by defining a tax rate on greenhouse gas emissions. – Provides corporations (and households, depending on the scope) an incentive to reduce emissions whenever doing so would cost less than paying the tax.	**Emission trading systems (ETS)** – Also referred to as **cap-and-trade** programs – The "cap" on GHG emissions declines annually to achieve the climate policy targets of its jurisdiction or members. – Allowances are **freely allocated or auctioned** to companies which can then "trade" allowances to comply with the cap on their emissions. – Companies with low emissions can sell their extra allowances to larger emitters.	**Carbon credits/offsets** – Generated by projects that **avoid, reduce, or remove GHG emissions** beyond a business-as-usual scenario. – Projects include **reforestation**, improved forest management, wetland restoration, and **renewable energy.** – Traded by individuals and companies on the voluntary markets (though some carbon offsets can also be used in select compliance markets). – Rules are established by independent standards bodies (both private and public).

Recently carbon credits have **started trading in commodity markets** (London Stock Exchange, KSA Exchange, and Xpansive) **adding liquidity and pricing transparency.**

Sources: Kearney Energy Transition Institute analysis

Carbon credits generally follow certain principals defined by standards

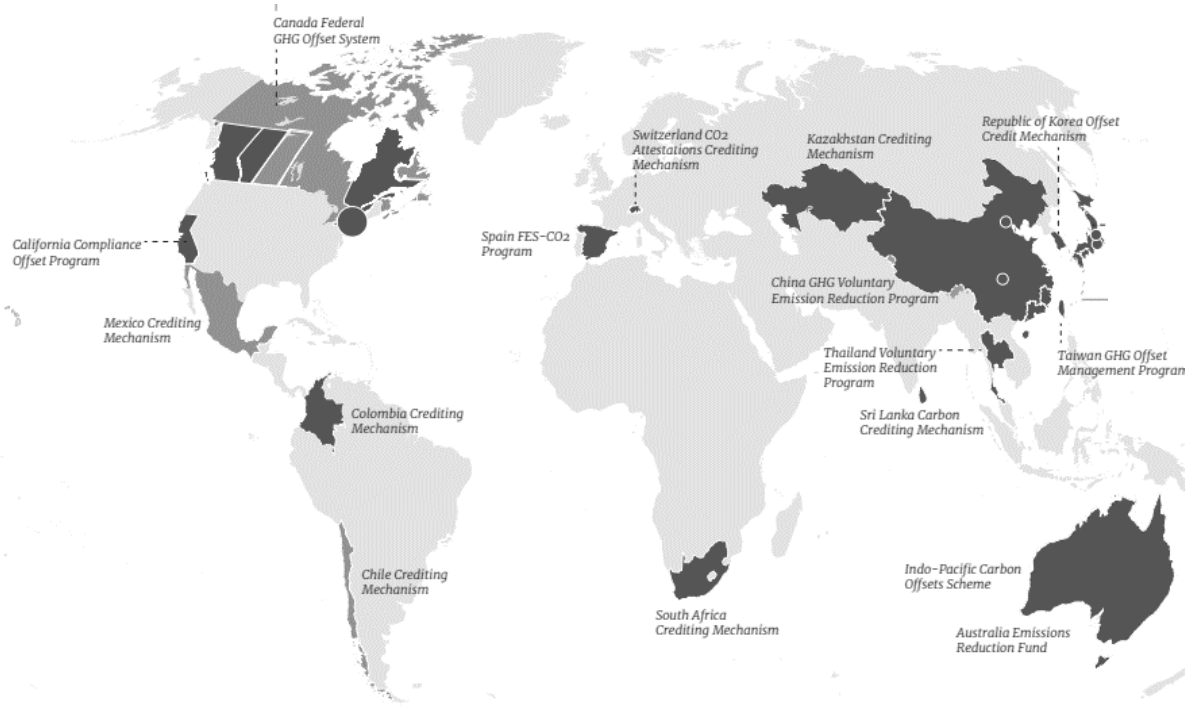
Principle	Description
Real	All emission reductions and removals—and the project activities that generate them—shall be proven to have **genuinely taken place.**
Measurable	All emission **reductions and removals shall be quantifiable**, using recognized measurement tools (including adjustments for uncertainty and leakage), against a **credible emissions baseline**.
Permanent	Carbon credits shall represent permanent emission reductions and removals. Risk of reversal should be minimized; mechanisms should be in place for compensations in case they occur. The internationally accepted norm for **permanence is 100 years**.
Additional	Additionality is a fundamental criterion for any offset project. Project-based **emission reductions and removals shall be additional** to what would have occurred if the project had not been carried out.
Independently verified	All emission reductions and removals shall **be verified to a reasonable level** of assurance by an **independent and qualified third party.**
Unique	**No more than one carbon credit can be associated with a single emission** reduction or removal as one (1) metric ton of carbon dioxide equivalent (CO_2eq). Carbon credits shall be **stored and retired in an independent registry**.

Sources: World Bank (2019), "State and trends of Carbon Pricing; Kearney analysis

National and subnational crediting mechanisms are being implemented across the globe

Crediting mechanisms implemented

Non-exhaustive



Implemented Under development

4.2 Voluntary markets and carbon crediting

Crediting mechanisms implemented

National:

- China GHG Voluntary Emission Reduction Program
- J-Credit Scheme
- Republic of Korea Offset Credit Mechanism
- Switzerland CO_2eq Attestations Crediting Mechanism
- Australia Emissions Reduction Fund
- Thailand voluntary emissions program

Subnational:

- Fujian Forestry Offset Crediting Mechanism
- Guangdong Pu Hui Offset Crediting Mechanism
- Québec Offset Crediting Mechanism
- Saitama Crediting Mechanism
- Saitama Forest Absorption Certification System
- Tokyo Offset Mechanism

Crediting mechanisms under development

National:

- Canada GHG Offset System
- Kazakhstan Crediting Mechanism
- Mexico Crediting Mechanism
- South Africa Crediting Mechanism
- Chile Crediting Mechanism

Subnational:

- Nova Scotia Crediting Mechanism
- Washington State Crediting Mechanism

Note: "Implemented“ crediting mechanims have the required framework (for example, legislation mandate) as well as the supporting procedures, emissions reduction protocols, and registry systems in place to allow for crediting to take place.
Sources: Worldbank; Kearney analysis

The main compliance markets do not allow compensating carbon emissions from NBS (nature-based solutions) projects developed abroad

Integration of NBS offset solutions in key compliance markets

Market	Local NBS allowed for offset?	NBS credits from foreign projects?	Comments
European Union ETS	✗	N/A	– The EU has a domestic emissions reduction target and **does not currently envisage continuing the use of international credits for EU ETS compliance after 2020**. – Provisions will need to be applied through implementing decisions over the coming years and set under Article 6 of the Paris Agreement. – In its current Phase IV (2021–2030), the ETS current legislation does not allow the use of offsets mechanisms.

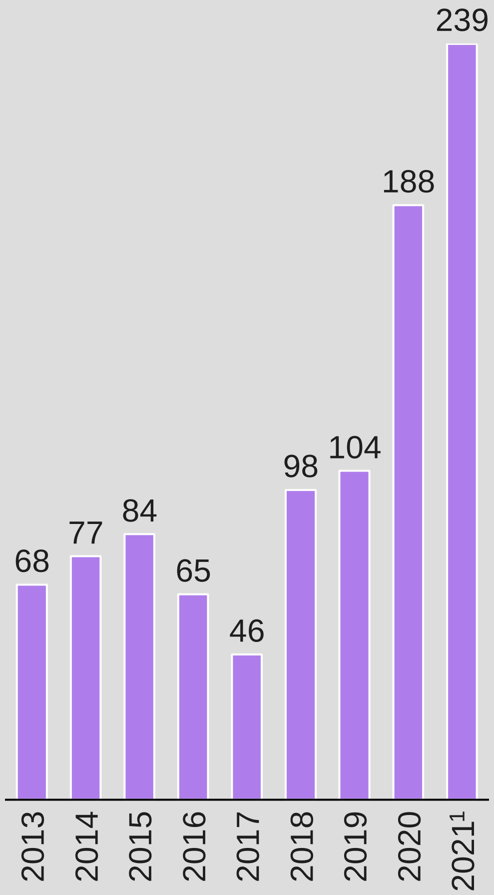
South Korea ETS	✓	Depending on project structuring	– Offset solutions (for example, Korean Offset Credits - KOCs) are limited to 10% of an entity's compliance obligation, reduced to 5% when offset is based on international projects.
			– Offsets from international projects are allowed since 2018, when a Korean company:
			  – Has at least 20% of the ownership rights, operating rights, or the voting stocks are owned by a Korean company;
			  – Supplies the low-carbon technology worth at least 20% of the total project cost; or
			  – Funds the project with a national or regional government operating in a UN-designated Least Developed Country or a low-income economy as classified by the World Bank.

California's Cap & Trade market	✓	✗	– **Offset solutions are accepted but only for NBS solutions located anywhere in the US territory and are limited to 4% to 8% of total emissions.** – California has also linked its system with the Canadian province of Quebec's cap-and-trade program, meaning that businesses in one jurisdiction can use emission allowances (or offsets) issued by the other for compliance. – California's program includes MOU with Mexico and Brazil, which are developing projects to reduce emissions from deforestation and land degradation (REDD).

Market size of voluntary carbon offsets has increased substantially in recent years; however, prices are still low

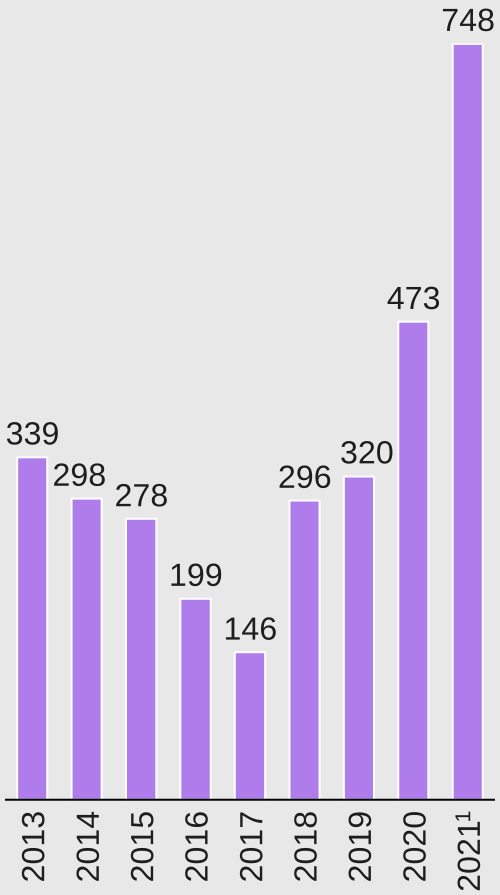
Market size by traded volume of voluntary carbon

$MtCO_2eq$



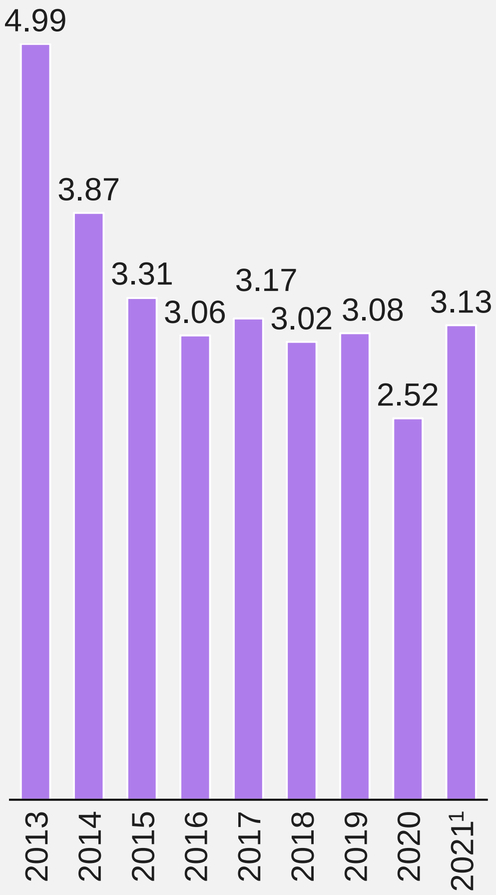
Market size by traded value of voluntary carbon

USD million



Carbon price in global voluntary markets

USD per tCO_2eq



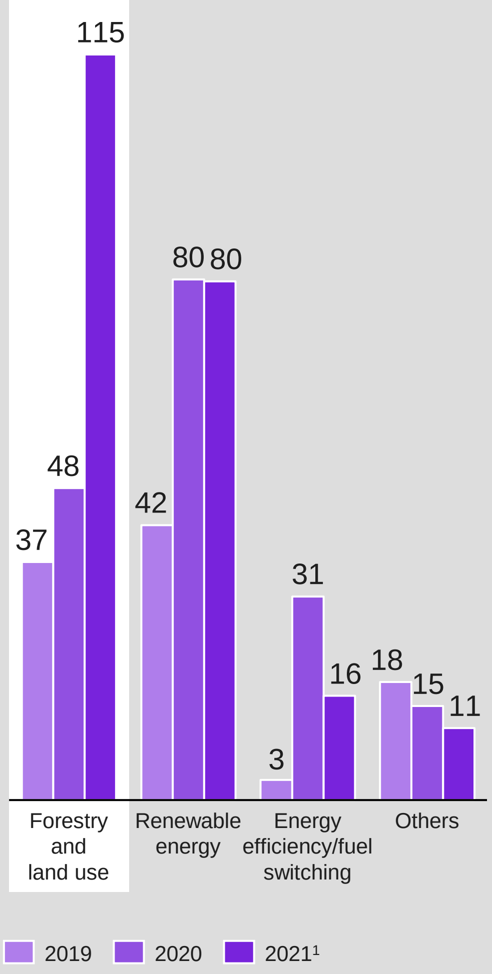
1. January–August 2021
Sources: Ecosystem Marketplace; Kearney analysis

4.2 Voluntary markets and carbon crediting

Forestry and land-use projects have driven the voluntary market growth and command a price premium of approximately 5 USD/tCO_2eq

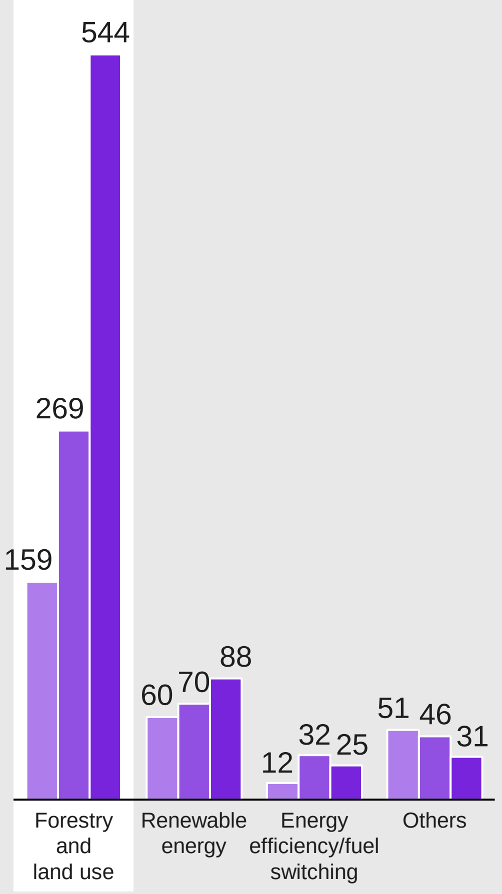
Market size by traded volume of voluntary carbon

$MtCO_2eq$



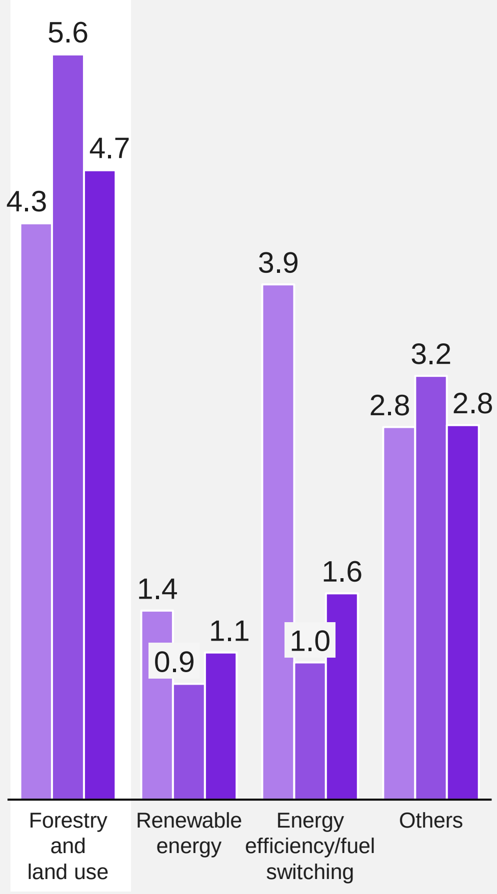
Market size by traded value of voluntary carbon

USD million



Carbon price in global voluntary markets

USD per tCO_2eq



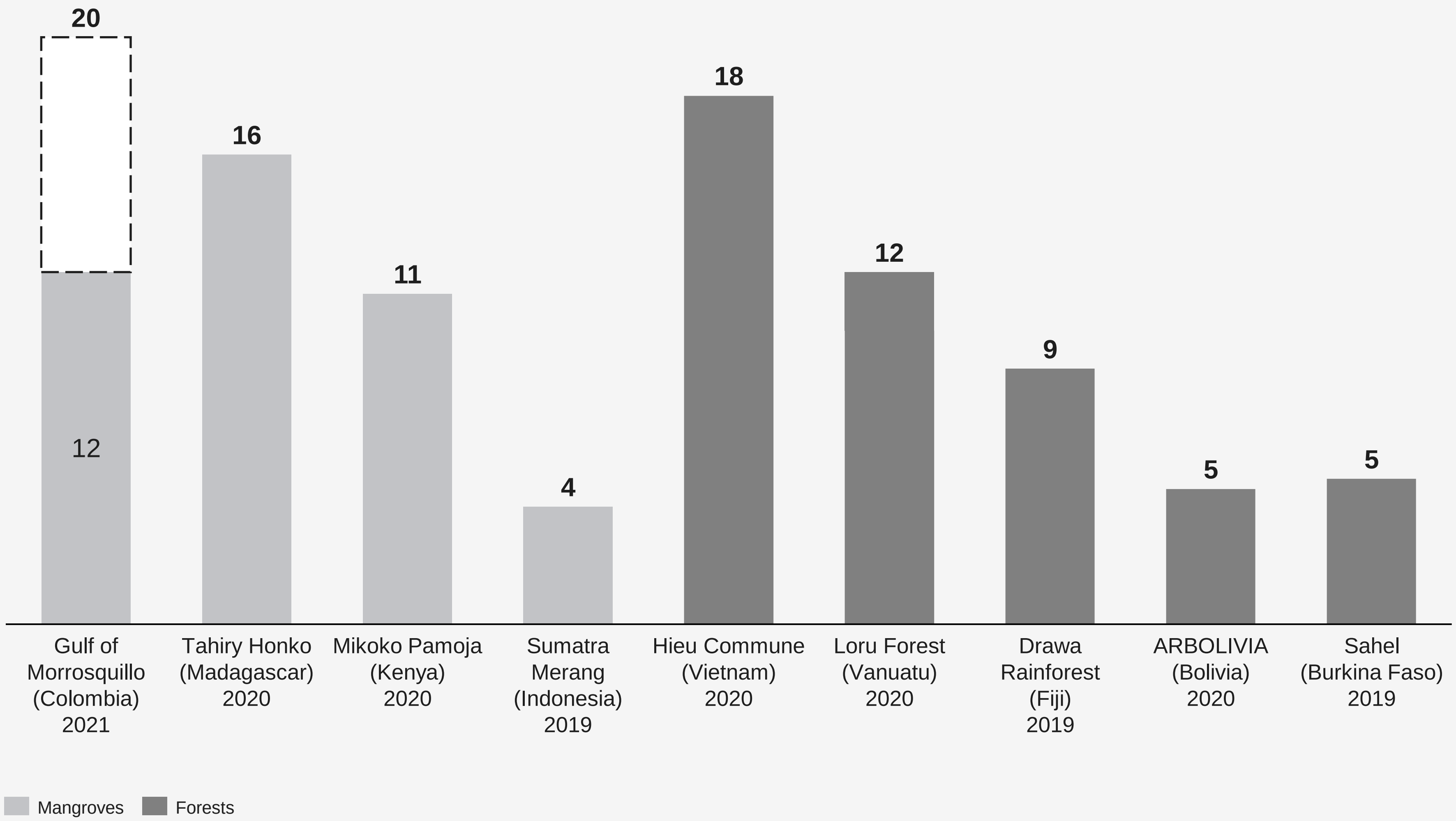
1. January–August 2021
Sources: Ecosystem Marketplace; Kearney analysis

4.2 Voluntary markets and carbon crediting

Analysis from real NBS projects showcases high volatility in prices

Carbon credits prices reported for mangroves and forests projects[1]

USD/ton



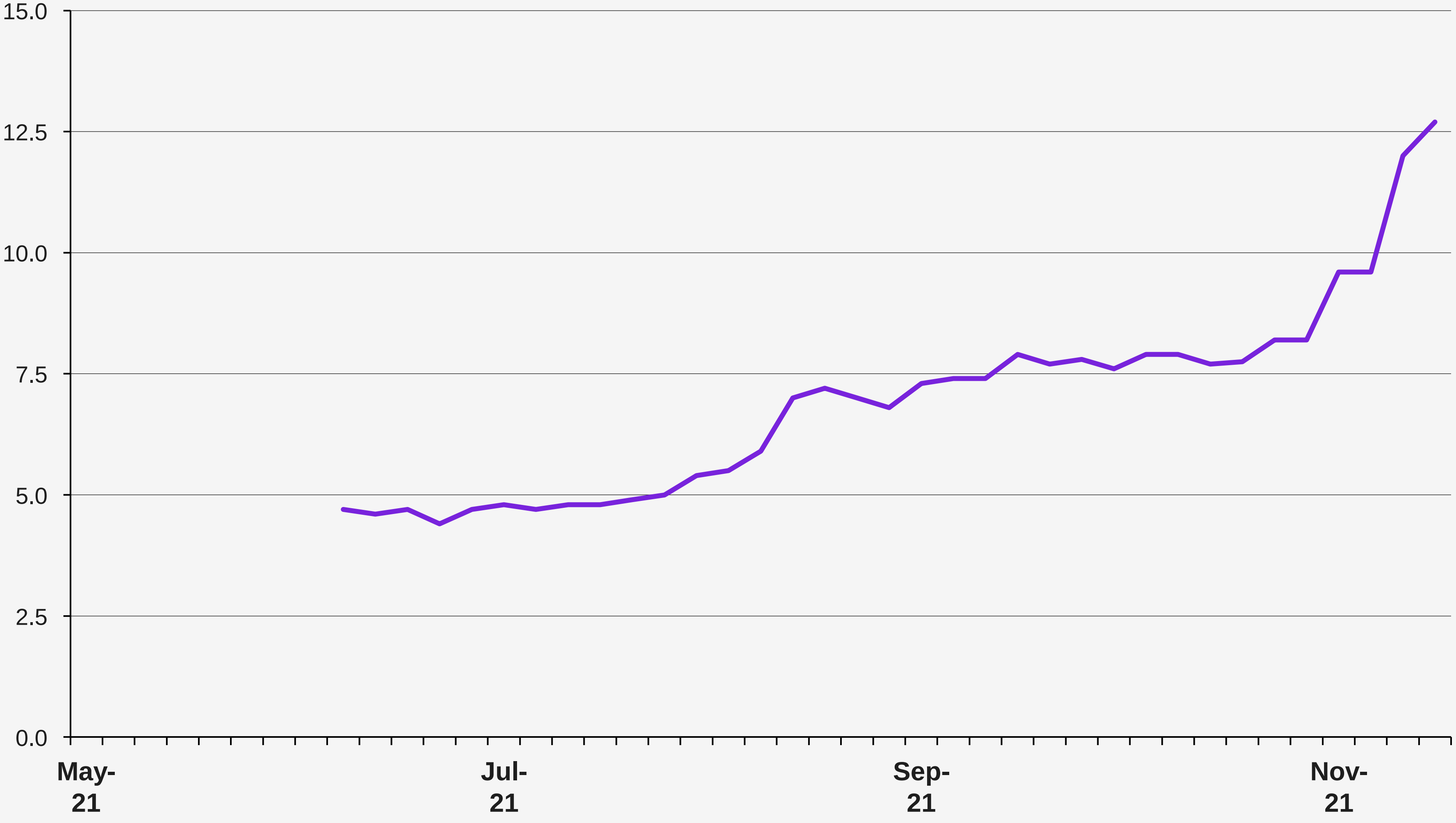
1. Additional certifications (for example, biodiversity) and blue carbon project's high demand mentioned as main reasons for the price premium.

Sources: expert interviews, Ecosystem Marketplace's State of the Voluntary Carbon Markets 2021, Verra Project Database, Plan Vivo Project Database, press desktop research; Kearney analysis

4.2 Voluntary markets and carbon crediting

Recent increases in climate ambition from governments have supported carbon prices worldwide

Platts NBS carbon credit prices
USD/MtCO$_2$eq



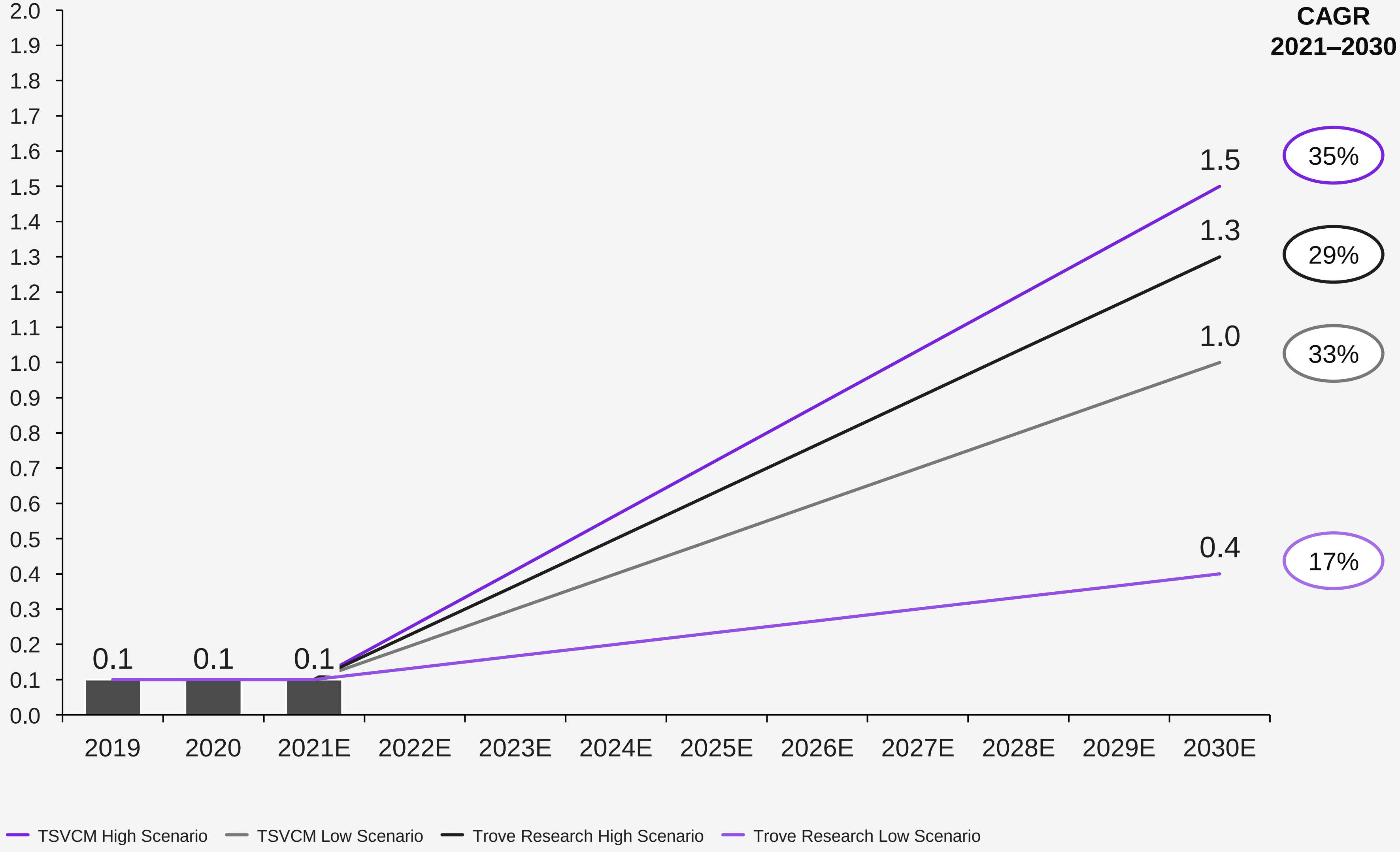
Sources: S&P Global Platts; Kearney analysis

4.2 Voluntary markets and carbon crediting

Carbon offsets voluntary market demand is expected to increase between 17 and 35% annually until 2030

Global voluntary carbon credit demand projection

$GtCO_2eq$, 2021–2030



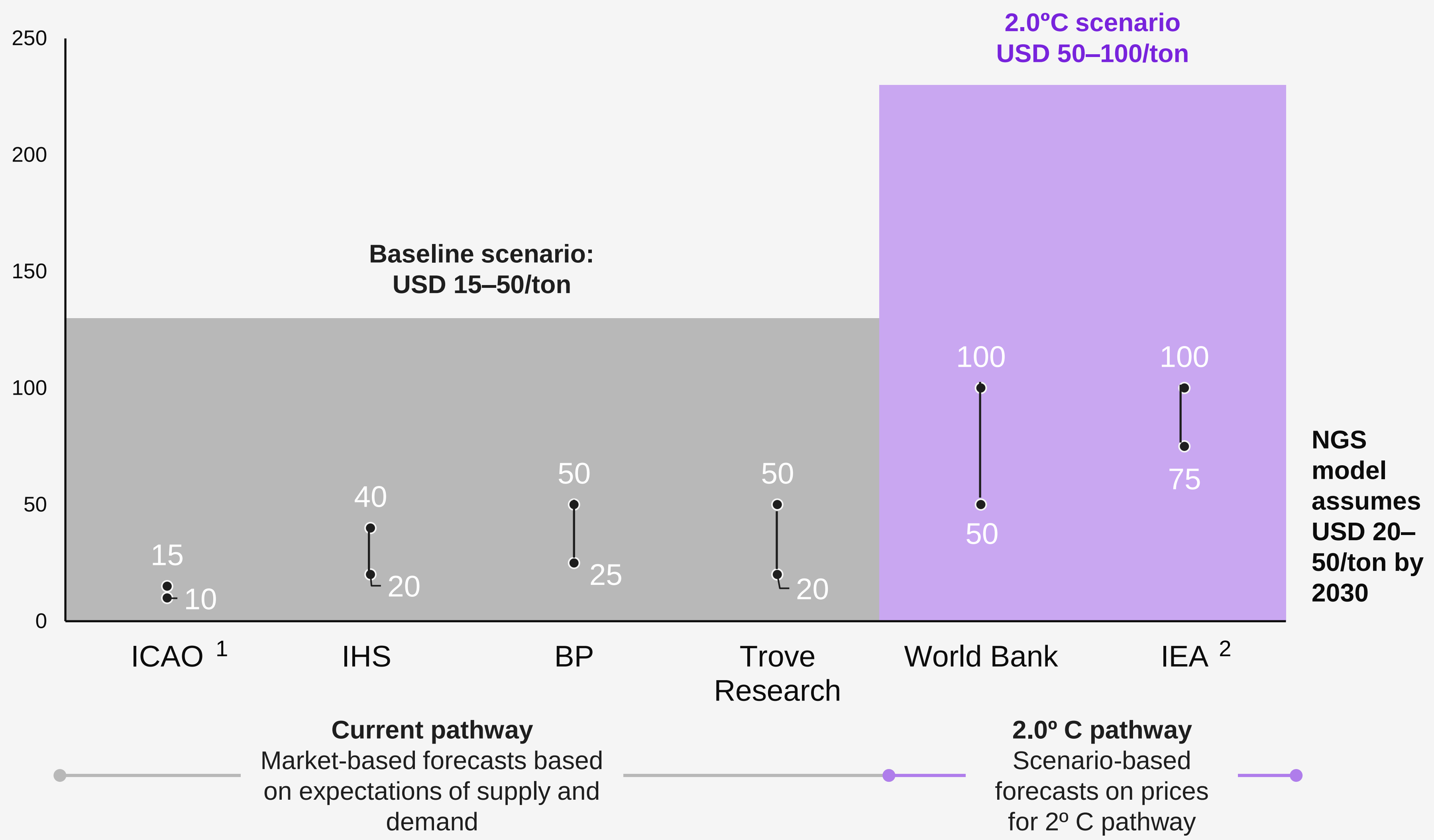
Sources: Taskforce on Scaling Voluntary Carbon Market report, Trove Research and University College London – Global Carbon Credit Supply model (2021); Kearney analysis

4.2 Voluntary markets and carbon crediting

CO2 prices in the voluntary market are projected to reach between USD 50/ton and USD 100/ton depending on the scenario

Carbon offsets voluntary market prices in 2030

USD/tCO_2eq



Notes: ICAO – projected carbon prices as a result of CORSIA. Compliance markets 2026 onward; forecast blends voluntary and compulsory markets.
Sources: World Bank Voluntary Carbon Market Insights: 2018 Outlook and First Quarter trends; Report of the High-Level Commission on Carbon Prices, 2017; Committee on Aviation Environmental Protection (CAEP): Analysis on the estimation of CO_2 emissions reductions and costs expected to result from CORSIA, 2019; IHS Markit, 2019; IEA World Energy Outlook 2019; BP Energy Outlook 2019; Trove Research (2021); Kearney analysis

There are some implied risks of entering the carbon credit market…

Potential risks of entering the carbon credit market – 1/2

Risk title	Description	Rationale	Treatment actions
Carbon price	Carbon credit price volatility due to demand/supply imbalance or lack of regulatory incentives	Uncertainty on carbon credits price evolution directly affects forests' and mangroves' revenues	– Establish bilateral long-term contracts with partners to secure minimum volume offtake and fixed prices – Target markets with carbon regulation in place – Establish risk-sharing model with trading partner – Confirm offtake agreement before final investment decision for projects
Land accessibility	Difficult access to the substantial areas of suitable land required for the plantations	Availability and cost of land	– Engage with government entities to ensure sufficient suitable land is available for development of projects
Natural physical and biological risk	Physical risks (for example, fires or extreme weather) or biological risks (for example, diseases or pests) affecting the plantations	Unpredictable natural physical risks such as forest fires and extreme weather conditions will impact plantation survival rate and ultimately projects' costs	– Implement procedures to prevent and protect plantations (for example, establishment and maintenance of fire-breaks and towers for fire risk; planting frost- and wind-tolerant species for extreme weather conditions;..) – Implement procedures to prevent and protect plantations from biological risks (for example, plantations across different locations; plantations of diverse and resistant species to address pest risk)
Operational risk	Potential higher investment costs due to operational constraints	Increasing global demand for forestation projects may originate seeds shortage and manpower shortage	– Secure long-term contracts for seeds supply and/or develop own nurseries – Leverage technology for labor-intense activities (for example, drones for plantations)
High funding cost	Limited green financing with reduced cost of debt	High upfront costs and large pay-back periods challenge the financing for these projects which require adequate financing structures to become bankable	– Secure government incentives for credit enhancement with development institutions – Engage with institutional investors as well as public NGOs to secure adequate project financing structures that reduce cost of debt

Source: Kearney analysis

…which should be taken into account by the new entrants

Potential risks of entering the carbon credit market – 2/2

Risk title	Description	Rationale	Treatment actions
Reputational damage	Potential accusations of greenwashing	Nature-based solution project as a sustainable-related project may contribute to “greenwashing accusations” and result in reputational damage	– Implement processes for transparent and consistent results reporting as well as for impact reporting once operations start – Develop partnerships with partners/organizations that are well-recognized for their sustainable purpose and commitments to decrease risk
Accreditation of funding credits	Inability to manage and succeed in the accreditation process due to lack of know-how	Risk of delayed accreditation and therefore sale of carbon credits	– Partner with an experienced environmental consultancy with track record in VERRA and similar standards methodologies
Regulatory risks	The carbon credit market is heavily influenced by government policies and regulations	Changes in regulations, such as the introduction of new carbon taxes or emissions targets, can significantly affect the demand for carbon credits and the market price	– Keep a close track of regulatory changes – Government advocacy and dialog at the industry and company level
Lack of standardization	Different types of carbon credits may have varying degrees of credibility and effectiveness	Investors find it difficult to evaluate the quality of carbon credits and may lead to confusion and mistrust in the market	– Industry should move to globally accepted standards which are consistent and transparent
Counterparty risk	Failure of a counterparty to deliver on the obligations	Carbon credit transactions often involve multiple parties, including project developers, brokers, and verifiers. Each of these parties carries a certain level of counterparty risk	– Comprehensive due diligence and sound risk management practices can mitigate, but not eliminate, counterparty risks

Source: Kearney analysis

Carbon offsets are popular but there are concerns about their effectiveness to help meet net zero goals

Carbon offsets can be a useful tool in addressing climate change, but they must be carefully evaluated and managed to ensure their effectiveness.

4.2 Voluntary markets and carbon crediting

Limitations of carbon offsets

Avoided emissions rather than reduced emissions:

- Offsets neither cancel the emissions they're linked to nor reduce the emissions present in the atmosphere.

Additionality:

- One of the key principles of carbon offsets is additionality, which means that emissions reductions from offset projects must be additional to what would have happened anyway without the project
  - However, it can be difficult to establish the additionality of offset projects.

Leakage:

- It is defined as an unintended consequence of offset projects, which can offset the intended emissions reductions.
  - For example, a renewable energy project may displace emissions-intensive activities to another location, where they may continue to generate emissions.

Permanence of carbon offsets:

- Forests that were protected by carbon offsets have already burned in wildfires, releasing the carbon that had been captured in the trees (for example, California).

Quality issues:

- Project types facing quality issues, such as non-additionality and over-crediting, are the norm, eroding the credibility and trust in the carbon offset markets:
  - A recent report claims ~90% of rainforest carbon offsets by the world's leading carbon standard are worthless.
  - An analysis of California's USD 2 billion forest offsets program found that 29% of the offsets were overestimating the benefit to the climate.
  - A working paper of more than 1,000 wind farms in India funded by carbon credits found that at least 52% of the projects very likely would have been built even if the carbon credits hadn't existed.

Scaling issues:

- While there are many potential offset projects, such as renewable energy or reforestation, not all projects may be financially viable or meet the necessary requirements for verification and additionality.
- This limits the availability of suitable offset projects.

Sources: Press search, 90% of the rainforest carbon offsets worthless; Kearney Energy Transition Institute analysis

Currently, carbon removal accounts for a small percentage of corporate climate procurements and investments, in contrast to carbon offsets, which continue to dominate corporates' emission efforts

4.2 Voluntary markets and carbon crediting

Carbon removal vs. carbon offsets

- Carbon removals occur when existing carbon in the atmosphere is captured and permanently stored outside of the atmosphere. The effect is immediate, in contrast to carbon offsets, which reduce or compensate for future emissions.

Types of carbon removal projects:

- Projects should conform to strict guidelines on additionality, carbon accounting, durability, leakage, benefits/risks, reporting, monitoring, verification, etc.:
  - Forestation and agroforestry.
  - Mangrove forestation (often classified as a form of blue carbon) including tidal marshes, seagrasses, and other forms of coastal and marine carbon sequestration
  - Improved forest management that increases carbon stocks in forests and in harvested wood products
  - Conservation and/or regenerative practices to restore soil carbon
  - Biomass-based pathways
  - Carbon mineralization projects mimicking the natural processes that bind carbon in rock in both underground (*in situ*) and above ground (*ex situ*) sites
  - Direct air capture

Transition from offsets to removals

- Industry leaders, such as Amazon, Apple, Delta, Meta, Alphabet, Mars, Shopify, Stripe, SwissRe, United, and Velux, are now including carbon removal in climate strategies.
- **Frontier** is an advance market commitment to buy an initial USD 925 million of permanent carbon removal between 2022 and 2030. It's funded by **Stripe, Alphabet, Shopify, Meta,** and tens of thousands of businesses using **Stripe Climate.**
- **Microsoft's Climate Innovation Fund** has committed to invest USD 1 billion over the next few years into new carbon removal technologies.

Lack of a common framework

- Quality and certification remains a major challenge, for example, how to describe under which conditions various carbon removal technologies and solutions should operate and, ultimately, how the carbon removed should be accounted for.
- Of the **55 million tons** proposed last year to Microsoft by carbon removal companies, only **2 million tons** met the set of prerequisites built from scratch by its in-house experts.

Sources: Press search, Negative emissions platform, Criteria for high-quality carbon dioxide removal; Kearney Energy Transition Institute analysis

EU's new proposed certification framework for carbon removals could be a landmark in global carbon credits market

It assumes importance as many key decisions pertaining to international carbon markets (under the Article 6 of Paris Agreement) were deferred to COP 28.

Capture of fossil carbon for storage (CCS) or utilization (CCU) is not covered.

First EU-wide voluntary framework to reliably certify high-quality carbon removals

Overview

In addition to emission reduction, carbon removal from the atmosphere is essential to meet EU's goal to become the first climate-neutral continent by 2050.

- The proposal sets out rules for the independent verification of carbon removals, as well as rules to recognize certification schemes that can be used to demonstrate compliance with the EU framework.

The proposal will focus on cutting-edge clean technologies while fostering economic value.

- Promote multiple carbon removal solutions such as industrial technologies (for example, BECCS, direct air carbon capture and storage – DACCS), carbon farming practices in forestry and agriculture, and long-lasting products and materials which can store carbon
- Enable innovative forms of private and public financing
- Help create new business models for farmers and foresters

The Commission will develop tailored certification methodologies for the different types of carbon removal activities, supported by an expert group.

Sources: press search, European Commission; Kearney Energy Transition Institute analysis

Benefits

- Boost innovative carbon removal technologies and sustainable carbon farming solutions, and contribute to the EU's climate, environmental, and zero-pollution goals
- Significantly improve the EU's capacity to quantify, monitor, and verify carbon removals
- Higher transparency to ensure trust from stakeholders and industry, and prevent greenwashing

Criteria to ensure the quality and comparability of carbon removals

- **Quantification:** Carbon removal activities need to be measured accurately and deliver unambiguous benefits for the climate.
- **Additionality:** Carbon removal activities need to go beyond existing practices and what is required by law.
- **Long-term storage:** Certificates are linked to the duration of carbon storage so as to ensure permanent storage.
- **Sustainability:** Carbon removal activities must preserve or contribute to sustainability objectives such as climate change adaptation, circular economy, water and marine resources, and biodiversity.

5. Appendix and bibliography

Acronyms (1/2)

A/R: Afforestation and restoration

AFOLU: Agriculture, forestry and other Land Use

AIM4C: The Agriculture Innovation Mission for Climate (AIM for Climate / AIM4C) is a joint initiative by the United States and the United Arab Emirates

AP: Action Plans

AU: Artificial upwelling

AWD: Alternative Wetting and Drying

BECCUS: Bioenergy with Carbon Capture Utilization and Storage (CCUS)

COP: Conference of the Parties

CCUS: Carbon capture utilization and storage

CDR: Carbon dioxide removal, also called "negative emissions technologies" (pls refer to the Negative Emissions Technologies FactBook) are anthropogenic activities removing CO2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage but excludes natural CO2 uptake not directly caused by human activities (IPCC).

CH_4: Methane

CO_2/CO_2eq: Carbon Dioxide (equivalent)

COP: Conference of the Parties

DACCS: Direct Air Carbon Capture and Storage

DRC: Democratic Republic of Congo

EPA: Environmental Protection Agency (US)

ETS: Emission Trading Scheme

EU: European Union

FAO: Food and Agriculture Organization

FCLP: Forest and Climate Leaders' Partnership

FCPF: Forest Carbon Partnership Facility

GCAM: Global Change Assessment Model

GHG: Greenhouse Gas

IAM: Integrated assessment models

ICAO: International Civil Aviation Organization

IEA: International Energy Agency

IHS: IHS Markit Global Carbon Index

IPCC: Intergovernmental Panel on Climate Change

ITMO: Internationally Transferred Mitigation Outcomes (ITMO) under the Paris Agreement

KSA: Kingdom of Saudi Arabia

LATAM:

LULUCF: Land Use, Land-Use Change and Forestry

MIG: Middle East Green Initiative

NAMA: Nationally Appropriate Mitigation Actions

NBS: Nature-based solutions

NDC: Nationally Determined Contributions

NFMS: National Forest Monitoring System

Appendix

Acronyms, Bibliography & Picture credits

Acronyms (2/2)

NH_3/ NH_4: Ammonia gas/ Ammonium

N_2O: Nitrous Oxide

NO_3/ NO_x: Nitrate / Nitrogen Oxides

NORAD: Norwegian Agency for Development Cooperation

NPCC: National Policy on Climate Change

NS: National Strategies

NZE: Net Zero Emissions by 2050 Scenario by IEA

PES: Payment for Ecosystem Services

R&D: Research and Development

RDP: Rural Development Programs

REDD+: Reducing Emissions from Deforestation and Forest Degradation

SIS: Safeguards and safeguards Information Systems

STEPS: Stated Policies Scenario by IEA

tCO_2/yr: tonnes CO_2 per year

TRL: Technology Readiness Level

TSVCM: Taskforce on Scaling Voluntary Carbon Market

UAE: United Arab Emirates

UN: United Nations

UNFCCC: United Nations Framework Convention on Climate Change

USD: United States Dollar

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Appendix

Acronyms, Bibliography & Picture credits

Picture credits (1/2)

Slide 11: Main sources of greenhouse gas emissions and removals (link)

Slide 17: Forestland (link); Net Forest Conversion (link); Forest fire (link); Drained organic soils (link)

Slide 22: Forest fire (link)

Slide 26: Cow (link); Manure (link); Manure management (link); Manure fertilization (link); Rice cultivation Indonesia (link); Synthetic fertilizers (link); Crop residues (link); Residues burning (link); Savana fires (link); Drained organic soils (link)

Slide 28: Enteric fermentation process in cows (link)

Slide 29: Adapted from Research Review of Methane Emissions from Korean Rice Paddies (link)

Slide 30: Nitrogen Basics – The Nitrogen cycle (link)

Slide 41: Wetlands (link); Uplands (link)

Slide 42: Boreal forest (link); Bushland landscape (link); Grasslands (link); Tundra biome (link)

Slide 43: Salt marsh (link); Swamp (link); Peatland (link)

Slide 48: Wetlands (link); Uplands (link)

Slide 55: 10 Causes of Deforestation: The Roots of Forest Degradation (link)

Slide 56: Coastal Wetlands by istockphoto, Getty images (link)

Slide 58: Savanna Grasslands (link)

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Picture credits (2/2)

Slide 59: Diversification of forest management systems in Ireland (link)

Slide 60: How Forest Management Prevents Forest Fires (link)

Slide 57: How soil can help solve our climate problem (link)

Slide 65: Agroforestry helps farmers make greener land and better life (link)

Slide 66: Biochar, a great solution (link)

Slide 68: Manure management (link)

Slide 69: Nutrient management (link)

Slide 70: Draining paddy fields could cut methane from rice production (link)

Slide 72: Countries can effectively reduce food waste with innovative waste management solutions (link)

Slide 96: Rice cultivation (link); Coffee plant (link); Rice plant (link)

The ETI has a collection of FactBooks providing an overview of solutions to reduce GHG emissions

Carbon Emissions Assessment

Introduces key scientific concepts of emission estimation together with other potential environmental impacts, from anthropogenic activities at different scales and highlights related uncertainties, providing case analysis across key industrial sectors and applications

Carbon Capture & Storage (CCUS)

Provide an overview of the latest changes in the CCUS landscape. It summarizes the main R&D priorities, analyzes the economics of the technology, and presents the status and future of large-scale integrated projects.

Gas Hydrates

Assesses the potential of this resource, by presenting key concepts; E&P technologies; R&D; and HSE challenges of potential exploitation of gas-hydrate resources

H2 applications and business models

Provides an overview of hydrogen-related technologies, emerging applications, and new business models. Covers the entire value chain and analyzes the environmental benefits and economics of this space

Electricity Storage

Summarizes status and future development, technology hurdles and economics, R&D focus areas. Outlines its pertinent role in the Energy Transition as an enabler

Introduction to Smart Grid

Examines the innovations of Smart Grid technologies, gives an assessment of the transition to a modern, digital, and optimised electric grid

Biomass to energy

Provides an overview of biomass related technologies, applications and business models, covering the entire value chain, analyzing the environmental benefits and economics of this space along with key insights.

Solar Photovoltaic

Summarizes the status of the PV industry and its prospects, technology challenges, R&D focus areas, and the economics of PV technology

Introduction to Natural Gas

Assesses the reasons behind the growing importance of natural gas within the global energy mix and associated challenges, and technology developments

Negative Emissions Technologies

Summarizes the status of the negative emissions technologies and their prospects, lists the main technological hurdles and principal areas for research and development, and analyzes the economics of this space.

Wind Power

Summarizes the status of the wind industry and its prospects, the main technology hurdles, R&D focus areas, and analyses the economics of this technology.

Climate Change

Summarizes scientific studies, concepts, projections, human-induced changes and consequences, key uncertainties and issues of debate

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