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Status, potential and challenges

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Abstract: U.S. Country Report

This report describes the current state of agriculture in the U.S. with regard to the greenhouse gas (GHG) emissions it produces and the climate and other socio-economic policies that it faces. We identify options that could reduce agricultural emissions and estimate the mitigation potential of those options. Finally, we identify barriers to adopting these mitigation strategies and some possible solutions to overcoming those barriers.

Kurzbeschreibung: USA Länderbericht

Dieser Bericht beschreibt den aktuellen Stand der Landwirtschaft in den USA im Hinblick auf die von ihr verursachten Treibhausgasemissionen und die klimapolitischen und anderen sozioökonomischen Maßnahmen, denen sie ausgesetzt ist. Wir identifizieren Optionen, die die landwirtschaftlichen Emissionen reduzieren könnten, und schätzen das Minderungspotenzial dieser Optionen ab. Abschließend werden die Hindernisse für die Einführung dieser Minderungsstrategien und einige mögliche Lösungen zur Überwindung dieser Hindernisse aufgezeigt.

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List of abbreviations

AFOLU	Agriculture, forestry and other land use
CAFOs	Concentrated animal feeding operations
CO_2	Carbon dioxide
CH_4	Methane
CSAF	Climate-Smart Agriculture and Forestry
CSP	Conservation Stewardship Program
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FSA	Farm Service Agency
GDP	Gross domestic product
GHG	Greenhouse gas
IFA	International Fertiliser Association
IPCC	Intergovernmental Panel on Climate Change
LTS	Long-term strategy
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Measurement, reporting and verification
$MtCO_2e$	Mega tonnes of CO_2 equivalent
NDC	Nationally Determined Contributions (in Paris-Agreement)
NRCS	Natural Resource Conservation Service
NUE	Nitrogen use efficiency
N_2O	Nitrous oxide
RCPP	Regional Conservation Partnership Program
SOC	Soil organic carbon
UNFCCC	United Nations Framework Convention on Climate Change
USDA	U.S. Department of Agriculture

Summary

The aim of this report is to identify possible emission mitigation options in the agricultural sector of the United States, the barriers towards implementing these options and provide some recommendations on how to overcome these barriers. The report begins with a description of the current state of agriculture in the U.S. with regard to the GHG emissions it produces, and the climate and socio-economic policies that shape the sector. We then identify three key options that could reduce agricultural emissions and discuss the mitigation potential of a wider range of measures that has been identified by various studies. Finally, we identify barriers that act at the farm, national, international and consumer level along with possible steps to overcoming those barriers.

Agriculture shapes the U.S.'s landscape since half of the land is used for agricultural purposes, of which 18% is cropland and 27% is pasture and range land. Agriculture in the U.S. is generally highly intensive and industrialised. In 2021, agriculture contributed about 0.9% to the economy (GDP). 40.8% of all agricultural land is operated by large-scale family or commercial farms, which make up only 7.5% of all farms. Approx. 20% of U.S. agricultural production is exported with China being the largest export market followed by Canada and Mexico and approx. 11% of food (by value) consumed domestically is imported. The agricultural sector in the U.S. contributes 1.4% of employment.

Agriculture accounted for around 10% of the U.S.'s total greenhouse gas emissions in 2019, corresponding to 664 $MtCO_2e$, excluding Land Use, Land-Use Change and Forestry (LULUCF). The main emission sources for the sector include enteric fermentation (27%), synthetic fertilizer application (10%) and manure management (12%). Agricultural greenhouse gas (GHG) emissions have increased by 12% since 1990, which has been driven by a 9% increase in nitrous oxide emissions from managed soils (including fertiliser, manure applied to soils, manure left on pasture, and crop residues) and a 60% increase in combined methane and nitrous oxide emissions from manure management systems. Emissions from other agricultural sources have remained relatively stable since the 1990s. Beef production accounts for more than half of the greenhouse gas emissions from livestock in the U.S. and is primarily driven by consumer demand since 90% of U.S. beef is consumed domestically. The U.S. is among the world's top meat consumers, with per capita consumption amounting to 124 kg/year in 2017 compared to the global average of 43 kg/year. Additionally, the country has high levels of food waste as almost 40% of the U.S. food supply is wasted.

While the U.S. long-term mitigation strategy (LTS) does not set any explicit target for agricultural emission reductions, it recognises the importance of the AFOLU sector for reducing non-CO_2 emissions and scaling up land-based carbon sinks. The U.S. Farm Bill is an all-encompassing law that governs agricultural and food programmes and related policies. The bill is revisited and renewed every five years. The most recent bill was the Agricultural Improvement Act of 2018 and will expire in 2023.

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The current iteration of the bill provides support to farmers for commodity crops facing revenue losses and disaster assistance, assists producer conservation efforts, encourages on-farm renewable energy development, and was amended to encourage cover crops and other climate-resilient practices by expanding the crop insurance program coverage. However, the Farm Bill still prioritises specialised commodity production over agricultural diversification and conservation practices. Agricultural subsidies from the Farm Bill are evidenced to be less accessible to smaller farms, fail to encourage conservation practices, discourage diversification, and systematically exclude marginalised farmers and farmworkers. The Growing Climate Solutions Act of 2021, still waiting to be passed by the House of Representatives, is centred around creating new sources of income for climate-smart agricultural activities. The USDA recently announced the Partnerships for Climate-Smart Commodities pilot programme, which will provide USD 1 billion (986 million EUR) in funding to incentivise producers and landowners to implement agricultural practices that reduce GHG emissions or sequester carbon. The economy-wide Inflation Reduction Act of 2022 includes specific provisions for climate-smart agriculture, and protection and restoration of carbon sinks. However, the Act is also criticised for boosting support for ethanol production and consumption, thereby supporting monoculture practices that are problematic for biodiversity and soil erosion.

Three mitigation options were identified for detailed analysis based on the contribution of different emission sources, the potential for socio-economic and environmental co-benefits, the country-specific context of the agricultural sector and the general feasibility for implementation.

For the U.S., we selected the following three mitigation measures:

- Improving nutrient management
- Improving manure management
- Improving grazing land management.

These three on-farm mitigation measures form part of a broader set of mitigation options that have been identified for the U.S., including improving rice cultivation and increasing land-based carbon sinks through restoration and reforestation.

Implementing these full range of on-farm mitigation measures could lead to mitigation of non-CO_2 emissions by up to around 95 $MtCO_2e$ below 2018 levels in 2030. Estimates for the potential of carbon sequestration are much higher in magnitude, with 10-85 $MtCO_2$ specifically from improving grazing land management and potentially much more when all land use options are considered. However, carbon sequestration on land carries substantial uncertainties and the risk of reversibility so should not be prioritised at the expense of mitigating non-CO_2 emissions.

Demand-side measures, including changing diets and reducing food loss and waste, were not quantified here but have substantial additional mitigation potential.

There are critical barriers that hinder the implementation of measures to achieve the outlined mitigation potentials and impair other activities to reduce greenhouse gas emissions in the agricultural sector. For the selected mitigation measures, we identified technical, economical, and policy/legal barriers. More generally, high investment costs, lacking knowledge, uncertainty around impacts on yields, and cultural and social habits act as barriers at farm level. Additionally, specific targets for reducing agricultural non-CO_2 emissions are still lacking.

To accelerate the uptake and implementation of the measures described in this report, the U.S. could 1) enhance the national climate mitigation framework in agriculture with concrete, sector specific targets, 2) align other environmental and food security objectives with mitigation objectives by better integrating objectives into existing agricultural policies, and 3) adjust subsidies and insurance mechanisms to better incentivise sustainable practices, and disincentives the unsustainable ones, such as over-use of fertiliser. In addition, there is substantial mitigation potential in the U.S. from demand-side measures that shift dietary choices and reduce food waste. These mitigation policies and incentives should also foster co-benefits between adaptation and mitigation in the agricultural sector.

Zusammenfassung

Ziel dieses Berichts ist es, mögliche Optionen zur Emissionsminderung im Agrarsektor der Vereinigten Staaten zu identifizieren, die Hindernisse für die Umsetzung dieser Optionen aufzuzeigen und Empfehlungen für die Überwindung dieser Hindernisse zu geben. Der Bericht beginnt mit einer Beschreibung des aktuellen Zustands der Landwirtschaft in den USA im Hinblick auf die von ihr produzierten Treibhausgasemissionen und die klimatischen und sozioökonomische Politik. Anschließend werden drei wichtige Optionen zur Verringerung der Emissionen, die im Zusammenhang mit der Landwirtschaft stehen, aufgezeigt und ihr Minderungspotenzial abgeschätzt. Auch andere Minderungsmaßnahmen werden kurz erörtert. Abschließend werden Hindernisse auf betrieblicher, nationaler, internationaler und Verbraucherebene sowie mögliche Schritte zur Überwindung dieser Hindernisse aufgezeigt..

Die Landwirtschaft prägt das Landschaftsbild der USA, da die Hälfte des Landes für landwirtschaftliche Zwecke genutzt wird, davon 18 % als Ackerland und 27 % als Weide- und Weideland. Die Landwirtschaft in den USA ist sehr intensiv und industrialisiert. Im Jahr 2021 trug die Landwirtschaft etwa 0,9 % zur Wirtschaft (BIP) bei. 40,8 % aller landwirtschaftlichen Flächen werden von großen Familien- oder Gewerbebetrieben bewirtschaftet, die nur 7,5 % aller Betriebe ausmachen. Rund 20 % der US-Agrarproduktion werden exportiert, wobei China der größte Exportmarkt ist, gefolgt von Kanada und Mexiko. 11 % der im Inland konsumierten Lebensmittel (nach Wert) werden importiert. Der Agrarsektor trägt in den USA zu 1,4 % der Beschäftigung bei.

Auf den Agrarsektor entfielen im Jahr 2019 rund 10 % der gesamten Treibhausgasemissionen der USA, was 664 Megatonnen CO2-Äquivalenten (MtCO_2e) entspricht, ohne Landnutzung, Landnutzungsänderung und Forstwirtschaft (LULUCF). Zu den wichtigsten Emissionsquellen des Sektors gehören die enterische Fermentation (27 %), die Ausbringung synthetischer Düngemittel (10 %) und die Güllewirtschaft (12 %). Die landwirtschaftlichen Treibhausgasemissionen (THG) sind seit 1990 um 12% gestiegen, was auf einen 9%-igen Anstieg der Lachgasemissionen aus bewirtschafteten Böden (einschließlich Düngemittel, auf Böden ausgebrachter Dung, auf Weiden belassener Dung und Ernterückstände) und einen 60%igen Anstieg der kombinierten Methan- und Lachgasemissionen aus Dungbewirtschaftungssystemen zurückzuführen ist. Die Emissionen aus anderen landwirtschaftlichen Quellen sind seit den 1990er Jahren relativ stabil geblieben. Die Rindfleischproduktion ist für mehr als die Hälfte der Treibhausgasemissionen aus der Viehhaltung in den USA verantwortlich und wird in erster Linie durch die Verbrauchernachfrage angetrieben, da 90 % des US-Rindfleischs im Inland konsumiert wird. Die USA gehören zu den größten Fleischkonsumenten der Welt, mit einem Pro-Kopf-Verbrauch von 124 kg/Jahr in 2017 im Vergleich zum weltweiten Durchschnitt von 43 kg/Jahr. Darüber hinaus gibt es in den USA eine hohe Lebensmittelverschwendung, da fast 40 % der Lebensmittel in den USA im Müll landen.

Die langfristige Minderungsstrategie der USA (LTS) setzt zwar kein ausdrückliches Ziel für die Verringerung der landwirtschaftlichen Emissionen, erkennt aber die Bedeutung des AFOLU-Sektors für die Verringerung der Nicht-CO_2-Emissionen und die Vergrößerung der landbasierten Kohlenstoffsenken an. Das US-Landwirtschaftsgesetz (Farm Bill) ist ein allumfassendes Gesetz, das Agrar- und Lebensmittelprogramme und damit verbundene Maßnahmen regelt. Das Gesetz wird alle fünf Jahre überarbeitet und erneuert. Das letzte Gesetz war der Agricultural Improvement Act von 2018 und läuft 2023 aus.

Die aktuelle Fassung des Gesetzes sieht Unterstützung für Landwirte vor, die mit Einkommensverlusten konfrontiert sind und leistet Katastrophenhilfe, unterstützt die

Bemühungen der Erzeuger um den Naturschutz, fördert die Entwicklung erneuerbarer Energien in den Betrieben und wurde dahingehend geändert, dass der Anbau von Deckfrüchten und andere klimaresistente Praktiken gefördert werden, indem der Geltungsbereich des Ernteversicherungsprogramms erweitert wird. Die Farm Bill gibt jedoch nach wie vor der spezialisierten Rohstoffproduktion den Vorrang vor der landwirtschaftlichen Diversifizierung und den Praktiken des Naturschutzes. Es hat sich gezeigt, dass die Agrarsubventionen der Farm Bill für kleinere landwirtschaftliche Betriebe weniger zugänglich sind, dass sie keine Naturschutzmaßnahmen fördern, dass sie von einer Diversifizierung abhalten und dass sie marginalisierte Landwirte und Landarbeiter ausschließen. Der Growing Climate Solutions Act von 2021, der noch auf seine Verabschiedung durch das Repräsentantenhaus wartet, zielt darauf ab, neue Einkommensquellen für klimagerechte landwirtschaftliche Aktivitäten zu schaffen. Das USDA kündigte kürzlich das Pilotprogramm Partnerships for Climate-Smart Commodities an, das eine Milliarde US-Dollar (986 Mio. EUR) zur Verfügung stellen wird, um Erzeuger:innen und Landbesitzer:innen Anreize zu bieten, landwirtschaftliche Praktiken anzuwenden, die Treibhausgasemissionen reduzieren oder Kohlenstoff binden. Das wirtschaftsweite Gesetz zur Verringerung der Inflation von 2022 enthält spezifische Bestimmungen für eine klimagerechte Landwirtschaft sowie den Schutz und die Wiederherstellung von Kohlenstoffsenken. Es wird jedoch auch kritisiert, dass das Gesetz die Förderung der Ethanolproduktion und des Ethanolverbrauchs ankurbelt und damit Monokulturen unterstützt, die für die biologische Vielfalt und die Bodenerosion problematisch sind.

Auf der Grundlage des Beitrags der verschiedenen Emissionsquellen, des Potenzials für positive sozioökonomische und ökologische Auswirkungen, des länderspezifischen Kontexts des Agrarsektors und der generellen Durchführbarkeit wurden drei Minderungsoptionen für eine detaillierte Analyse ausgewählt.

Für die USA wurden die folgenden drei Minderungsmaßnahmen ausgewählt:

- Verbesserung des Nährstoffmanagements
- Verbesserung des Güllemanagements
- Verbesserung der Weideflächenbewirtschaftung.

Diese drei Maßnahmen sind Teil eines breiteren Spektrums von Minderungsoptionen, die für die USA identifiziert wurden, darunter die Verbesserung des Reisanbaus und die Vergrößerung von Kohlenstoffsenken durch Wiederherstellung und Aufforstung.

Die Umsetzung des gesamten Spektrums an Minderungsmaßnahmen in landwirtschaftlichen Betrieben könnte zu einer Verringerung der Nicht-CO_2-Emissionen um bis zu 95 $MtCO_2e$ gegenüber dem Niveau von 2018 im Jahr 2030 führen. Die Schätzungen für das Potenzial der Kohlenstoffsequestrierung liegen viel höher: 10-85 $MtCO_2$ speziell durch die Verbesserung der Weideflächenbewirtschaftung und weit mehr bei Berücksichtigung aller Landnutzungsoptionen. Die Kohlenstoffsequestrierung auf dem Land ist jedoch mit erheblichen Unsicherheiten und dem Risiko der Reversibilität behaftet und sollte daher nicht auf Kosten der Verringerung von Nicht-CO_2-Emissionen priorisiert werden. Maßnahmen auf der Nachfrageseite, einschließlich der Änderung von Ernährungsgewohnheiten und der Verringerung von Lebensmittelverlusten und -abfällen, wurden hier nicht quantifiziert, haben aber ein erhebliches zusätzliches Minderungspotenzial.

Es gibt kritische Barrieren, die die Umsetzung von Maßnahmen zur Erreichung der skizzierten Minderungspotenziale behindern und andere Aktivitäten zur Reduzierung von Treibhausgasemissionen im Agrarsektor beeinträchtigen. Für die ausgewählten

Minderungsmaßnahmen haben wir technische, wirtschaftliche und politische/rechtliche Hindernisse identifiziert. Generell wirken hohe Investitionskosten, mangelndes Wissen, Ungewissheit über die Auswirkungen auf die Erträge sowie kulturelle und soziale Gewohnheiten als Hindernisse auf betrieblicher Ebene. Darüber hinaus fehlen nach wie vor spezifische Ziele für die Verringerung der landwirtschaftlichen Nicht-CO_2-Emissionen.

Um die Übernahme und Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, könnten die USA 1) den nationalen Rahmen für den Klimaschutz in der Landwirtschaft durch konkrete, sektorspezifische Ziele verbessern, 2) andere Umwelt- und Ernährungssicherheitsziele mit den Klimaschutzzielen in Einklang bringen, indem die Ziele besser in die bestehende Agrarpolitik integriert werden, und 3) Subventionen und Versicherungsmechanismen anpassen, um bessere Anreize für nachhaltige Praktiken zu schaffen und nicht nachhaltige Praktiken, wie den übermäßigen Einsatz von Düngemitteln, zu verhindern. Darüber hinaus besteht in den USA ein erhebliches Minderungspotenzial durch nachfrageseitige Maßnahmen, die zu einer Änderung der Ernährungsgewohnheiten führen und die Lebensmittelverschwendung reduzieren. Diese Maßnahmen und Anreize zur Eindämmung des Klimawandels sollten auch den gemeinsamen Nutzen von Anpassung und Eindämmung im Agrarsektor fördern.

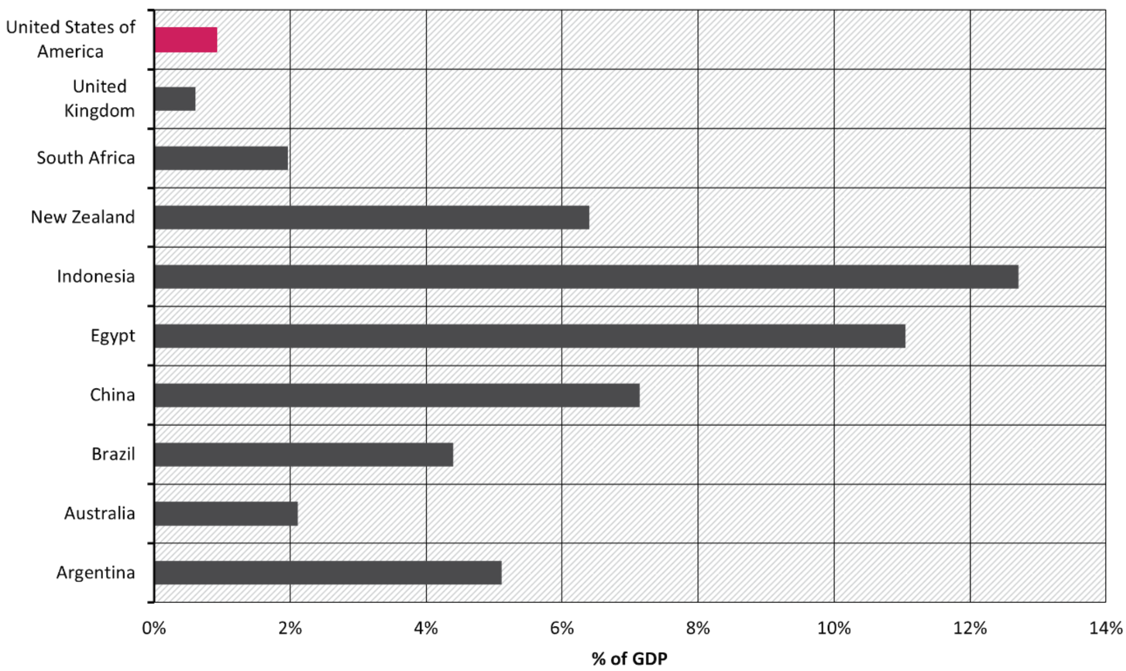
1 General characteristics of the agricultural sector and policy landscape

1.1 Characteristics of agriculture sector in the United States

The United States has a large, internationally competitive agricultural sector due to its abundance of land, diverse soil, and range of climactic conditions, which allows for a wide range of crop and livestock goods to be produced (OECD 2016). The U.S. agricultural system is highly industrialised and characterised by monocultures, high mechanization, agrochemical and pharmaceutical inputs, farm consolidation, and market concentration (Johns Hopkins, 2022).

The output of the U.S. agricultural sector contributes 0.9% of gross domestic product (GDP), which is relatively low compared to the global average of 3.5% (Figure 1; OECD, 2021). The sector is quite consolidated, with 3.6% of farms accounting for 58% of total agricultural production value due to high labour productivity (OECD 2016).

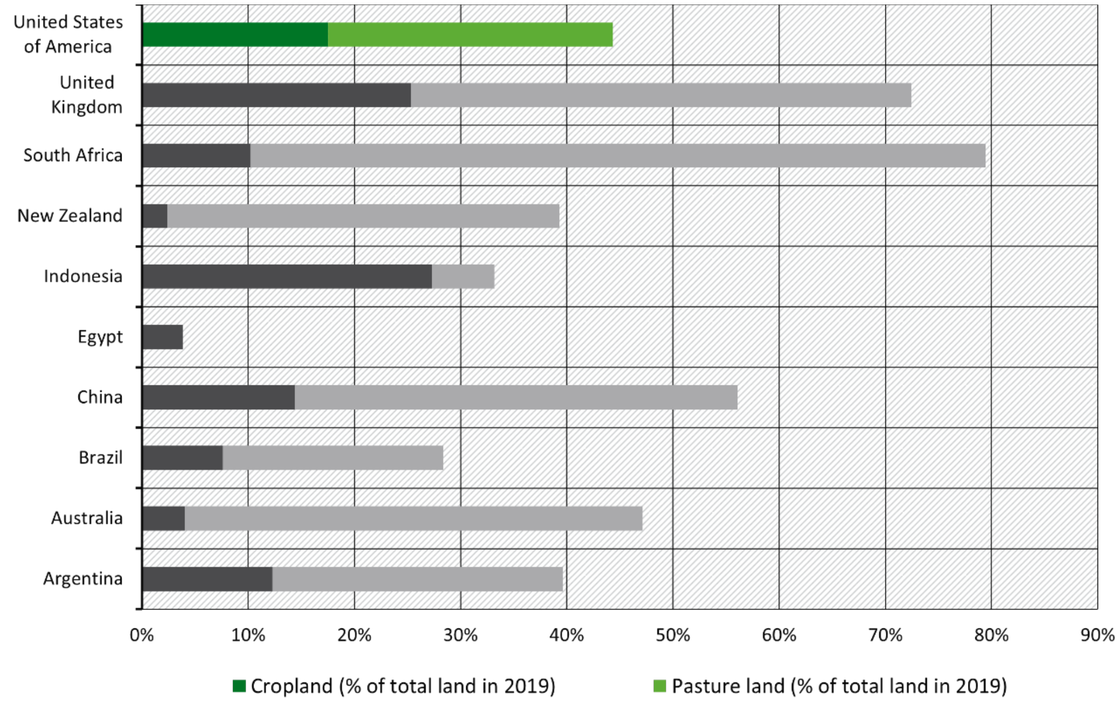
Figure 1: Agriculture, fisheries, and forestry's contribution to GDP (2019)



Source: **World Bank (2022)** data for all countries except New Zealand due to lack of data. Value for New Zealand was taken from **OECD (2021)**.

Agricultural activities have significantly shaped the U.S. landscape. Close to half of the land in the U.S. is used for agricultural purposes, of which 18% is cropland and 27% is pasture and range land (Figure 2). 40.8% of all agricultural land is operated by large-scale family or commercial farms, which make up only 7.5% of all farms (Spangler et al. 2020).

Figure 2: Agricultural land as a share of total country area (2019)



Source: FAO (2022b) data for all countries. Data includes "Cropland" and "Land under permanent meadows and pastures".

The U.S. agricultural sector is highly diversified across regions. California is the leading agricultural state, accounting for 12% of U.S. production value with a focus on intensive fruit, vegetable, nut, and dairy farming (OECD 2016). The Midwest and Great Plains states, with extensive field crop and livestock production systems, comprise 46% of agricultural production value (ibid). The rich soils, favourable climate, and use of advanced technology have made the Midwest Corn Belt one of the most productive regions on Earth during peak season (Bagley *et al.*, 2015).

Approximately 20% of U.S. agricultural production is exported, which primarily consists of food grains, oil seeds and their manufactured products, fruits and nuts, and meat products (USDA, 2022d). China is the largest market for U.S. agricultural exports, followed by Canada and Mexico (USDA, 2022c).

Around 11% of food (by value) consumed domestically is imported (USDA, 2022d). Horticultural products such as fruits, vegetables, nuts, and wine make up about half of imports, while sugar and tropical products like coffee and cocoa usually comprise around one fifth of imports (USDA, 2022a). Vegetable oils, processed grains, red meat and dairy imports have significantly grown in recent years (ibid).

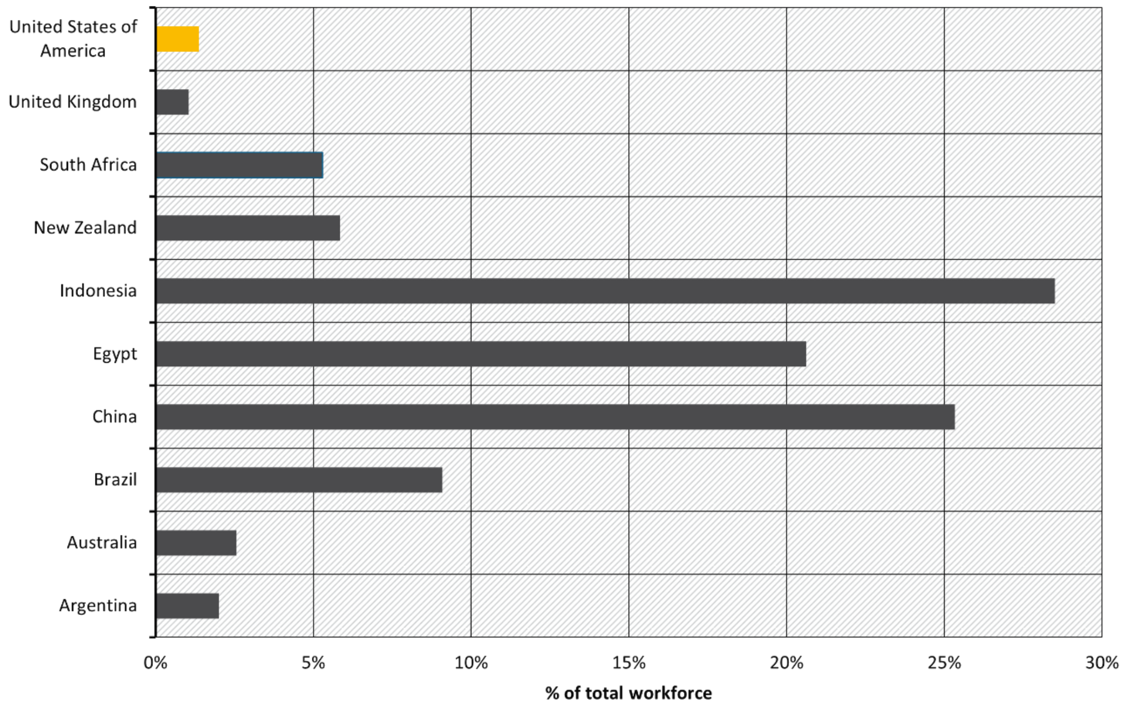
Over the years, the U.S. agricultural sector has transitioned towards a consolidated and specialised system. Fewer farms own increasingly more land, and they continue to produce a few selected crops via highly mechanised processes in favour of productivity and efficiency (Spangler *et al.*, 2020). While the extent of environmental pressure per unit of production has decreased due to innovations and productivity gains, continuing to meet demand while sustaining economic viability by specialisation has come at the expense of environmental health, biodiversity, natural resources, and the quality of life for farmers (ibid; OECD 2016).

Spurred by the need to scale up production and increase profit margins, the heavy fertilisation, monocropping, intensive tilling, use of genetically modified crops, and intensive livestock systems that characterise the industrial agricultural systems in the U.S. has resulted in significant soil infertility and depletion, air and water pollution, algal blooms from nutrient overload, loss of biodiversity, and impacts to human health (NRDC, 2020).

1.2 Socio-economic dimensions

The agricultural sector in the U.S. contributes 1.4% of employment (Figure 3). Migrant farmworkers make up 73% of the U.S. agricultural labour force. The U.S. agricultural system requires 1.5 to 2 million hired workers each year, but farmers have been struggling to fill these positions in recent years (FWD.us, 2021). While COVID-19 has exacerbated the issue, it is also attributed to current U.S. immigration policy and rising incomes in Mexico (ibid). The loss of employees has meant that some farmers are forced to leave 15–20% of their crops unharvested, which subsequently reduces farm income and raises food prices (Walsh, 2017).

Figure 3: Agricultural employment as a share of the total workforce (2019)



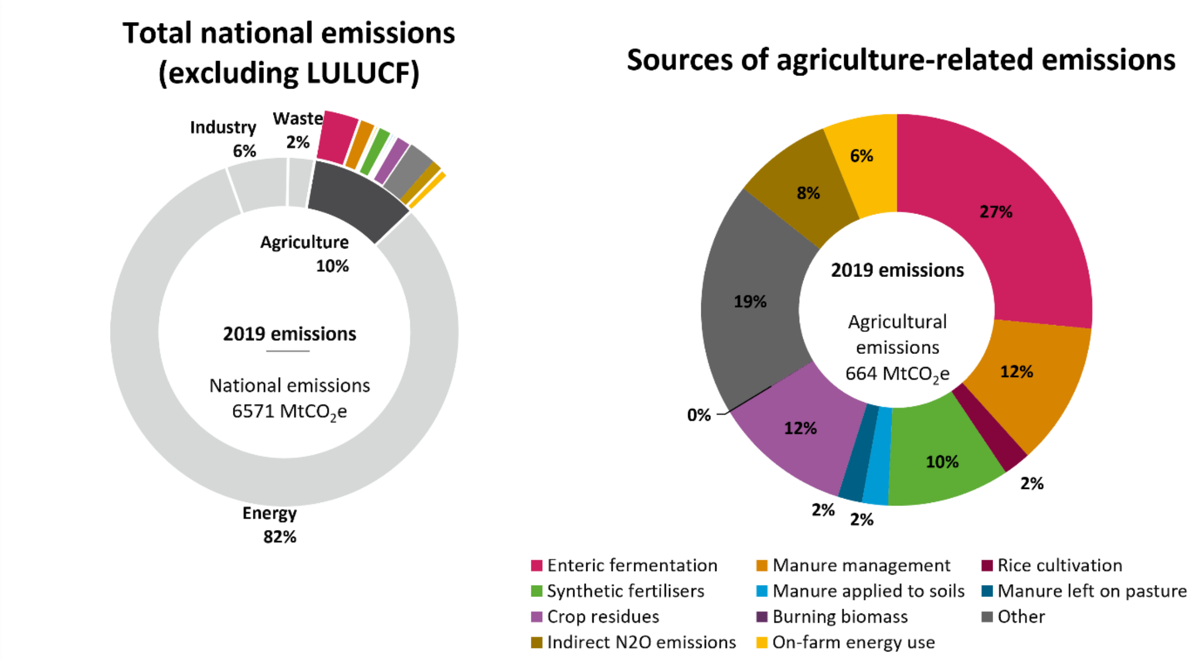
Source: **World Bank (2021)** data for all countries except Argentina due to data discrepancy. Value for Argentina was taken from **OIT (2021)**.

Agriculture accounts for close to 80% of U.S. water consumption when including groundwater and surface water (McNabb, 2019). Non-renewable groundwater extraction has several negative environmental impacts including land subsidence, water quality degradation, and sea level rise (Graham *et al.*, 2021). In particularly vulnerable regions like the Southwest, over 25% of agricultural yields could be lost from unsustainable water use (ibid).

1.3 Greenhouse gas emissions from the agriculture, forestry and other land use (AFOLU) sector and drivers

Agriculture accounted for around 10% of the U.S.'s total greenhouse gas emissions in 2019, equating to 664 mega tonnes of CO_2 equivalent ($MtCO_2e$), excluding Land use, Land-Use Change and Forestry (LULUCF) (Figure 4). The main emissions sources for the sector include enteric fermentation (27%), synthetic fertiliser application (10%), and manure management (12%) (ibid).

Figure 4: United States' GHG emissions profile (2019)

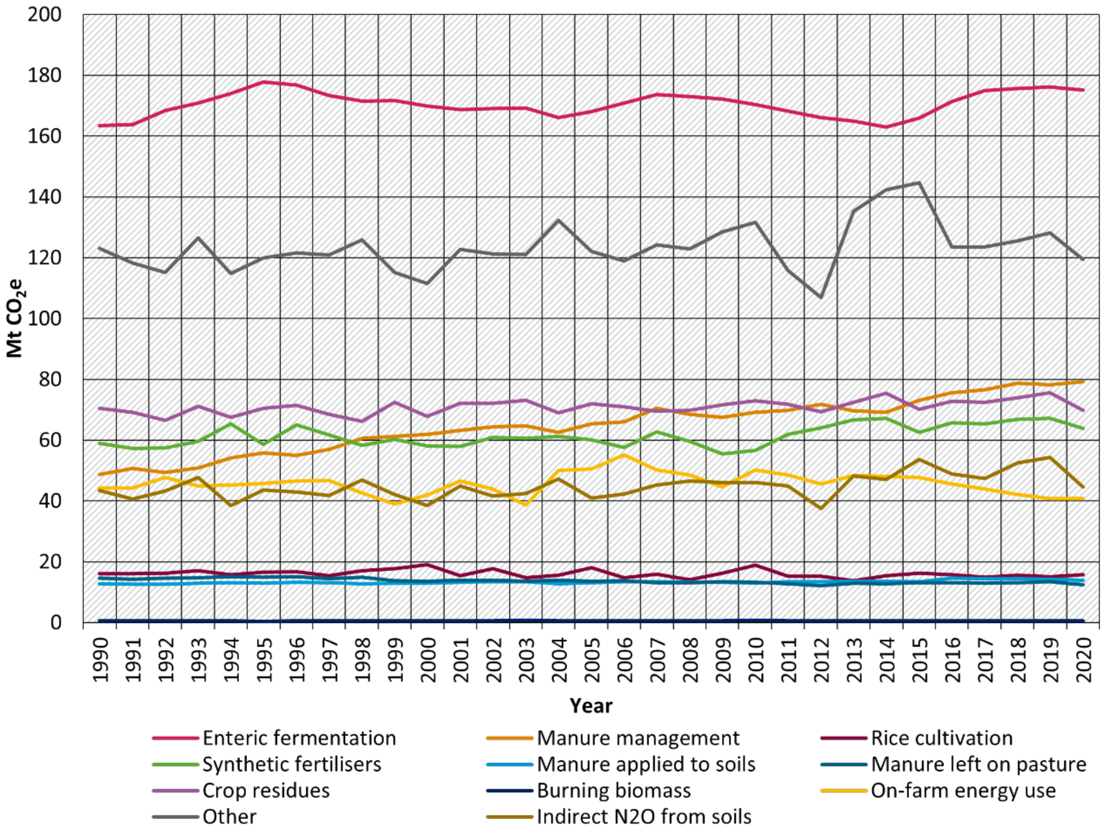


Source: **United States of America (2022)**. For on-farm energy use, no information is available in the U.S. National Inventory Report. Data for on-farm energy use has thus been taken from **FAO (2022a)**, acknowledging high uncertainties.[1] The category 'Other' includes CO_2 emissions from liming and urea application as well N_2O emissions from mineralisation of soil organic matter and from cultivation of organic soils.

Agricultural greenhouse gas (GHG) emissions have increased by 12% since 1990, which has been driven by a 9% increase in nitrous oxide emissions from managed soils (including fertiliser, manure applied to soils, manure left on pasture, and crop residues) and a 60% increase in combined methane and nitrous oxide emissions from manure management systems (US EPA, 2022a). Emissions from other agricultural sources have remained relatively stable since the 1990s (ibid; Figure 5).

[1] While on-farm energy use is generally reported under energy sector emissions for national data, we include it as an agriculture-related emissions source in this study because of its role in agricultural production (fuel use in harvesters, stable heating, grain drying etc.) and its relevance in several countries in terms of magnitude and mitigation potential. However, due to relatively high uncertainties in FAO data in the case of the U.S., no mitigation measures for on-farm energy use are evaluated in this paper. We refer to 2019 instead of 2020 data, which was the latest data available at the time of writing, due to COVID-related economic dynamics that affected national emissions in 2020.

Figure 5: Agriculture-related emissions in the United States (1990–2020)



Source: **United States of America (2022)**. For on-farm energy use, no information is available in the U.S. National Inventory Report. Data for on-farm energy use has thus been taken from **FAO (2022a)**, acknowledging high uncertainties.

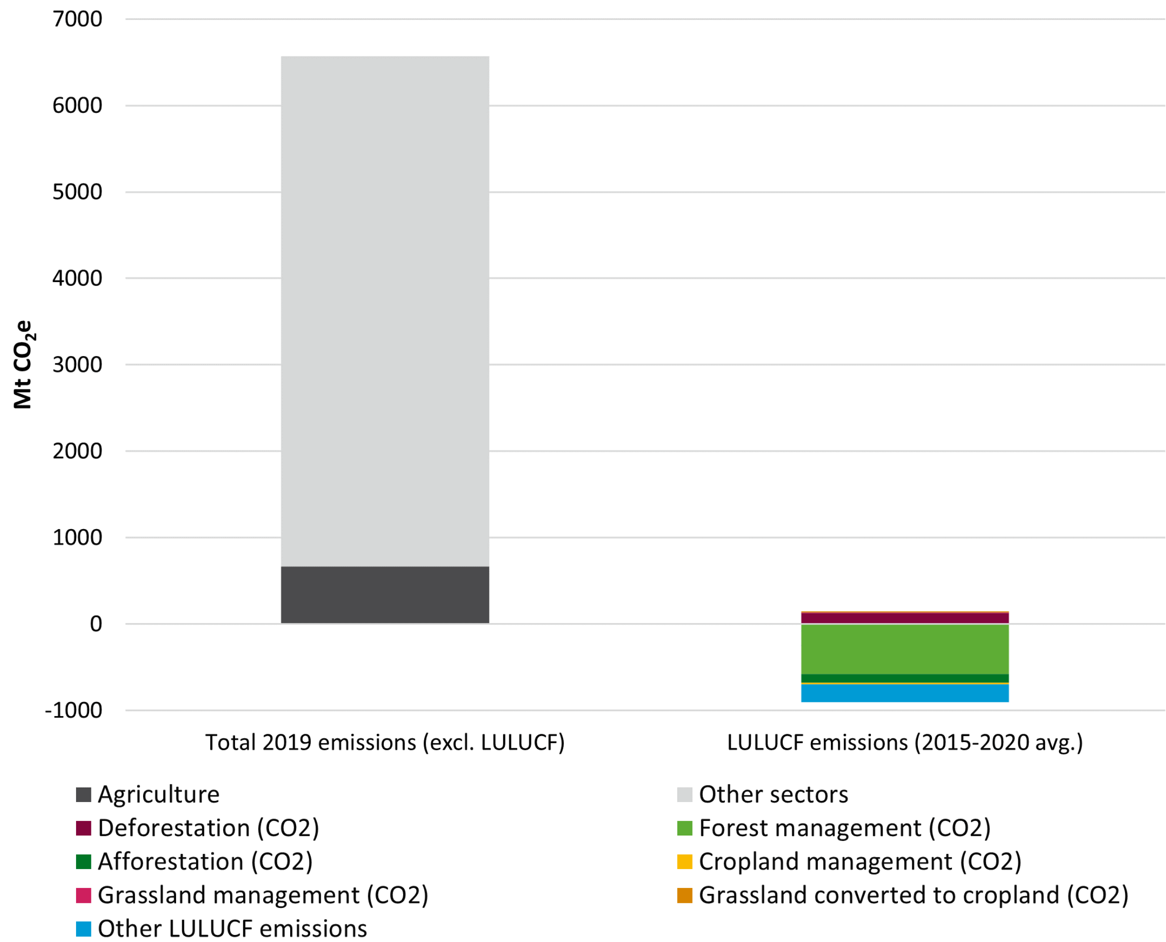
Beef production accounts for more than half of the greenhouse gas emissions from livestock in the U.S. and is primarily driven by consumer demand, since 90% of U.S. beef is consumed domestically (Tichenor *et al.*, 2017). The U.S. has a low emissions intensity per unit of beef due to the system's high productivity levels. Feedlots make up 97% of U.S. cattle finishing phases, in contrast to 3% that are grass-finished (Cusack *et al.*, 2021). Despite this, the sheer number of cattle are responsible for high absolute GHG emissions.

While feedlot-finished cows emit less methane from enteric fermentation per tonne of meat or milk produced than grass-finished cows, the concentrated animal feeding operations (CAFOs) that are common in the U.S. produce significant amounts of manure and slurry and are a breeding ground for diseases. Many CAFOs store excess manure in lagoons or pits, where it breaks down anaerobically and exacerbates methane production from livestock (Hribar, 2010). These manure-sourced methane emissions are not included in the emissions intensity considered above. Similarly, emissions associated with growing feed for animals in feedlots are not included either. Furthermore, the cramped, confined conditions of CAFOs not only raise concerns for animal welfare, but human health can also suffer due to air pollutants, contaminated water, and diseases spread from farms (ibid).

The U.S. is the third largest emitter of N_2O due to its high synthetic fertiliser application rates. The significant nitrogen surplus from fertiliser overapplication has led to groundwater pollution, the contamination of waterways, the impairment of aquatic ecosystems, and the creation of anoxic dead zones, most notably in the Gulf of Mexico (Sela *et al.*, 2018). Many farmers do not apply fertiliser during the active growing season, but rather before or at planting for logistical ease. However, this practice increases nitrogen losses (ibid). Typical nitrogen fertiliser application rates can be decreased by 15–20% in the U.S. without significant yield losses (Olander *et al.*, 2011).

The LULUCF sector is a considerable emissions sink in the United States, but the extent of removals is minor relative to total national emissions (Figure 6). While emissions from forest converted to other land uses, LULUCF fires, and drained organic soils are minimal compared to overall emissions, they still amount to over 100 $MtCO_2e$ (ibid).

Figure 6: **United States' land use, land use change and forestry (LULUCF) emissions (average over the period 2015–2020) relative to total national emissions in 2019 (excl. LULUCF)**

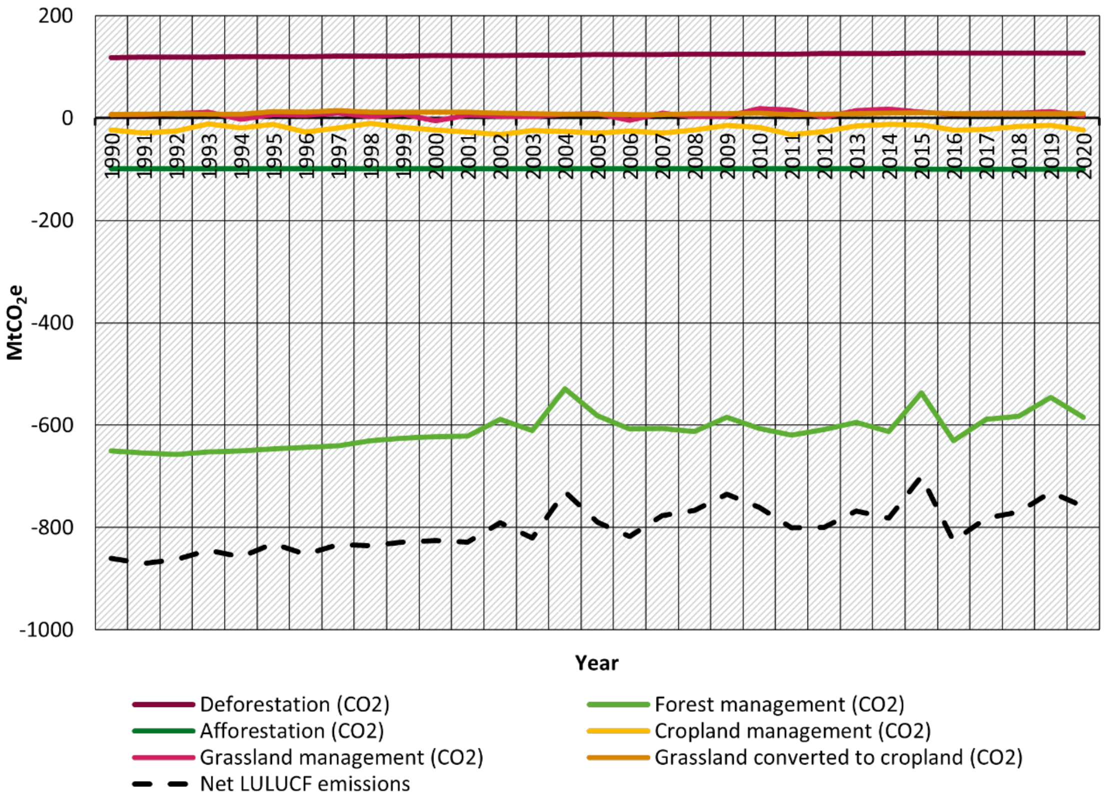


Source: **United States of America (2022)**. The category "other LULUCF emissions" includes carbon dioxide (CO_2) emissions from wetlands, emissions from settlements, emissions from other land, and harvested wood products, as well as all non-CO_2 LULUCF emissions, referring to methane (CH_4) and nitrous oxide (N_2O) emissions primarily from organic soils, nitrogen mineralisation/immobilisation, and biomass burning. Emissions from LULUCF have high interannual variability so average emissions over 6 years is presented to avoid anomalous data.

The U.S. LULUCF sector has historically remained a large emissions sink, though the extent of this sink has been decreasing in recent years (Figure 7). Total sequestration from the LULUCF sector has decreased by 11% since 1990 due to decreased carbon accumulation in forests and land use change driven by agricultural expansion and urbanisation (US EPA, 2022a). Episodic forest fires have resulted in increased GHG emissions in certain years (ibid; Figure 5).

While the LULUCF sector is currently regarded as an emissions sink, land use and land use change still contribute to a considerable amount of GHG emissions at 109 $MtCO_2e$ in 2019 (FAO, 2022a). Most emissions from land use change in the U.S. occur from land being converted to cropland or settlements (US EPA, 2019b). The expansion of soy and corn area for biofuels and animal feed has come at the expense of grasslands and wetlands. Most expansion has occurred on marginal land less suitable for cultivation, depleting agriculturally-vital ecosystem services provided by grasslands and releasing emissions (Lark *et al.*, 2015).

Figure 7: LULUCF emissions in the United States (1990–2020)



Source: **United States of America (2022)**. Does not include a category for "other LULUCF emissions," consisting of CO_2 emissions from wetlands, emissions from settlements, emissions from other land, and harvested wood products, as well as all non-CO_2 LULUCF emissions, referring to CH_4 and N_2O emissions primarily from organic soils, nitrogen mineralisation/immobilisation, and biomass burning.

1.4 Government structures and agricultural policy framework

The United States' Nationally Determined Contribution (NDC) states a GHG emissions reduction target of 50–52% below 2005 levels by 2030, corresponding to a range of 3,715–4,219 $MtCO_2e$ in reductions (Climate Action Tracker, 2021). Although there is no explicit emissions reduction target for the agriculture sector, the government plans to scale up climate-smart agricultural practices such as cover crops, reforestation, rotational grazing, and nutrient management to achieve their NDC target (United States of America, 2021b). The U.S.'s climate target is currently deemed to be 5–10% short of a 1.5°C compatible domestic target in line with the Paris Agreement (Climate Action Tracker, 2021).

The U.S. has additionally set a goal to achieve net zero emissions by the year 2050. While their long-term strategy (LTS) does not set any explicit target for agricultural emissions reductions, it recognises the importance of the AFOLU sector for reducing non-CO_2 emissions and scaling up land-based carbon sinks (United States Department of State, 2021).

The U.S. Environmental Protection Agency (EPA) has the authority to regulate GHG emissions under the Clean Air Act, although related actions and policy are currently limited to the transport, industry, and waste sectors rather than agriculture (CRS, 2021). The U.S. Department of Agriculture (USDA), headed by the Secretary of Agriculture, is responsible for providing technical and financial assistance to promote voluntary GHG emissions reduction activities and climate-smart agriculture (ibid).

The U.S. Farm Bill is an all-encompassing law that governs agricultural and food programmes and related policies. The bill is revisited and renewed every five years (CRS, 2019). The most recent bill was the Agricultural Improvement Act of 2018 and will expire in 2023 (ibid).

The current iteration of the bill provides support to farmers for commodity crops facing revenue losses and disaster assistance, assists producer conservation efforts, encourages on-farm renewable energy development, and was amended to encourage cover crops and other climate-resilient practices by expanding the crop insurance program coverage (ibid; Lehner & Saylor, 2019).

However, the Farm Bill still prioritises specialised commodity production over agricultural diversification and conservation practices (Spangler *et al.*, 2020). Agricultural subsidies from the Farm Bill are evidenced to be less accessible to smaller farms, fail to encourage conservation practices, discourage diversification, and systematically exclude marginalised farmers and farmworkers (ibid).

The 2018 Farm Bill introduced or amended several agricultural conservation programs in the U.S. Most notably include the Environmental Quality Incentives Programs (EQIP), the Regional Conservation Partnership Program (RCPP), and Conservation Stewardship Program (CSP), all of which provide technical and financial resources to farmers to implement or maintain existing conservation practices (Stubbs, 2022). These programs have received significant funding from the Inflation Reduction Act (The White House, 2023).

The USDA's Conservation Reserve Program compensates farmers for stopping production on environmentally sensitive land, and provides assistance for farmers to establish practices such as nutrient management and conservation tillage (USDA, 2022b). The Farm Service Agency (FSA) estimates that the programme protects more than 20 million acres of land and mitigates over 12 $MtCO_2e$ annually (United States of America, 2021a).

The Biden Administration's Executive Order on Tackling the Climate Crisis at Home and Abroad recognises AFOLU as an important sector for mitigating emissions. The order tasked the USDA with creating a Civilian Climate Corps Initiative aimed at mobilising and training workers to conserve and restore public lands, increase reforestation, and increase carbon sequestration in agriculture (White House, 2021). It also called on the USDA to develop recommendations for an agricultural and forestry climate strategy (ibid).

The Climate-Smart Agriculture and Forestry (CSAF) Strategy, based on the Executive Order, is currently under development. Recommendations for the strategy include identifying and quantifying the most promising CSAF practices, ensuring the strategy takes diversity and inclusion into account, leveraging existing USDA programmes to support CSAF, and adopting market-based approaches for CSAF products (USDA, 2021b).

The Growing Climate Solutions Act of 2021, still waiting to be passed by the House of Representatives, is centred around creating new sources of income for climate-smart agricultural activities. The bill directs the USDA to provide technical assistance and develop a certification programme to support farmers seeking to participate in voluntary carbon markets and be rewarded for climate-smart agricultural practices (Climate Action Tracker, 2021).

The USDA recently announced the Partnerships for Climate-Smart Commodities pilot programme, which will provide USD 1 billion (986 million EUR) in funding to incentivise producers and landowners to implement agricultural practices that reduce GHG emissions or sequester carbon (U.S Department of Agriculture, 2022). The other purpose of this programme is to develop markets for climate-smart products and increase the competitive advantage of U.S. producers (ibid).

1.5 Current developments and trends

The U.S has the largest organic market in the world and accounts for roughly half of the global market. Organic food makes up around 5.5% of food sales nationwide, compared to 1.5% for the UK or 2.2% for New Zealand (FiBL and IFOAM, 2019). The amount of certified organic farms increased by 56% between 2011 and 2016 (Bialik and Walker, 2019). Certified organic food in the U.S. must be produced without the use of conventional pesticides and herbicides, petroleum- and sewage-based fertiliser, genetic engineering, antibiotics, and growth hormones, while adhering to animal health and welfare standards (ibid). Despite the magnitude of the market, organic farming systems still only make up a small fraction of national agricultural production.

Instead, U.S. producers are incentivised to increase outputs, expand farm area, specialise in few crops, and to use monocultures rather than diversify their practices (Iles and Marsh, 2012; Spangler *et al.*, 2020). Although community-supported agriculture, farmers markets, and outreach campaigns supporting local products promote diversification in crop production, farmers are still constrained by competition and lack of political support (ibid).

While some climate-smart agriculture practices have been widely adopted by U.S. farmers, other practices have significant room to scale up. For instance, crop rotation practices are extremely prevalent in the U.S. Between 84–92% of corn, soybean, and wheat acreage involves some form of rotation (FAO, 2015). However, continuous no-till practices are applied on only 21% of all cultivated cropland (Creech, 2021). While the extent of farmers utilising cover crops has doubled between 2012 and 2017, this only accounts for 5% of total harvested cropland (USDA, 2021a).

On the other hand, genetically engineered crops have been widely adopted by U.S. farmers, with herbicide-tolerant crops occupying more than 94% of soybean area and 89% of corn area (FAO 2015). As a result, glyphosate-resistant weeds have been spreading and affecting crop yields (ibid).

Agroforestry and silvopastoral practices have been implemented to some extent in the U.S. The USDA has released an Agroforestry Strategic Framework that outlines research and outreach objectives for greater agroforestry implementation on farms (USDA, 2019). There is no clear picture on the current extent of farmland applying agroforestry or silvopastoral practices, but it can be feasibly applied on 10% of U.S. cropland and pastureland (Udawatta and Jose, 2011).

1.5.1 Diets and food waste

Demand-side and external factors have played a major part in shaping the U.S. agricultural landscape. Food waste, dietary habits, the COVID-19 pandemic, and climate change impacts all influence agricultural processes and related emissions.

The U.S. is among the world's top meat consumers, with per capita consumption amounting to 124 kg/year in 2017 compared to the global average of 43 kg/year (Ritchie *et al.*, 2019). Meat consumption in the U.S. is thereby significantly above the recommendation of 15.7 kg per capita from the planetary health diet[2]. Meat consumption in the U.S. has been relatively stable over the past 20 years, but the primary commodity consumed has shifted from beef to chicken (Kuck and Schnitkey, 2021). Consumption patterns have recently been influenced by changes in corn prices and disposable income levels (ibid).

The demand for livestock in the U.S. has significantly influenced the end-use of some of the country's most important commodities. 40% of domestic corn and 60% of domestic soybean production are used as livestock feed (ibid). Most land-use change emissions come from forestland and pasture being converted to cropland in order to expand corn and soy production, part of which is attributed to the demand for animal feed (DeLonge, 2017; US EPA, 2020).

Close to 40% of the U.S. food supply goes uneaten, the majority of which is wasted at the household level (NRDC, 2017). Food waste also corresponds to an enormous loss of embedded resources that go into producing the food. Between 18–28% of U.S. cropland is used to grow food that is ultimately wasted, and food waste represents 19–27% of fertiliser used (ibid). A significant amount of food waste in the U.S. is still disposed of in landfills, where it generates methane emissions.

1.5.2 Recent developments in national context

More recently, the economy-wide Inflation Reduction Act of 2022 includes specific provisions for climate-smart agriculture, and protection and restoration of carbon sinks (The White House, 2023). The Inflation Reduction Act gives a substantial financial boost to existing programmes that support GHG mitigation and the restoration or preservation of carbon stocks. Around USD 20 billion are earmarked for existing conservation programmes, including the Environmental Quality Incentives Program (EQIP), the Regional Conservation Partnership Program and the Conservation Stewardship Program. A further USD 9 billion are dedicated to "Preserving and Protecting the Nation's Lands and Waters for Climate Mitigation and Resilience," including grants for urban tree planting, technical and financial assistance for boosting sequestration on forest land, and wildfire mitigation and response efforts. The Act also provides over USD 12bn in funding for rural clean energy initiatives (incl. for agricultural producers), many of which are administered by the USDA (ibid).

The Inflation Reduction Act provides a much-needed injection of finance into agricultural mitigation and resilience but has also come under criticism. For example, the Act boosts support for ethanol production and consumption, thereby supporting monoculture practices that are problematic for biodiversity and soil erosion (Philpott, 2022). The Act also fails to address some of the biggest sources of emissions, including meat production or food waste (Jones, 2022). In 2023, the Farm Bill will be renegotiated, as is carried out every 5 years. The Farm Bill has the potential to provide complement the Inflation Reduction Act and provide additional support for sustainable agricultural processes.

The U.S. agricultural system is also subject to impacts from external factors. For instance, COVID-19 border closures exacerbated the U.S. agricultural sector's labour shortage, due to the sector's high dependence on immigrant workers (FWD.us, 2021). The chronic labour storage has resulted in a significant increase in imported fruits and vegetables and higher on-farm food waste from unharvested crops (ibid).

Wildfires have had a significant impact on agricultural systems in certain regions. In 2020, California experienced its largest wildfire season in recorded history, where over 1.7 million

[2] https://eatforum.org/eat-lancet-commission/the-planetary-health-diet-and-you/

hectares of land burned (CAL FIRE, 2022). The fires caused extensive harvest losses, livestock deaths, and infrastructure and ecosystem damage, not to mention the health risks in the aftermath (California State Assembly, 2020). Targeted livestock grazing to reduce wildfire fuel has been touted as an agricultural-based fire prevention measure that could be practiced in addition to prescribed burning (ibid). Under future warming scenarios, the frequency and intensity of wildfires is predicted to increase, which can result in permanent land cover conversion and significant impacts to rural and indigenous communities and their agricultural production capabilities (USGCRP, 2018).

1.6 Vulnerability and adaptation

Since the U.S. encompasses a wide range of climates, the impacts of climate change on agricultural yields will manifest quite differently across the country. In general, climate change in the U.S. will result in higher average temperatures with greater variability, altered precipitation patterns, increased extreme weather incidences, and greater pest and disease pressures (OECD, 2016).

The U.S. agricultural system is predicted to be fairly resilient to the short- and middle-term effects of climate change due to its high flexibility to engage in adaptive behaviours such as expanding irrigated acreage, regionally shifting the acreage of specific crops, and changing inputs and cultivation practices (Walthall *et al.*, 2013). This resilience could reasonably persist until mid-century, when temperature increases exceeding 1°C and extreme changes in precipitation would result in extensive yield losses (ibid).

In the long term, implementing adaptive measures including drought-, pest-, and heat stress-resistant crops and animals, diversified crop rotations, improved soil quality, and integrated livestock-crop systems are recommended to minimise the negative impacts of climate change (Walthall *et al.*, 2013).

The U.S. Department of Agriculture (USDA) developed a National Adaptation Plan in 2014 that outlines steps that can be taken by government agencies to build resilience across the agriculture and forestry sectors (USDA, 2014). This includes the establishment of USDA Climate Hubs that aid in tool and strategy development and implementation, conducting regional vulnerability assessments, and stakeholder education and outreach (ibid).

In line with the Biden Administration's Executive Orders on Tackling the Climate Crisis at Home and Abroad, the USDA released an action plan for strengthening adaptation actions and resiliency in the agricultural sector that builds upon the National Adaptation Plan. It reinforces the importance of disseminating climate-smart agriculture practices like cover crops, no-till, crop rotation, nutrient management, prescribed grazing, and agroforestry that can improve soil health and thus build resiliency to climate change impacts (USDA, 2021a).

2 Key areas with high mitigation potential

2.1 Introduction

In this section, we quantify the potential of three mitigation options and explore the co-benefits and barriers to their implementation in a country-specific context. In selecting which three mitigation options to quantify, the contribution of different emission sources was considered, along with the potential for socio-economic and environmental co-benefits, the country-specific context of the agricultural sector (see Section 1) and the general feasibility for implementation.

2.1.1 Selection of priority mitigation actions

Synthetic fertiliser use makes up a high share of agricultural emissions (10%, Figure 4) in the U.S., part of which can be attributed to its overuse. Nitrogen fertiliser application rates can be decreased by 15–20% in the U.S. without incurring significant yield losses, meaning there is significant potential to mitigate emissions via improved nutrient and fertiliser management (Olander *et al.*, 2011). Reducing nutrient losses on agricultural land also helps address the problem of eutrophication and the appearance of anoxic dead zones, most notably in the Gulf of Mexico.

Manure management makes up ~10% of sectoral emissions (Figure 4). In recent years, new government regulations on applying manure to land have shifted manure management practices on some pasture-based farms from daily spread systems to storing and managing the manure on-site. The CAFOs associated with highly industrialised livestock systems also produce significant amounts of manure that must be stored and managed, as opposed to manure left on pasture in extensive grassland systems.

Pastureland makes up almost a third of US country area. Improved grazing land management can preserve and potentially enhance natural carbon stocks on pasture on large areas in the country.

For the US, we therefore selected the following measures:

- Improving nutrient management
- Improving manure management
- Improving grazing land management.

Even though enteric fermentation drives the largest share of AFOLU emissions, we did not select improvements in livestock emissions intensity as a priority mitigation action for the USA. As a significant share of beef and dairy farming in the USA is CAFO-based, the emissions intensity per tonne of meat produced is relatively low and there is minimal room for further implementing further efficiency strategies (e.g. improved feed, lifecycle management) (Cusack *et al.*, 2021). Instead, we choose here to focus on other aspects of agricultural systems where intensity improvements are still feasible. Nevertheless, meat consumption in the U.S. is significantly above the recommendations by the planetary health diet which suggests consumption levels of 15.7 kg per capita/year as a level compatible with planetary boundaries[3]. In our recommendations section, we therefore highlight how changes in diet and reductions in food waste with consequent declines in total livestock numbers could lead to reductions in livestock emissions.

[3] https://eatforum.org/eat-lancet-commission/the-planetary-health-diet-and-you/

2.1.2 Overall mitigation potential

On the basis of estimates provided in the literature, implementing the three selected mitigation options could contribute to an overall emissions reduction of 45-80 $MtCO_2e$ in 2030, or 7-12% of current agricultural emissions, and could result in additional carbon sequestration of 10-85 $MtCO_2e$/year. We note that there is high uncertainty in terms of the long-term soil carbon dynamics that can affect the extent of sequestration. In general, carbon sequestration options should not replace the deep decarbonisation needed in GHG emissions to meet climate pledges and 1.5°C compatible emissions levels.

According to a study from the EPA (US EPA, 2022b), the US agricultural sector could reduce its overall non-CO_2 GHG emissions in 2030 by 37 $MtCO_2e$ below baseline at no cost, or a technically feasible 93 $MtCO_2e$ with 'increasing costs'. In the latter scenario, the highest abatement potential by magnitude comes from livestock (73 $MtCO_2e$), followed by rice cultivation (9 $MtCO_2e$) and croplands (8 $MtCO_2e$). On the other hand, the highest abatement potential by percent reduction from the 2030 baseline comes from rice cultivation (55%), followed by livestock (27%) and croplands (3%). The mitigation options for livestock in the EPA's assessment include measures to reduce both enteric fermentation and manure management (in the form of digesters and covered lagoons) (US EPA, 2019a). However, many of the measures outlined to reduce enteric fermentation carry considerable environmental and health risks, including antibiotics, bovine growth hormones, and anti-methanogen vaccines. The 2022 study focused on non-CO_2 emissions only and did not estimate carbon sequestration potential on agricultural lands.

A different study by Eagle et al. (2022) outlines an ambitious emissions reduction target of 560 $MtCO_2e$ below 2018 levels for the US AFOLU sector based on current technical feasibility and near-term innovations. The overall estimate is very high but includes removals of 330 $MtCO_2e$. CO_2 emissions of up to 135 $MtCO_2$ could be avoided primarily from avoided land conversion but also from avoided fertiliser production and on-farm energy use. The report estimates that the US could achieve 63 $MtCO_2e$ in methane emission reductions from livestock and rice cultivation; 34 $MtCO_2e$ from enteric fermentation and 25 $MtCO_2e$ from manure mitigation measures. A further 32 $MtCO_2e$ of nitrous oxide emissions reductions could be achieved through improved nitrogen management and livestock manure management. The measures considered included feed optimisation, herd health, selective breeding, feed additives, animal drugs, improved genetics, covering lagoons, and solid-liquids separation (ibid). As with the EPA report, some of these measures carry environmental and animal welfare risks[4].

The three mitigation measures outlined in the following sections thus form a part of a broader set of measures that would be necessary to bring the US AFOLU sector on track to reaching long-term climate targets with additional measures including improvements to rice cultivation, reducing on-farm energy use emissions, reducing land-use change, and enhancing natural sinks, especially forests.

By 2030, under a business-as-usual scenario, livestock emissions are expected to have used half of the remaining global GHG emissions budget consistent with a 1.5°C pathway (Harwatt, 2019). While quantifying demand-side mitigation options are outside the scope of this study, excluding dietary shifts from animal to plant protein from climate pledges and mitigation plans increases the risks of exceeding the 1.5°C temperature limit, requires unrealistic, substantial GHG emissions reductions in other sectors, and increases reliance on negative emission technologies

[4] Feed additives in particular carry not just health and animal welfare risks, but also have highly uncertain efficacy and the potentially more effective options are far from commercially viable.

(Harwatt, 2019). This is particularly relevant for developed countries such as the US, which has one of the world's highest meat consumption rates and is one of the world's top meat producers.

2.2 Prioritised mitigation options

2.2.1 Improved nutrient management

Measure

While synthetic fertiliser use has and continues to play an important role in increasing global food supply, its overuse has resulted in extensive environmental pollution and nitrous oxide emissions. Globally, around 50% of nitrogen applied to crops is not absorbed (Searchinger *et al.*, 2019). The overuse of synthetic fertilisers does not derive additional productivity benefits, although it results in more costs and environmental degradation. Nutrient losses and corresponding nitrous oxide emissions from the overuse of synthetic fertiliser can be mitigated by more precise fertiliser application (at the right rate, time, and source) and the inclusion of legumes in integrated production systems (ibid).

Status

An estimated 28% of US cropland currently exceeds the nitrogen loss threshold. The USDA's Natural Resource Conservation Service (NRCS) has launched several initiatives regarding funding and outreach for nutrient management measures as a result of bolstered funding from the Inflation Reduction Act (USDA, 2022e).

While the US has achieved a relatively high nitrogen use efficiency (NUE) – 71.6% in 2014 – there is still scope to improve the nitrogen uptake of crops even further (Systemiq, 2022). For example, taking Iowa as a case study, more farms could apply fertiliser in a split, rather than a single application to allow for more precise dosing. Split application is currently occurring on 20% of Iowan maize area. About 72% of Iowan maize fields apply fertiliser in excess and eliminating this surplus would reduce fertiliser inputs by 18% (ibid).

Potential

A study by Fargione et al. (2018) estimates a mitigation potential of up to 52 $MtCO_2e$/year from cropland nutrient management in 2025. This estimate consists of four improved practices – reducing fertiliser application rates, switching from anhydrous ammonia to urea, improved timing of application, and varying application rate within a single field. The four practices are implemented on all applicable area, ranging from 35% to 64% of cropland.

A reported financed by the International Fertiliser Association (IFA) estimates that eliminating surplus application of mineral nitrogen fertiliser from all US maize production could result in emission reductions of 6.4–11.9 $MtCO_2e$/year in 2050 (Systemiq, 2022). This option is considered to be low cost. Another 6.5–7 $MtCO_2e$/year could be avoided by implementing maize-soya crop rotations in place of maize-maize, however, there are potentially higher costs to implementing crop rotations and would change overall production. Combined, these measures would achieve mitigation of 13–19 $MtCO_2e$/year. Estimates from the Systemiq report are likely lower than those from Fargione et al., (2018) due to different coverage in terms of crops included and mitigation actions considered.

Co-benefits

Improved nutrient management has positive economic benefits for farmers since it reduces the need for synthetic fertiliser application and associated costs. US farmers who adopt a nutrient management plan are estimated to save USD 30 per acre of cropland (USDA, 2022e). Well-managed soils in terms of nutrients also provide yield benefits over the long term, thus decreasing the risks for farmers and the need to expand agricultural land. Avoiding nutrient losses from overuse results in improvements to air, water, and soil quality as it reduces environmental pollution and eutrophication (Roe *et al.*, 2021).

Barriers

Technical barriers: Optimised nutrient management is dependent on multiple factors, including soil moisture, temperature, oxygen concentration, and available carbon and nitrogen, which varies on a farm-to-farm level. As a result, the same activity can have different emission outcomes from one farm to its neighbour (Systemiq, 2022). This variance and the lack of granular data makes it difficult to prescribe solutions, as they are not one-size-fits-all.

A lack of capacity building efforts also impacts the uptake of improved nutrient management. Some US farmers have not yet made a connection between fertiliser use and climate change, as they receive recommendations for fertiliser application from fertiliser dealers rather than scientists and extension offices (Stuart *et al.*, 2014).

Economic barriers: Some nutrient management measures require up-front investments, while optimising fertiliser application is more labour-intensive than conventional systems. Additionally, farmers overuse fertiliser to ensure their yields do not increase (Roe *et al.*, 2021).

Policy/legal barriers: The US currently lacks a comprehensive federal policy on regulating fertiliser use, which often results in overuse by farmers as they apply as much as deemed necessary. In addition, current agricultural subsidies focus on paying farmers based on production volumes or past yields, incentivising farmers to overapply fertiliser to maximise their yields (UCS, 2016).

2.2.2 Improved manure management

Measure

The most appropriate mitigation option for manure management depends on farm size and existing infrastructure (Pape *et al.*, 2016). In the US, most manure management emissions are associated with dairy and swine operations. Primary mitigation options include the use of digesters to produce biogas that can be flared or used to generate electricity or heat. Covering existing anaerobic lagoons allows for CH_4 gas to be captured, while separation of solids allows for easier handling of liquid manure, reduces odours, and can reduce risks of groundwater pollution.

Status

Emissions from manure management increased slightly over the last decade reaching 78 $MtCO_2e$ in 2019. In 2010, 85% of CH_4 emissions from manure management were produced from dairy or swine operations using anaerobic lagoons, deep pits, or liquid/slurry systems, all of which have possible mitigation options.

Potential

The EPA estimates an 85% manure emissions reduction per head of livestock when switching from anaerobic manure management to digesters, based on Intergovernmental Panel on Climate Change (IPCC) emissions factors (US EPA, 2019a, pg 224). Implementing a range of improved manure management practices on large pig and dairy farms across the US is estimated to have a mitigation potential of up to approx. 30 $MtCO_2e$/year by 2030 at a carbon price of USD 100/tCO_2 (Eagle *et al.*, 2022). 25 $MtCO_2e$ of this is from CH_4 reductions with an additional 5 $MtCO_2e$ from N_2O. Most of this potential can be achieved at a relatively low cost of less than 30 USD/tCO_2e (Pape *et al.*, 2016).

Co-benefits Covering existing lagoons has numerous co-benefits, including odour reduction and pollution control (air, soil, water) (Roe *et al.*, 2021). The separation of solids from liquids can reduce the costs needed for manure storage and potentially reduce management costs from transporting manure with high nutrient content to other fields (MacSween and Feliciano, 2018). The use or sale of electricity generated from burning captured biogas from anaerobic digesters can also reduce costs for the farmer, while also producing fertiliser in the form of digestate (ibid).

Barriers **Economic barriers:** Improving manure management on farm can require high up-front costs for infrastructure, especially in the case of anaerobic digesters, which also require more labour for regular maintenance and management (US EPA, 2022).

Biophysical/environmental barriers: Different temperatures and amounts of sunlight impact the efficacy of lagoons and as such, require the appropriate equipment (Bristola, 2023). Cold temperatures inhibit anaerobic bacteria and can lead to longer times for processing. Most importantly, improper management risks methane slips, releasing CH_4 into the atmosphere, and increased N_2O emissions.

2.2.3 Grazing land management

Measure Controlling the stocking rate, intensity, and duration of grazing provides a favourable environment for vegetation growth and organic matter inputs, which has the potential to increase soil organic carbon (SOC) stocks and thus enhance carbon sequestration on grasslands (FAO and ITPS, 2021). For example, applying rotational grazing practices where livestock are moved from one section of pasture to another ensures even grazing and allow pastures to recover between grazing periods. Rotational grazing can further reduce fertiliser inputs on grassland and improve animal productivity through higher forage quality (ibid).

Status The USDA's Natural Resource Conservation Service (NRCS) has promoted rotational grazing for improved environmental outcomes for some years now, and provides financial and technical assistance to farmers to implement the practice (Whitt and Wallander, 2022). Approximately 40% of US cow-calf operations apply some form of rotational grazing, but only 40% of that implements intensive rotational grazing practices (ibid). It is unclear what this translates to in terms of hectares.

Potential Estimates for the sequestration potential of improved grazing land management vary considerably. According to Fargione et al. (2018) implementing grazing optimisation on 53 Mha of US grasslands (~19% of total) has a maximum carbon sequestration potential of around 11 $MtCO_2e$/year. On the other hand, Chambers et al. (2016) estimate the sequestration potential of prescribed grazing to be between 33–85 $MtCO_2e$/year (applying sequestration rate from Table 3 to previous assumption of 53 Mha of grassland). Using a global model, Roe *et al.* (2021) find a cost-effective carbon sequestration potential on US grasslands of 146 $MtCO_2$/year over the period 2020–2050. This latter estimate is much higher

	and likely incorporates measures in addition to grazing land management to achieve the full sequestration potential.
Co-benefits	Rotational grazing practices and other forms of grazing management usually improve soil structure, protect against soil erosion, and enhance soil biodiversity, resulting in improved soil health and functioning (FAO and ITPS, 2021). Improvements in soil health also have positive implications for adaptation and drought management.
Barriers	**Technical barriers:** The measurement, reporting and verification (MRV) of soil carbon stock gains on grassland and corresponding emissions reductions is challenging due to its uncertainty and complexity (OECD, 2019). Farmers also cite a lack of adequate information on rotational grazing as a barrier towards its adoption (Wang *et al.*, 2020). **Economic barriers:** Grazing land management requires increased infrastructure needs (e.g. more fences), resulting in higher upfront and maintenance costs that can deter adoption by farmers (FAO and ITPS, 2021). **Legal barriers:** Insecure land tenure highly inhibits the uptake of regenerative practices. Leased farmland is often short-term and requires permission to erect infrastructure, which is contrary to the long-term planning and implementation needed to effectively sequester more carbon on grasslands via improved grazing management (O'Connor, 2020).

Natural carbon sequestration: Risks and uncertainties

The estimated carbon sequestration potential of below- or above-ground land-based mitigation measures, such as rotational grazing, cover crops, agroforestry, or silvopastoralism, is quite high and often overshadows the overall mitigation potential of agricultural systems. However, its effectiveness is highly uncertain and dependent on multiple site-specific factors (Nabuurs *et al.*, 2022). In general, carbon accumulation in soils or vegetation carries risks of non-permanency and reversibility. Increased carbon stocks will eventually reach a new equilibrium in the long-term when net CO_2 removals from the atmosphere reach zero and will no longer be an active sink (Garnett *et al.*, 2017; Landholm *et al.*, 2019). Soil carbon gains are reversible and can be undone if improved management practices are not maintained or stocks decrease due to climactic factors. In agroforestry systems, as with all natural systems, there is a risk that fires, climate change, or disease could cause carbon to be re-released into the atmosphere (Meyer *et al.*, 2020). While natural carbon sequestration measures should not replace the decarbonization needed in the agricultural sector to meet climate targets and 1.5°C compatible emissions levels, they have numerous co-benefits, are an effective climate change adaptation measure, and should therefore continue to be supported and implemented.

3 Barriers to implementing mitigation potential

In this section, we examine the main barriers to the mitigation of agricultural emissions identified for the country, building on the findings of a report on general barriers prepared under this research project (Siemons *et al.*, 2023) and the country-specific circumstances described in Section 1 of this report. The analysis of barriers below follows the clustering proposed in the above-mentioned report, according to the relevant governance level for taking action, while taking into account the classification from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (IPCC, 2019) within each of the governance levels.

3.1 Farm level

Many mitigation measures require upfront investment, such as purchasing anaerobic digesters for manure management or constructing fences to manage rotational grazing. Coupled with uncertainties around the impact of changing practices on yields and consequently economic returns, these investment costs present a financial and economic barrier to farmers who may be operating on tight budgets and not have funds available for investing (Walton Family Foundation and Boston Consulting Group, 2022). A lack of awareness of some of the potential co-benefits of mitigation measures can exacerbate a reluctance to invest.

A lack of technical knowledge for implementing mitigation measures can be an additional hindrance, and particularly challenging for those measures that need to be adapted to the farm and crop specific circumstances, such as many of those for nutrient management.

Finally, cultural barriers and a general resistance to changing existing practices need to be overcome to initiate changes in on-farm management practices (Toman *et al.*, 2022; Walton Family Foundation and Boston Consulting Group, 2022).

3.2 National level

Currently, national policies like subsidies promote high-emitting agricultural practices such as fertiliser overapplication and meat production. At the same time, there is a lack of strong regulations on fertiliser overuse and its environmental harms or on limiting the impacts of manure management.

Changing these policies and regulations is challenging in the U.S. political context with a high likelihood of push-back to proposed reforms. That push-back would likely be supported by major agribusiness interests that have strong lobby potential. Farms in the U.S. have become increasing consolidated, giving an influential voice to a few companies.

Some national legal frameworks make the implementation of mitigation measures more difficult. For example, insecure land tenure highly inhibits the uptake of regenerative practices on grazing land. Leased farmland is often short-term and requires permission to erect infrastructure, which is contrary to the long-term planning and implementation needed for carbon sequestration measures, and exacerbates the financial challenges to farmers highlighted above (O'Connor, 2020).

3.3 International level

If mitigation measures taken in the U.S. are costly, it may mean increasing imports of products with higher emissions intensity from abroad. This is a particular risk in the case of producing grains as feedstock for livestock which often drives land use change, both in the U.S. and abroad.

Pursuit to remain competitive in international agricultural markets may further deter action in terms of implementing mitigation measures if those measures come, or are perceived to come, at an additional cost.

3.4 Consumer level

As in many countries, changes toward healthier and more environmentally friendly diets face social and cultural barriers. In the U.S., per capita meat consumption is one of the highest in the world and has remained steady over the last two decades (Ritchie *et al.*, 2019). Reducing meat consumption would mean a substantial shift in long-term patterns. At the same time, many in the U.S. suffer from food poverty and cannot afford a healthy diet. In 2021, 10.2% of U.S. households were food insecure (USDA, 2023). Any measures to target emissions should support a transition to a healthy and affordable diet for all.

With 40% of food being wasted, reducing on-farm and retail food waste also has a high mitigation potential in the U.S. (NRDC, 2017). Changing eating habits and consumer preferences for how food is supposed to look contribute to reducing the emissions produced from food that is ultimately unused. In addition, any food that is not eaten can be used more effectively and with lower methane emissions if it is redirected away from landfill towards industrial uses or composting (ibid).

4 Recommendations

In a world compatible with the Paris Agreement, the agricultural sector will need to meet the growing food demand of people and animals, while contributing to other equally relevant climate and development objectives and adapt to a changing climate. Mitigation action in the United States, one of the large emitters globally, is essential for limiting global temperature increase, including in the agricultural sector.

To maximise emission reductions in the agriculture sector, the United States would need to take a multi-faceted approach. This study identified and quantified three mitigation actions in the USA's agricultural sector that would improve productivity and provide environmental and economic co-benefits: improving manure management, nutrient management, and grazing land management. Based on existing literature, we estimate a 2030 mitigation potential of 50–80 $MtCO_2e$ below 2018 levels from changing manure and nutrient management practices. Changes to management practices with significant mitigation potential include optimising the timing and amount of fertiliser application, including legumes in integrated production systems, covering existing anaerobic manure lagoons, and separating solid and liquid waste.

Literature that has explored further mitigation across the agricultural system has identified additional options, including changes to rice cultivation and livestock management, that could lead to non-CO_2 emission reductions of up to 95 $MtCO_2$ below 2018 by 2030. However, some of the livestock management options presented may conflict with animal welfare priorities and entail environmental risks, although most of the mitigation potential is derived from changes to practices that would not increase harm to animals and would lead to other environmental benefits, including reduced eutrophication, improved soil quality, and in some cases reduced operational costs.

In addition to reducing non-CO_2 emissions from agriculture, the U.S. also has substantial potential for increasing the amount of carbon sequestered on domestic land. A key on-farm measure that can help to increase carbon stored on grazing land is to adapt changes to grazing land management, including adopting rotational grazing. Various studies estimate a sequestration potential of 11–85 $MtCO_2$ through modified grazing land management (Chambers *et al.*, 2016; Fargione *et al.*, 2018). As practices to enhance soil carbon stocks have many co-benefits for soil health that can also help with building climate resilience, it makes sense to pursue such measures. However, there are high uncertainties in measuring changes to soil carbon stocks and care should be taken that efforts to enhance carbon stocks do not displace efforts to reduce GHG emissions (see box on natural carbon sequestration above). Further options for enhancing carbon stocks that were not considered in detail in this report include restoration of degraded lands, adoption of agroforestry or silvopastoral practices, and avoided land conversion.

This report did not examine CO_2 emissions from on-farm energy use in detail, although it is a substantial contributor to total agriculture emissions (~6%, Figure 4). Unlike non-CO_2 emissions from biological processes, CO_2 emissions from energy use can be almost completely eliminated through electrification or use of sustainable biofuels meaning that this sub-sector represents significant additional mitigation potential.

Under its NDC, the US intends to reduce economy-wide emissions by 50–52% below 2005 levels by 2030, or by 3,715–4,219 $MtCO_2e$. The estimated potential mitigation of up to 95 $MtCO_2e$ from agriculture only provides a small share of this overall mitigation goal but is still significant, and greater when the sequestration potential on agricultural lands is also pursued. Furthermore, the mitigation potential reported here is for technical reductions only; additional potential resides in options to reduce food loss and waste and in switching to more sustainable diets, thereby reducing livestock numbers and their associated emissions. With agriculture contributing 10% of total national emissions, utilising all mitigation options available in the sector could contribute substantially to the overall NDC goal. Two of the areas we identified as having substantial mitigation potential – nutrient management and rotational grazing – are both mentioned in the NDC. Although manure is acknowledged as a major source of emissions, it is not specifically mentioned in the list of actions. It is possible that some elements of manure management are encapsulated under "climate smart agriculture", but the NDC does not make explicit what's considered under the term.

Despite many co-benefits and opportunities, the successful implementation of agricultural mitigation measures is hampered by numerous barriers on the farm-, national-, international-, and consumer-level. For the selected mitigation measures presented in more detail in this report, we identified technical, economical and policy/legal barriers. At the farm level, economic and financial barriers are a key concern. Changing practices often comes with up-front costs and uncertainties about the impacts on yields. Coupled with a lack of technical knowledge about new practices and cultural barriers to change, there may be substantial resistance to adopting practices that are less common. These challenges can be exacerbated by the precarious financial situation of many farmers and a lack of financial support for implementing change (section 3).

Overcoming these barriers and advancing on the measures proposed in this report means enhancing the national mitigation framework in the agricultural sector and reconciling agricultural goals and mitigation options, while protecting the sector from environmental and economic risks. Some concrete options are outlined in the following paragraphs:

1. *Enhancing the role of agriculture in the national climate mitigation framework*

Both the USA's NDC and Long-Term Low Emissions Development Strategy (LTS) include mitigation actions in the agriculture sector. The overall target for the USA is 50–52% below 2005 levels in 2030. The NDC doesn't specify a separate target for agriculture, but the LTS describes several measures to reduce non-CO_2 emissions that would amount to 80 $MtCO_2e$ in mitigation potential in 2030. The U.S. could specify concrete targets for the agriculture sector to raise the profile of mitigating agricultural emissions.

Currently, both the NDC and LTS do not include demand-side measures, such as reducing food loss and waste or changing diets, and the focus is instead strongly on enhancing carbon sequestration. The plans are also missing measures to address other, significant environmental impacts of current agricultural practices, particularly enhanced pollution driven by CAFOs and the biodiversity and soil health impacts of monoculture cropping. Policy changes to address these issues could have long-term positive benefits in terms of soil health, biodiversity, and resilience to climate impacts.

The U.S. was an initiator, along with the EU, of the Global Methane Pledge, committing to reduce domestic methane emissions by 30% below 2020 by 2030. Reducing agricultural methane emissions could help the U.S. to meet its pledge (The White House, 2021).

2. *Align overall agricultural policy framework with climate mitigation objectives*

The USA has strong agricultural policies, some of which already support climate friendly practices. However, climate is not their main focus and there is significant room for better aligning existing agricultural policies with mitigation and adaptation goals.

The Inflation Reduction Act of 2022 already boosted support for conservation practices in the USA through providing additional finance to existing programs. In 2023, the US Farm Bill will be renegotiated – as is carried out every 5 years. This bill has potential both to increase financial support for existing programs and to incentivise practices that are not yet taken up. Although the Farm Bill often receives bi-partisan support overall, there may be considerable resistance to including additional explicit climate mitigation measures.

As many regulations in the USA are passed at state, rather than federal level, there exist additional opportunities for states to incentivise and support shifts to sustainable farming practices.

3. Selected ideas for how mitigation could be strengthened

A number of concrete ideas have been proposed for how the above and other policies could be strengthened in a manner that supports overcoming existing barriers.

- **Reform crop insurance systems** to limit support for high GHG emission activities (e.g. livestock rearing) and increase support for practices that reduce emissions and increase soil health, e.g. cover cropping (National Sustainable Agriculture Coalition, 2022; Sharma *et al.*, 2022; Toman *et al.*, 2022).

- **Reform subsidies in agriculture to avoid incentivising over-use of fertiliser** (National Sustainable Agriculture Coalition, 2022; Sharma *et al.*, 2022a)**.**

- **Provide further technical and knowledge support** for enhancing farmer's capacities to identify the right strategies for their farm (e.g. fertiliser application).

- **Broadly increase funding for conservation programmes** through the Farm Bill (Sharma *et al.*, 2022), including through the Conservation Stewardship Program that support farmers and ranchers in using lower-GHG agricultural techniques (National Sustainable Agriculture Coalition, 2022; Toman *et al.*, 2022).

- **Increase the extent of funding available for transitioning farms to more sustainable practices** (Sharma *et al.*, 2022).

- **Develop demand-side measures to change dietary choices and reduce food waste.** For example, national laws to standardize and clarify date labels coupled with informational programs could make it easier for consumers to understand the labelling and reduce food waste (NRDC, 2017).

- **Further develop policies to address international supply chains** to also ban commodities associated with legal deforestation and the destruction of other ecosystems than forests.

While this report focuses on improvements on the production of agricultural products, it is essential to highlight that without changes to dietary patterns, mainly in developed countries, a sustainable and just 1.5°C pathway is not feasible. International research reports that demand-side measures, such as shifting to less meat intensive diets and reducing food waste, have a high mitigation potential while contributing to other co-benefits at relatively lower costs (Roe *et al.*, 2021). Such measures are particularly relevant in the USA due to both the high average per capita consumption and high rates of food waste (section 1.5.1).

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