CLIMATE CHANGE
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Status, potential and challenges

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Abstract: Mitigating agricultural greenhouse gas emissions in Australia

This report describes the current state of agriculture in Australia 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: Länderbericht Australien

Dieser Bericht beschreibt den aktuellen Stand der Landwirtschaft in Australien im Hinblick auf die von ihr verursachten Treibhausgasemissionen (THG-Emissionen) sowie den aktuellen sozioökonomischen und klimapolitischen Rahmen für den landwirtschaftlichen Sektor. Wir identifizieren Optionen für Maßnahmen, die die landwirtschaftlichen Emissionen reduzieren könnten, und diskutieren das Minderungspotenzial dieser Optionen. Abschließend werden Hindernisse für die Umsetzung dieser Minderungsoptionen und einige mögliche Lösungen zur Überwindung dieser Hindernisse aufgezeigt.

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List of abbreviations

3-NOP	3-Nitrooxypropanol
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AFOLU	Agriculture, Forestry and Other Land Use
CO_2	Carbon dioxide
CH_4	Methane
DAWE	Department of Agriculture, Water and the Environment
DIRES	Department of Industry, Science, Energy and Resources
ERF	Emissions Reduction Fund
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land-Use Change and Forestry
Mha	Mega hectares
MLA	Meat & Livestock Australia
MRV	Measurement, reporting and verification
$MtCO_2e$	Mega tonnes of CO_2 equivalent
NDC	Nationally Determined Contribution (in Paris Agreement)
NSW	New South Wales
N_2O	Nitrous oxide
OECD	Organisation for Economic Co-operation and Development
SOC	Soil organic carbon
THG	Treibhausgas
UNFCCC	United Nations Framework Convention on Climate Change

Summary

The aim of this report is to identify possible emissions mitigation options in the agricultural sector, to identify barriers towards implementing those options and provide some recommendations on how to overcome those barriers. The report begins with a description of the current state of agriculture in Australia with regard to the GHG emissions it produces, and the climate and socioeconomic policies that shape the sector. We then identify three key options that could reduce agricultural emissions and estimate their mitigation potential. Finally, we identify barriers that act at the farm, national, international and consumer level along with possible steps to overcoming those barriers.

Australia plays a key role in the global agricultural landscape; the country contains the 3rd largest agricultural landmass, has the world's 2nd largest live cattle population, and is the 7th largest wheat exporter (Australian Government, 2021a). While agriculture only represents a small share of the countries' economy, Australia is still a key world supplier of several agricultural products including beef, live cattle, lamb, wheat, legumes, and sugar.

In 2019, Australia's agricultural sector produced an estimated 85 $MtCO_2e$ of emissions, contributing about 15% of total national emissions (excl. Land Use, Land-Use Change and Forestry (LULUCF)). The largest agricultural emissions sources are enteric fermentation (57%) and manure management (8%), most of which can be attributed to Australia's large beef and dairy herds. Compared to other high-income countries, the emissions intensity of cattle in grassland or mixed systems is still rather high in Australia and there is potential scope for improvement.

Agricultural activity has significantly shaped Australia's land use and corresponding emissions. From 1972 to 2014, over 7.2 million hectares of primary forest were cleared nation-wide, which comprises a loss of 7% of forest cover (Evans, 2016). Around three quarters of deforestation was attributed to clearing for pastures, with the rest attributed to cropping, forestry, urban development, and mining (ibid). Considering Australia's massive land area, there is high carbon sequestration potential from implementing land-use based mitigation options.

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 (see Section 1), and the general feasibility for implementation.

For Australia, we selected the following three mitigation measures:

- Implementation of silvopastoral systems
- Improved livestock emissions intensity
- Grazing management and improved pastures

According to our calculations, the implementation of these prioritised mitigation options could contribute to an overall emissions reduction of 6 $MtCO_2e$ compared to 2019 levels (assuming constant levels of production) and could result in additional carbon sequestration of 210–260 $MtCO_2e$/year by 2040. However, there is high uncertainty in terms of overlaps between mitigation options as well as in long-term soil and above ground carbon dynamics that can affect the extent of sequestration, and others have estimated a lower sequestration potential.

There are critical barriers that hinder the implementation of measures to achieve the outlined mitigation potentials and impair other activities to reduce GHG emissions in the agricultural

sector. Most barriers are on the farm level and the national level, with a lack of comprehensive, unbureaucratic policies to incentivise mitigation action and build knowledge of sustainable practices and their positive effects. The growth of international demand for meat and dairy products and domestic overconsumption and wasteful behaviour drive production up, and while these are not direct barriers to mitigation actions on the production side, they have competing effects on the total amount of GHGs emitted from the sector.

To accelerate the uptake and implementation of the measures described in this report, it is key to 1) more clearly translate national mitigation priorities to the agricultural sector, 2) in turn ensure that all agricultural policies are aligned with mitigation objectives and 3) implement sector policies to comprehensively address the areas in which most mitigation is possible. 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 aufzuzeigen, Hindernisse bei der Umsetzung dieser Optionen zu identifizieren und Empfehlungen zur Überwindung dieser Hindernisse zu geben. Der Bericht beginnt mit einer Beschreibung des aktuellen Stands der australischen Landwirtschaft im Hinblick auf die von ihr produzierten Treibhausgasemissionen und die klima- und sozioökonomische Politik, die den Sektor prägt. Anschließend werden drei wichtige Optionen zur Verringerung der landwirtschaftlichen Emissionen aufgezeigt und ihr Minderungspotenzial abgeschätzt. Schließlich zeigen wir Hindernisse auf, die auf betriebswirtschaftlicher, nationaler, internationaler und Verbraucherebene wirken, sowie mögliche Schritte zur Überwindung dieser Hindernisse.

Australien spielt eine Schlüsselrolle in der globalen Agrarlandschaft; das Land verfügt über die drittgrößte landwirtschaftliche Landfläche, hat den zweitgrößten Viehbestand der Welt und ist der siebtgrößte Weizenexporteur (Australian Government, 2021a). Obwohl die Landwirtschaft nur einen kleinen Teil der Wirtschaft des Landes ausmacht, ist Australien dennoch ein wichtiger Lieferant von verschiedenen landwirtschaftlichen Produkten wie Rindfleisch, Lebendvieh, Lammfleisch, Weizen, Hülsenfrüchten und Zucker.

Im Jahr 2019 verursachte der australische Agrarsektor schätzungsweise 85 $MtCO_2e$ an Emissionen, was etwa 15 % der gesamten nationalen Emissionen (ohne LULUCF) ausmacht. Die größten Emissionsquellen sind die enterische Fermentation (57 %) und der auf der Weide verbleibende Dung (8 %), die größtenteils auf die großen australischen Rinder- und Milchviehherden zurückzuführen sind. Im Vergleich zu anderen Ländern mit hohem Einkommen ist die Emissionsintensität von Rindern in Grünland- oder gemischten Systemen in Australien immer noch recht hoch, die potenziell verbessert werden könnte.

Die landwirtschaftliche Tätigkeit hat die Landnutzung und die entsprechenden Emissionen in Australien maßgeblich geprägt. Von 1972 bis 2014 wurden landesweit über 7,2 Millionen Hektar Primärwald gerodet, was einem Verlust von 7 % der Waldfläche entspricht (Evans, 2016). Etwa drei Viertel der Entwaldung wurden der Rodung für Weideflächen zugeschrieben, der Rest dem Ackerbau, der Forstwirtschaft, der Stadtentwicklung und dem Bergbau (ebd.). In Anbetracht der riesigen Landfläche Australiens gibt es ein hohes Potenzial für die Kohlenstoffbindung durch die Umsetzung von landbasierten Minderungsoptionen.

Auf der Grundlage des Beitrags der verschiedenen Emissionsquellen, des Potenzials für positive sozioökonomische und ökologische Nebeneffekte, des länderspezifischen Kontexts des Agrarsektors (siehe Abschnitt 1) und der allgemeinen Durchführbarkeit wurden drei Minderungsoptionen für eine detaillierte Analyse ausgewählt:

- Einführung von silvopastoralen Systemen
- Verbesserte Emissionsintensität der Viehhaltung
- Weidemanagement und verbesserte Weiden

Nach unseren Berechnungen könnte die Umsetzung dieser Minderungsoptionen zu einer Reduzierung der Emissionen um 6 $MtCO_2e$ im Vergleich zu 2019 beitragen (unter der Annahme eines konstanten Produktionsniveaus) und bis 2040 zu einer zusätzlichen Kohlenstoffbindung von 210-260 $MtCO_2e$/Jahr führen. Allerdings bestehen große Unsicherheiten in Bezug auf Überschneidungen zwischen Minderungsoptionen sowie in Bezug auf langfristigen Dynamiken

des Bodens und oberirdischen Kohlenstoffs, die das Ausmaß der Sequestrierung beeinflussen können. Andere Studien ermitteln ein geringeres Sequestrierungspotenzial.

Es gibt kritische Barrieren, die die Umsetzung von Maßnahmen zur Erreichung der skizzierten Minderungspotenziale behindern und andere Aktivitäten zur Verringerung der Treibhausgasemissionen im Agrarsektor beeinträchtigen. Die meisten Hindernisse bestehen auf der Ebene der landwirtschaftlichen Betriebe und auf nationaler Ebene, wo es an umfassenden, unbürokratischen Maßnahmen fehlt, die Anreize für Minderungsmaßnahmen schaffen und das Wissen über nachhaltige Praktiken und ihre positiven Auswirkungen fördern. Die wachsende internationale Nachfrage nach Fleisch- und Milchprodukten sowie der übermäßige Verbrauch und das verschwenderische Verhalten im Inland treiben die Produktion in die Höhe, und obwohl dies keine direkten Hindernisse für Minderungsmaßnahmen auf der Produktionsseite sind, haben sie konkurrierende Auswirkungen auf die Gesamtmenge der vom Sektor emittierten Treibhausgase.

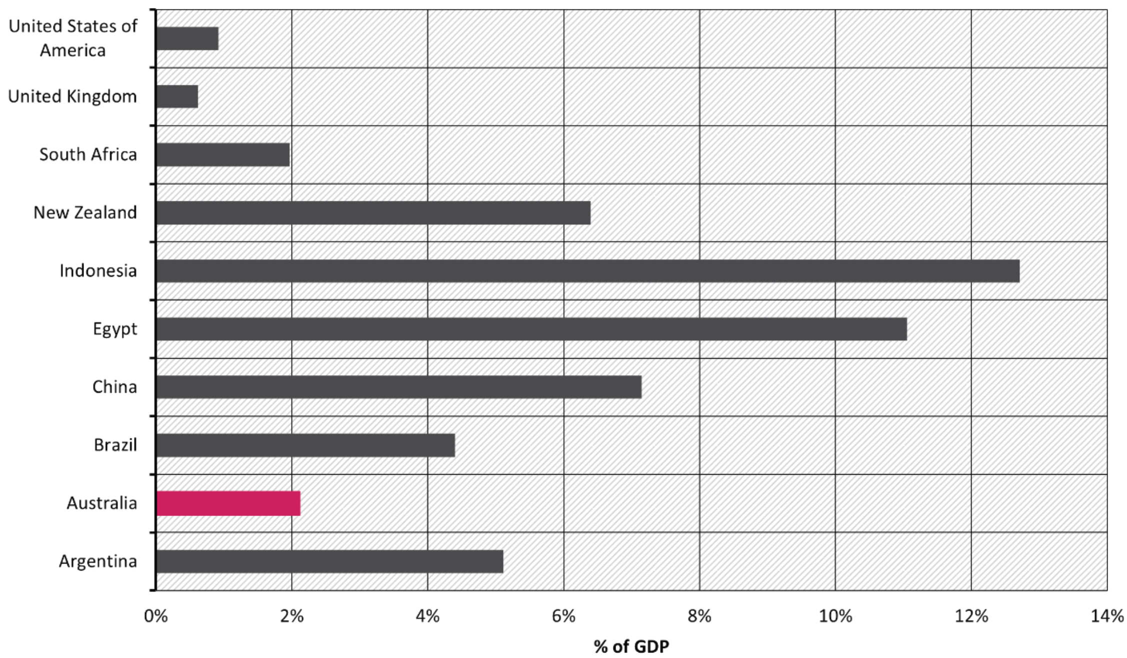
Um die Übernahme und Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, müssen 1) die nationalen Minderungsprioritäten klarer auf den Agrarsektor übertragen werden, 2) im Gegenzug muss sichergestellt werden, dass alle agrarpolitischen Maßnahmen mit den Minderungszielen in Einklang gebracht werden, und 3) sektorale Maßnahmen müssen so umgesetzt werden, dass sie die Bereiche, in denen die meisten Minderungen möglich sind, umfassend berücksichtigen. Diese Minderungsmaßnahmen und -anreize sollten auch den gemeinsamen Nutzen von Anpassung und Minderung im Agrarsektor fördern.

1 General characteristics of the agricultural sector and policy landscape

1.1 Characteristics of the agriculture sector in Australia

Australia plays a key role in the global agricultural landscape, considering the country contains the 3rd largest agricultural landmass, has the world's 2nd largest live cattle population and is the 7th largest wheat exporter (Australian Government, 2021a). Agriculture's contribution to Australia's Gross domestic product (GDP) was 2.5% in 2019, compared to the global average of 3.5% (Figure 1; OECD, 2021). While agriculture only represents a small share of the economy, Australia is still a key world supplier of several agricultural products including beef, live cattle, lamb, wheat, legumes, and sugar.

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



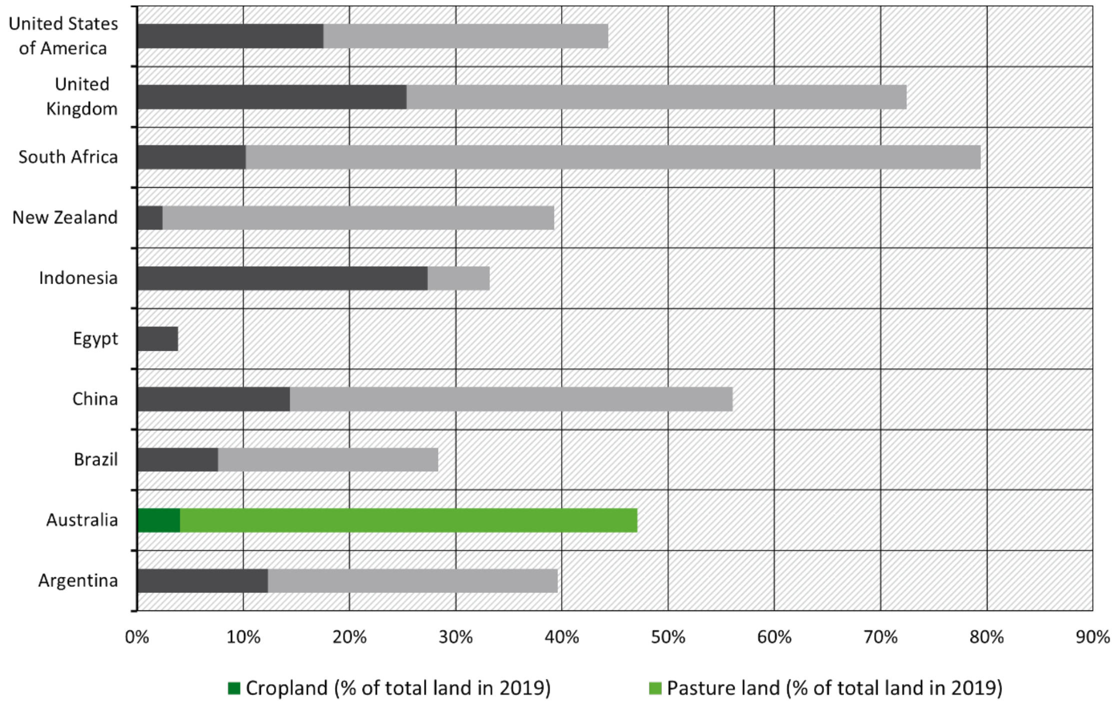
Source: **World Bank (2022)** data for all countries except New Zealand due to lack of data. Value for New Zealand was taken from **OECD (2021)**

Australia's agricultural sector produces a diverse range of crop and livestock products. The largest produced commodities in 2020/21 included cattle and calves (17% of total value), sheep and lambs (6%), wheat (14%), fruits and nuts (7%), vegetables (6%), and milk (6%) (ABARES, 2022). The livestock categories account for the production of both meat and live animals. By production volume, wheat is by far the largest crop, followed by barley and canola (Howden and Zammit, 2019).

Agricultural exports comprise 12.4% of total exports (OECD, 2021). Exports are a major component of Australia's food production, and around 72% of the total value of Australia's agricultural output is exported (ABARES, 2022). Between 2017 and 2020, this consisted of 84% of sugar produced, 78% of beef, 78% of mutton and lamb, 65% of canola, 67% of wheat and 92% of rice (ibid). Around 53% of agricultural exports go to Asian markets, and demand is expected to double between 2007 and 2050 (ibid).

Australian agriculture accounts for approx. 47% of the country's total land use (Figure 2). Most agricultural land consists of native vegetation used for livestock grazing (43%), while cropping and horticulture systems that are generally concentrated close to the coast only make up a small portion of land use (4%) (ibid). Two-thirds of Australia's total agriculture area is occupied by large farms with high revenues, who make up only one-fifth of broadacre farmers (ABARES, 2022). Broadacre farms refer to large-scale cereal, oilseed, or livestock grazing operations.

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

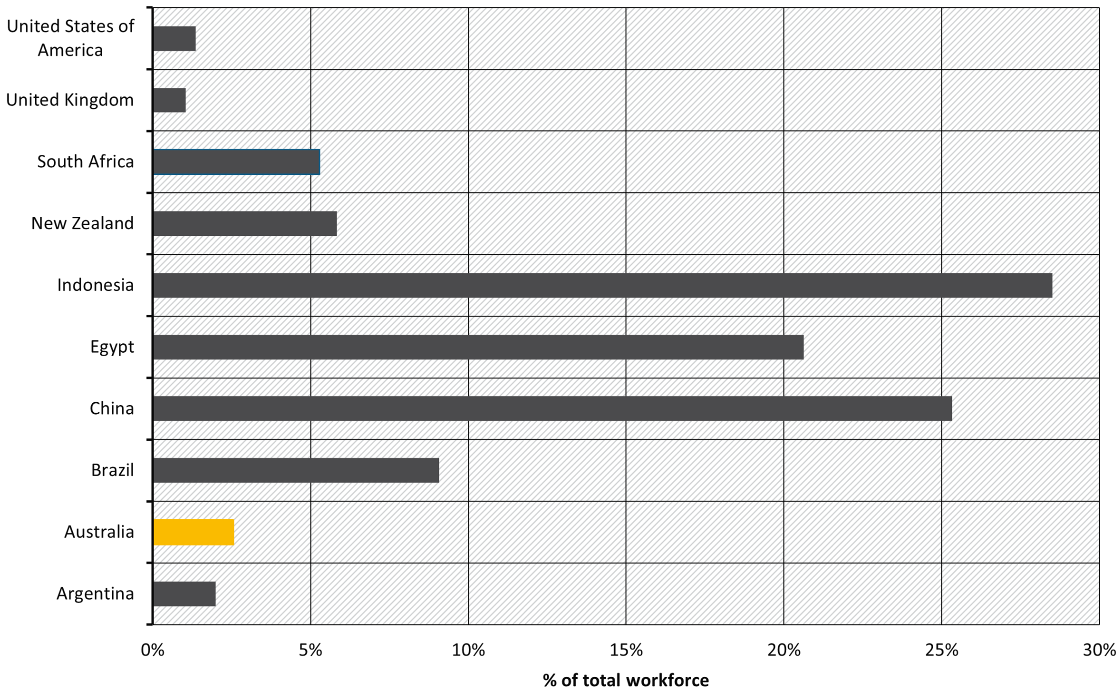


Source: **FAO (2022c)** data for all countries. Data includes "Cropland" and "Land under permanent meadows and pastures".

1.2 Socio-economic dimensions

The Australian agriculture sector has a relatively low share of employment, comprising 2.6% of the workforce in 2019 (Figure 3). The share of employment has fallen by 25% over the past three decades (ABARES, 2021). Broadacre (beef, sheep, wheat, mixed) farms are the largest employers, followed by horticulture and dairy farms (ibid). Farms have increasingly become more consolidated, and the total number of farms has roughly halved since the 1970s, with beef industry farms making up the largest proportion today (ibid). While large farms (earning over AUD$1 million per year) made up only 15% of total farms in 2019–2020, they accounted for 72% of total farm income and 60% of total output (ABARES, 2022).

Figure 3: Agricultural employment as a share of 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)**.

Indigenous land tenure and management has been an increasingly important topic in the Agriculture, Forestry and Other Land Use (AFOLU) sector. More than half of Australia's forests (69.5 million hectares) are classified as part of the Indigenous estate (ABARES, 2018). However, indigenous land management practices have not been incorporated into formal policy (ibid).

Indigenous people face significant barriers towards establishing land management practices, including high transaction costs, lack of access to land and shaky land tenure arrangements, cultural sensitivities, and lack of recognition (Hill et al., 2013). Indigenous groups have shown a special ability to manage bushfires and weed infestations, promote carbon sequestration, and stimulate other ecosystem services through the application of traditional knowledge (Martin, 2020). While the Australian government has established the Indigenous Carbon Farming Fund to build capacity and increase opportunities for indigenous participation in emissions abatement and carbon sequestration strategies, its efficacy is unclear.

Water scarcity has been a persistent issue in Australia due to the dry and variable climate. Agriculture's share of total water abstractions has dropped from 68% to 23% between 2000 and 2018, which is primarily attributed to drought conditions reducing the water available for agriculture (OECD, 2020). Pasture for grazing and cotton and sugar production use the most water in terms of volume (ibid).

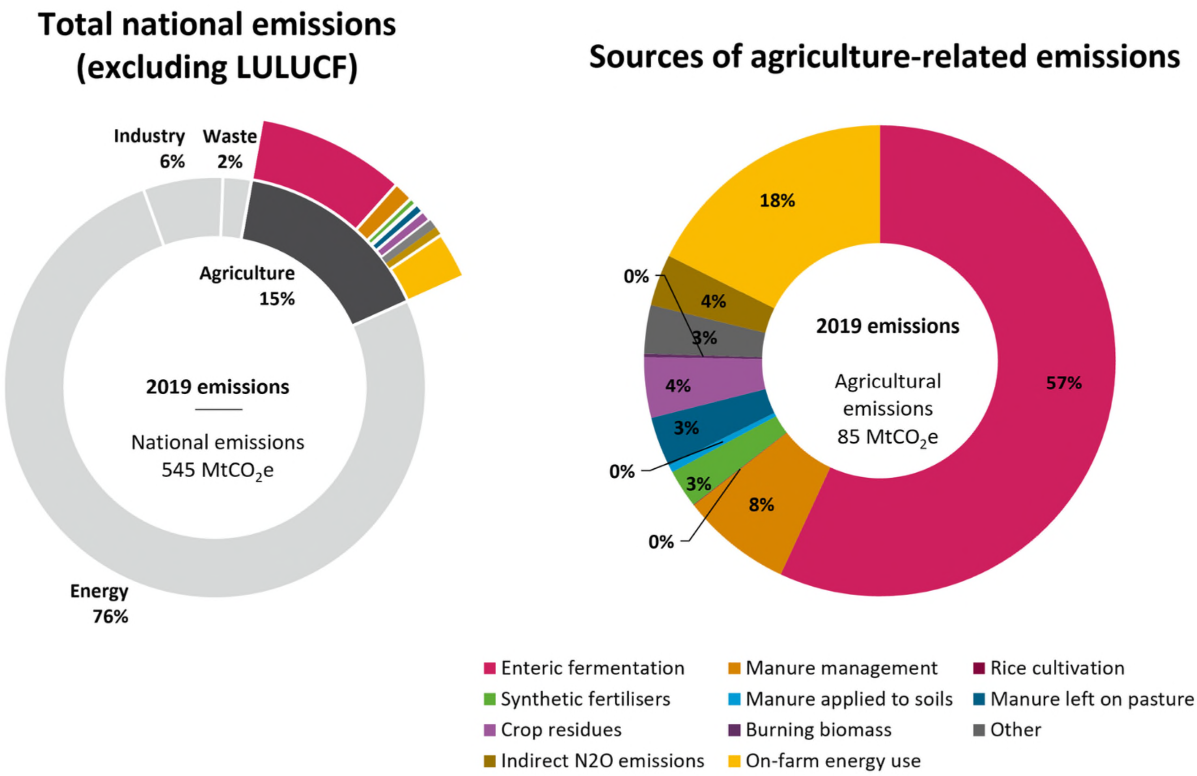
The Murray-Darling Basin is Australia's most important river system. It has faced severe drying of some catchments in recent years, leading to drinking water shortages and devastating local farmers (Martin, 2020). This crisis has been driven in part by inequitable water access. The New South Wales (NSW) government was discovered to have been aware of illegal floodplain harvesting by major upstream irrigators, thus limiting water access in downstream irrigators, communities and farmers (Brewster, 2020).

As a result, the government is currently in talks to implement a floodplain licensing system. This process has been embroiled in controversy, however, with the NSW government preemptively issuing licenses before any allowance was granted. The national government wants to ensure that community concerns on the equity and environmental impact of the licensing program are addressed before any approvals are made (Davies, 2022).

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

In 2019, Australia's agricultural sector produced an estimated 85 $MtCO_2e$ of emissions, contributing about 15% of total national emissions (excl. LULUCF) (Figure 4). The largest emissions sources are enteric fermentation (57%) and manure management (8%), most of which can be attributed to Australia's significant role as a beef and live cattle producer and exporter. On-farm energy use is likely also to be a major contributor to total agricultural emissions but this data is not reported directly to the United Nations Framework Convention on Climate Change (UNFCCC) and is only available from FAO.

Figure 4: Australia's GHG emissions profile, 2019



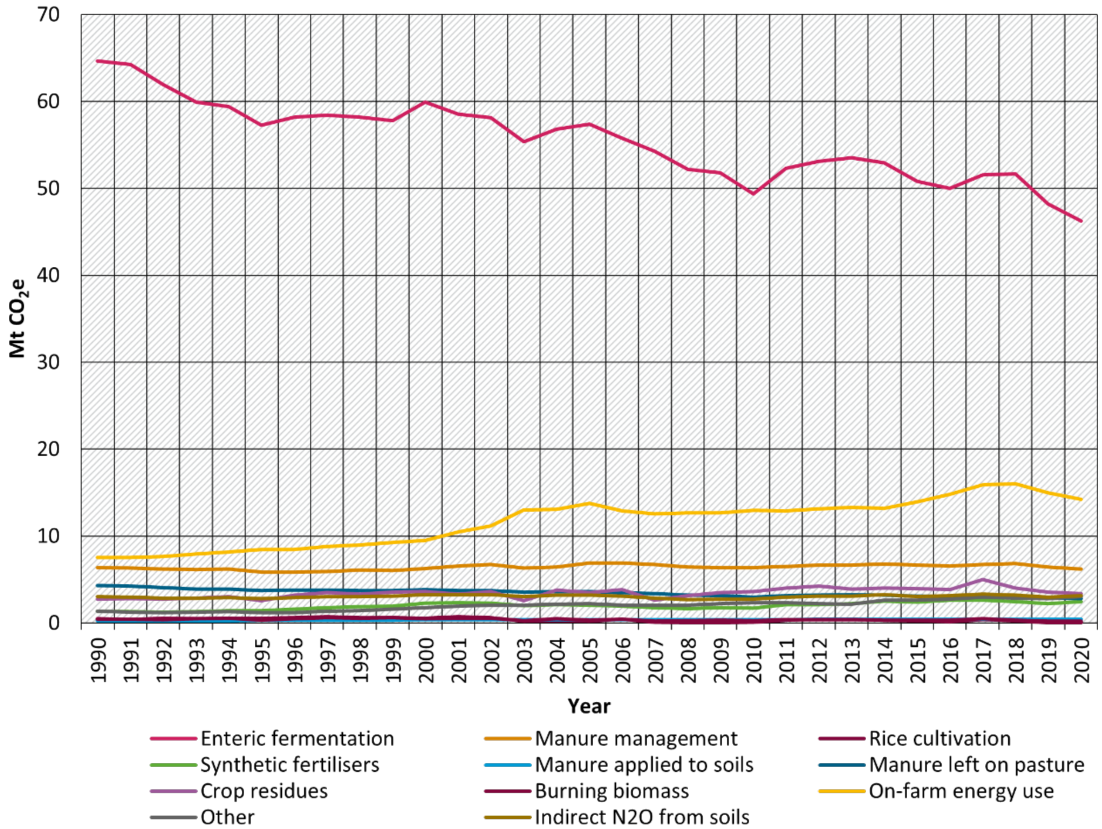
Source: **Australian Government (2022a)**. For on-farm energy use, no information is available in Australia's National Inventory Report. Data for on-farm energy use has thus been taken from **FAO (2022a)**, acknowledging high uncertainties.[1]

[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 rather high uncertainties in FAO data in the case of Australia, 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.

GHG emissions from the agricultural sector have been declining since the 1990s (Figure 5). Historic emissions have fluctuated based on climatic conditions. In particular, drought conditions have resulted in lower livestock numbers and corresponding GHG emissions (Australian Government, 2021d).

The general decrease in agricultural emissions since 2016 has been primarily driven by drought conditions, which has impacted both livestock and crop production. For instance, managed soil emissions decreased by 8.6% between 2018 and 2019 due to decreased crop yields and fertiliser consumption (Australian Government, 2022a). While rice cultivation is rather low in Australia, it has also been affected by recent drought conditions since the extent of production is strongly tied to water availability (ibid).

Figure 5: Agriculture-related emissions in Australia (1990–2020)



Source: **Australian Government (2022a)**. For on-farm energy use, no information is available in Australia's National Inventory Report. Data for on-farm energy use has thus been taken from **FAO (2022a)**, acknowledging high uncertainties.

In 2019, livestock enteric fermentation comprised over half of total agricultural emissions. The extent of enteric fermentation emissions has decreased somewhat since 1990, which is primarily attributed to the collapse of the "wool reserve price scheme" and consequent reduction in sheep numbers (ibid). Livestock numbers further declined between 2002 to 2010 due to drought conditions, while numbers rebounded between 2011 and 2017 from weather conditions (ibid). Since then, widespread drought has resulted in decreasing numbers of sheep and cattle (ABS, 2021).

Approx. 78% of total livestock emissions are attributed to pasture-raised beef, 18% to sheep meat, 4% to feedlots, and <1% to goats (Mayberry *et al.*, 2018). Around 60% of the Australian cattle industry operates on extensive grazing systems, primarily in the country's tropical and subtropical regions, which are characterised by a high enteric fermentation emissions intensity

(Henry *et al.*, 2012; Howden and Zammit, 2019). The extent of grain-fed cattle in feedlots has increased from 3.4% in 1990 to 12% of the herd in 2015 (Mayberry *et al.*, 2018). While grain-fed cattle produce less enteric fermentation emissions per unit of meat, their diets are more energy-intensive and they produce more manure (Australian Government, 2019). The number of grain-fed cattle relative to the total herd is projected to increase as farmers look towards more drought-resistant feeding systems (ibid).

Manure management emissions increased by 0.5% between 1990 and 2019 due to rising amounts of intensive cattle feedlot operations. Emissions decreased by 6.3% between 2018 and 2019 due to drought conditions causing increased feed prices and reduced stocking rates from less grain-fed cattle (Australian Government, 2022c). Overall, manure management emissions have been quite stable, with interannual fluctuations reflecting changes in management practices in response to dry conditions (ibid).

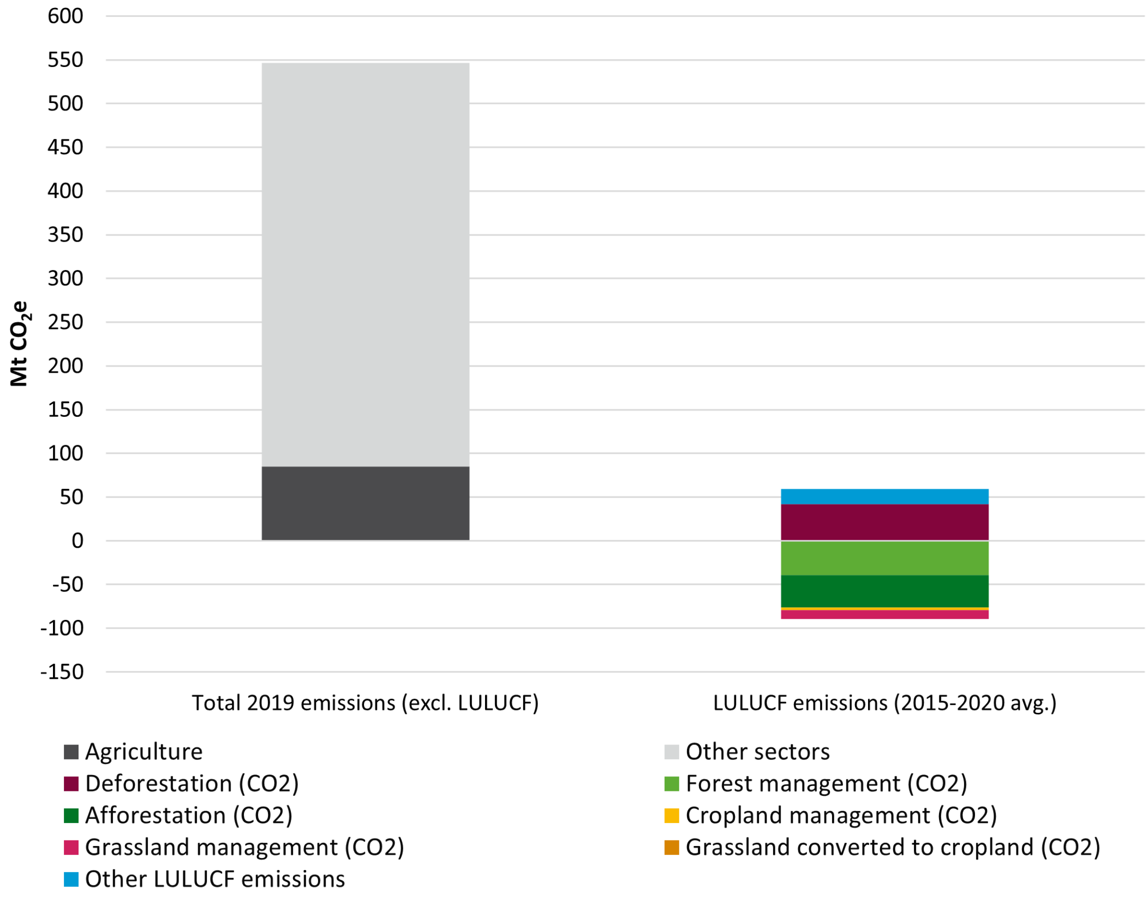
While emissions from the field burning of agricultural residues are low, they have further declined due to changes in management practices, shifting to stubble retention, and green cane harvesting, and use of trash blankets in the sugarcane industry (ibid).

Fires play a significant role in Australia's national GHG accounting and are reported under LULUCF. They are most common in the woodlands and grasslands of northern and central Australia, where the ecosystems are adapted to frequent fires due to traditional indigenous management practices and natural fire regimes (DIRES, 2020). While the carbon sink recovers to a large extent in both cases, human activities such as land clearing or salvage harvesting can lead to net emissions. Net emissions can also occur if the forest fails to recover after 10 to 15 years (ibid).

The 2019–2020 bushfires emitted between 400–700 $MtCO_2e$; assuming 90–95% of emissions are re-sequestered through natural regrowth of vegetation, the fires will potentially result in net GHG emissions between 20 and 70 $MtCO_2e$ after 10 years (Bishop *et al.*, 2021). The Australian Department of Industry, Science, Energy, and Resources is optimistic about forest recovery, citing the 2003 bushfires that showed a cumulative recovery of 84% of sequestration after 10 years and 96% after 16 years. However, changing climatic conditions and more frequent fires can affect recovery ability (ibid).

Agricultural activity has significantly shaped Australia's land use and corresponding emissions. From 1972 to 2014, over 7.2 million hectares of primary forest were cleared nation-wide, representing a loss of 7% of forest cover (Evans, 2016). Around three quarters of deforestation was attributed to clearing for pastures, with the rest attributed to cropping, forestry, urban development, and mining (ibid).

Figure 6: Australia's 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: **Australian Government (2022a)**. 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 (2015 - 2020) is presented to avoid outliers.

Australia's LULUCF sector is currently an emissions sink, although gross LULUCF emissions are still quite high (Figure 6). Deforestation has remained a major source of emissions, accounting for 40–50 MtCO_2e annually. Despite most forest clearing being of regrowth, 9% of deforestation occurs on previously uncleared land for agricultural expansion and urban development (Trewin *et al.*, 2021). Considering how varied LULUCF emissions estimates have been across years and sources, the extent and drivers of deforestation may be underestimates.

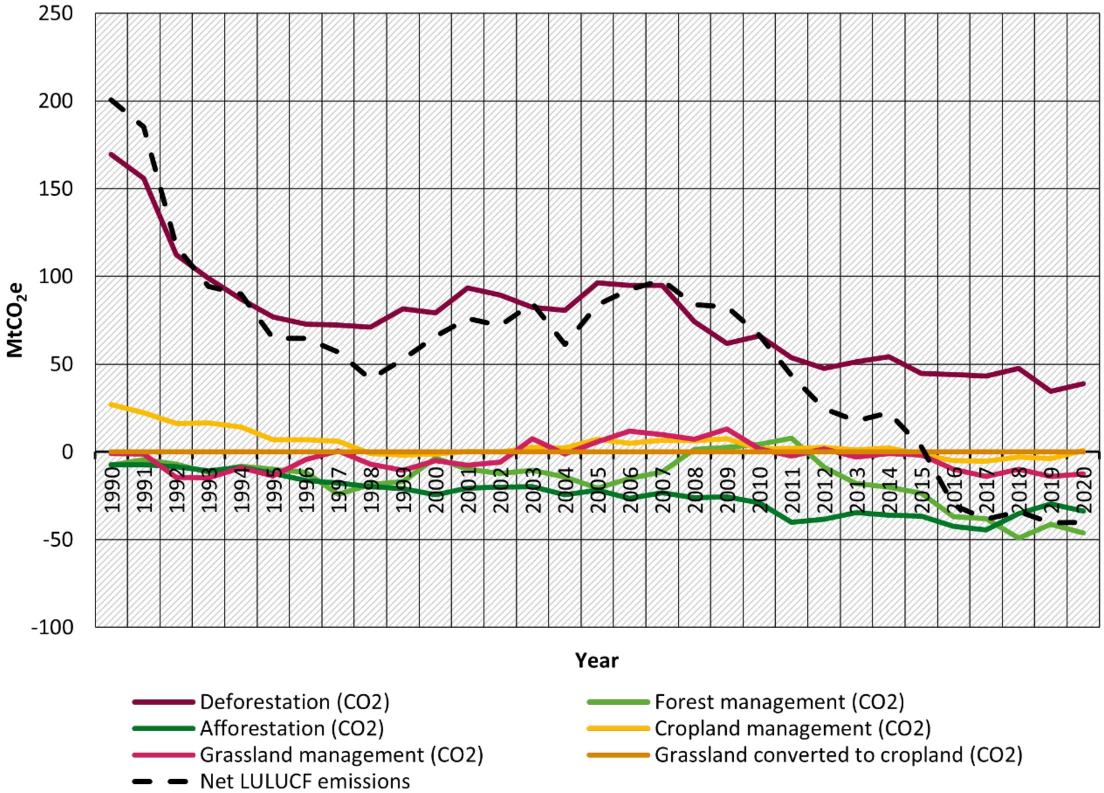
The Australian government has been heavily scrutinized for its LULUCF emissions reporting, since there are wide discrepancies between national-level and state-level estimates of forest clearing (Hannam and Cox, 2021). The extent of land clearing was found to be generally underestimated in Queensland, Australia's deforestation hotspot. This discrepancy can be explained in part by UNFCCC accounting rules. Under the rules, areas with 20% tree cover can still be characterised as forest in Australia, and national satellites do not register tree cover changes as land clearing if it is above this threshold (ibid).

Emissions from Australia's LULUCF sector dramatically decreased between the 1990s and early 2000s, and the LULUCF sector has reportedly been an emissions sink since 2015 (Figure 7).

While LULUCF emissions have fallen as a result of reduced land clearing, forest cover expansion, and declines in native forest harvesting, deforestation levels are still quite high in Australia (Australian Government, 2019; Climate Action Tracker, 2020). Australia is considered the world's worst developed country in terms of deforestation levels, particularly in Eastern Australia due to increased demand for livestock (ibid). An additional three to eight million hectares of forest could be lost in Eastern Australia by 2030 (ibid).

Globally, Australia has some of the most unproductive and nutrient-poor soil. It tends to be older, more deeply weathered, and less fertile than in Europe or North America, meaning that attempts to apply European farming methods on Australian soil has led to significant land degradation and soil management issues (Perroni, 2018). Land clearing and the removal of native vegetation for broadacre and livestock production can reduce soil carbon stocks by 20–70%, further contributing to GHG emissions (ibid).

Figure 7: LULUCF emissions in Australia (1990–2020)



Source: **Australian Government (2022a)**. 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

Following the election of the new government in May 2022, Australia increased the ambition of their Nationally Determined Contribution (in Paris Agreement) NDC, committing to a GHG emission reduction target of 43% below 2005 levels by 2030 (including LULUCF). This corresponds to a targeted emissions level of 354 MtCO2e in 2030. Australia's previous NDC set an emission reduction target of 26–28% below 2005 levels by 2030 (Australian Government, 2022b). The Australian government has not set an explicit target in their NDC for emissions reductions in the agricultural sector.

The Australian Government aims to achieve net zero emissions by 2050. For the agricultural sector, their long-term strategy (LTS) outlines an emissions target of 29–36% below 2005 levels and reducing the sector's emissions intensity by 40% in 2050 (Australian Government, 2021a). Most of the planned agricultural mitigation measures in the net zero strategy are focused on technological innovations. For instance, emerging technologies for livestock methane reduction including livestock feed supplements, alternative forage feeds, and genetic selection and breeding for low methane (ibid).

The net zero plan also aims to enrich soil carbon storage and enhance sequestration via technological improvements, better monitoring capabilities, and improved management practices, where soil carbon projects are estimated to provide a potential 17 $MtCO_2e$ in accredited offsets (Australian Government, 2021a). In order to meet its national net zero target, Australia will have to reduce annual emissions by 24 $MtCO_2e$ each year for 20 years (Wood *et al.*, 2021).

Mitigation actions will also be implemented on a more granular level. For example, the Western Australian Government has launched the development of their Sectoral Emissions Reduction Strategies (SERS) in December 2021, which will provide a robust and credible emissions reduction pathway for the region's agriculture sector to help achieve the net zero emissions target (Government of Western Australia, 2021).

In terms of institutional arrangements, the Department of Industry, Science, Energy and Resources (DIRES) is responsible for developing and administering the country's greenhouse gas mitigation actions and ensuring Australia meets its obligations under the Paris Agreement. They work in conjunction with the Department of Agriculture, Water and the Environment (DAWE) to support emissions reductions and climate change adaptation in the agriculture sector (DIRES, 2022).

The Australian government, in partnership with the National Farmers Federation, set the goal of increasing farm gate output to AUD$100 billion (66 billion EUR) by 2030 from the present day AUD$66 billion (43.5 billion EUR) under the Delivering Ag2030 plan (Australian Government, 2021b). Land stewardship and its emission reduction potential is outlined as an important step towards achieving the target, since agricultural production could reportedly increase by up to 58% just by improving soil management (ibid). Delivering Ag2030 heavily relies on productivity improvements and novel technologies, such as new feed technologies in the livestock sector, to coincide with emission reductions. It is unclear to what extent this will be possible in practice and risks an increase in emissions in line with increasing production.

The Emissions Reduction Fund provides incentives for farmers and forest growers to reduce emissions from agriculture and deforestation. For instance, farmers can register their carbon farming projects and earn carbon credits from reducing livestock emissions or increased soil carbon storage (Climate Action Tracker, 2020). However, only 1% of Australian carbon credit units came from agriculture in 2017–2018 (ibid).

The Carbon Farming Futures program, which ran from 2012 to 2017, invested over AUD$139 million (90 million EUR) to promote research and best practices to reduce emissions (ibid). This has been superseded by programs such as the Agriculture Biodiversity Stewardship Package, the National Soil Strategy, and National Landcare Program, each supporting research and development and enabling farmers to implement sustainable agriculture and land use practices (DAWE, 2021).

Despite Australia being the only developed country classified as a deforestation hotspot, there are currently no stringent national policies in place to prevent land clearing (Pacheco *et al.*, 2021). While Queensland had introduced a law imposing restrictions on land clearing in 2018, continued high rates of land clearing and habitat destruction for beef production suggest that the legislation is ineffective (Cox, 2022). Following the New South Wales government's decision to relax native vegetation laws in 2017, land clearing has risen by nearly 60% in the state (Cox, 2020).

1.5 Current developments and trends

Australian farmers have shown increasing interest in sustainable agriculture practices in response to drought conditions. This includes no- or low-till farming, crop diversification, and organic mulch soil cover. 11% of total global area under conservation agriculture is in Australia, corresponding to 17 million hectares or 36% of national cropland (Kassam *et al.*, 2015).

The extent of no-till practices on Australia's grain crop area reached a considerable 74% in 2016 and has become 'conventional practice' in response to drought conditions, since farmers can take better advantage of soil moisture left over from the summer (Llewellyn and Ouzman, 2019). In conjunction with no-till, more and more farms have adopted stubble retention from crop residues to retain organic matter on the soil and further reduce wind and soil erosion (ibid).

In order to build resilience to drought, many livestock farms (61%) have adopted grazing management systems such as rotational grazing or have set long-term requirements for cover crops on grassland (61% of farms) (Coelli, 2021; ABARES, 2022).

The Australian red meat industry has pledged to achieve carbon neutrality in 2030 while maintaining animal numbers. The mitigation actions outlined by Meat & Livestock Australia (MLA) to achieve their target include increasing productivity in feedlots and reducing enteric methane emissions via feed supplements, methane inhibitors, and legume plantings, improving productivity in grazing systems, and adopting improved savanna burning management methods (MLA, 2020). The roadmap also aims to increase carbon storage levels on pastures by integrating trees and shrubs and by planting legumes (ibid). However, some of the proposed mitigation measures, in particular feed additives and methane inhibitors, have highly uncertain efficacy, are far from commercially viable, and are associated with environmental and animal health concerns. In combination with the red meat industry's intention to maintain animal numbers and further increase beef production, as well as the high reliance on carbon sequestration, this puts the legitimacy of the target into question.

1.5.1 Diets and food waste

In addition to supply-side measures, Australia's agricultural landscape has been shaped by demand-side and external factors. Food waste, dietary habits, the COVID-19 pandemic, and climate change impacts all influence agricultural processes and related emissions.

In 2019, Australia produced 7.6 million tonnes of food loss and waste across the entire food supply chain, corresponding to 312 kilograms per capita, compared to around 275 kg per capita in Europe and 124 kg in South/Southeast Asia (Statista, 2020; FIAL, 2021). The consumption stage contributed almost one-third of total food waste, with primary production contributing the second largest amount at 22%. A large extent of on-farm food waste is attributed to Australia's export-oriented agricultural market (ibid). The production and disposal of ultimately wasted food contributed to 3.5% of Australia's emissions between 2018 and 2019, while the land used to grow wasted food amounted to over 25 million hectares, which is larger than the state of

Victoria (ibid). In line with the Sustainable Development Goals, Australia has developed a National Food Waste Strategy and set a target to halve its food waste by 2030 (ibid).

Australia's dietary footprint is quite similar to that of the United States and other developed countries, with relatively high meat and dairy consumption (Ritchie *et al.*, 2018). In the perspective of the Planetary Health Diet,[2] Australia's meat consumption is still over seven times and milk consumption more than two times the recommended amount to stay within health and planetary boundaries (Ritchie *et al.*, 2019).

However, per capita beef and lamb consumption declined between 1974 and 2014 by 45% and 64%, respectively, while per capita chicken and pork consumption respectively tripled and doubled during the same period (Ratnasiri and Bandara, 2017). The pattern of decline in ruminant meat and increase in non-ruminant meat consumption is projected to reduce annual per capita meat consumption emissions by 2.3% between 2010 and 2025 (ibid). Kangaroo meat has been proposed as a lower-emissions replacement of ruminant meat and can reduce dietary emissions by 4.3% by 2025 if it partially replaces beef (ibid).

1.5.2 Recent developments in national context

As in many developed countries, Australia has a high intake of discretionary ("junk") foods that provide minimal nutritional value. Discretionary food consumption contributes approximately one-third of Australia's dietary GHG emissions (Hadjikakou, 2017).

Australia's agricultural sector proved to be rather resilient to COVID-related disruptions in domestic and international supply chains. However, travel restrictions have resulted in the reduced availability of overseas workers and higher airfreight costs of high-value export commodities, which has particularly affected the horticulture, intensive production, and meat processing industries (ABARES, 2021). The higher costs of production have resulted in reduced output for horticultural products due to difficulties in harvesting (ibid).

The 2020 Australian bushfires severely impacted the country's agricultural sector. More than 12% of the national sheep flock and 9% of the national cattle herd lived in areas impacted by the fires, and over 100,000 livestock deaths occurred (Bell, 2020). In total, the Australian agriculture sector suffered AUD$4–5 billion in economic losses, attributed to direct fire damage to farm property, infrastructure, and land, food production losses, and health impacts on farm workers (Bishop *et al.*, 2021).

The recent extreme flooding in 2019 and 2022 also had a considerable impact on agricultural activities in North South Wales and Queensland. An estimated 600,000 heads of cattle were lost in 2019, while 475,000 heads or 2% of the national herd was affected by the 2022 floods. Many farms also suffered extensive infrastructure losses and crop damage (May, 2022).

1.6 Vulnerability and adaptation

Australia's agricultural system is highly vulnerable to climate change. Extended drought periods over the past 20 years have reduced average farm profits by 23% (Hughes and Gooday, 2021). Some farmers have adapted to drought conditions by shifting to grain-fed cattle. Farmers continue to adopt management practices such as conservation tillage and soil amelioration in order to preserve soil moisture and adapt to reduced rainfall during the growing season (ibid).

Australia is already experiencing the impacts of climate change, including rising temperatures, shifting rainfall patterns, a longer and more dangerous fire season, rising sea levels, and

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

increasing ocean acidification (Australian Government, 2021c). Climate change impacts are predicted to accelerate structural changes on farms. For instance, prompting a shift from cropping systems towards livestock and mixed farming systems, especially in low rainfall areas (Hughes and Gooday, 2021). Since smaller farms are more vulnerable to drought and other climate change risk, farm sizes are expected to increase while farm numbers decrease (ibid).

Droughts over the past decade have resulted in livestock deaths and limited access to irrigation water, causing financial strain on farmers. Irrigated agriculture produces almost one-third of the sector's economic value (Quackenbush, 2019). Historically, water scarcity has resulted in water for low-value agricultural activities (cereals, broadacre staple crops) being re-allocated to high value perennial horticulture activities (citrus, grapes, almonds) (Ejaz Qureshi *et al.*, 2013). Drought conditions are expected to be exacerbated with climate change and can have implications for food security and the country's export market (ibid).

The Australian Department of Agriculture, Water and the Environment (DAWE) has developed the country's National Climate Resilience and Adaptation Strategy for the years 2021 to 2025. This includes the Future Drought Fund, which will invest $100 million AUD (65 million EUR) to improve agricultural productivity and profitability, enhance the wellbeing of farming communities, and sustain the natural resources on which agriculture is dependent on in the face of exacerbated drought conditions (Australian Government, 2021c). The national adaptation plan does not outline suggestions for adaptation measures or specific steps the government is taking to improve the resiliency of the Australian agricultural system.

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), as well as the general feasibility for implementation.

2.1.1 Selection of priority mitigation actions

The livestock sector contributes over three quarters of Australia's agricultural GHG emissions (see Figure 4), most of which can be attributed to pasture-based beef. Compared to other high-income countries, the emissions intensity of cattle in grassland or mixed systems is still rather high in Australia. Implementing good practices in livestock rearing can result in some GHG emission reductions along with increased productivity. This is especially relevant as Australia aims to retain its position as a leading agricultural export country and increase farm gate output by 50% by 2030 (Australian Government, 2021b). However, Australia should simultaneously avoid shifting towards further intensified livestock production, which is associated with significant environmental degradation, increased manure management emissions, and high indirect emissions resulting from feed production and associated land use change.

Australian agriculture accounts for almost half of the country's land use (see Figure 2), most of which is natural pasture used for livestock grazing. Considering Australia's huge land area, there is high carbon sequestration potential from implementing land-use based mitigation options, such as silvopastoralism or rotational grazing.

For Australia, we thus selected the following measures:

- Implementation of silvopastoral systems
- Improved livestock emissions intensity
- Grazing management and improved pastures.

Historically and in recent years, deforestation and corresponding GHG emissions have been quite high, part of which can be attributed to agricultural expansion. Any mitigation action in Australia's agricultural sector must also address the drivers of deforestation. Land clearing in recent years has been partially attributed to the livestock sector in Queensland. Thus, the outlined measures should ensure they do not promote deforestation for livestock or livestock feed production.

2.1.2 Overall mitigation potential

According to our own calculations[3] and assumptions available in the literature, the implementation of the prioritised mitigation options could contribute to an overall emissions reduction of 6 $MtCO_2e$ in 2030 compared to 2019 levels (assuming constant levels of production), or 9% of Australia's agricultural GHG emissions, and could result in additional carbon sequestration of 210–260 $MtCO_2e$/year by 2040. However, there is high uncertainty in

[3] See section 2.2.1. Further methodological details can be found in the final report for this project, available at https://www.umweltbundesamt.de/publikationen/ambitious-ghg-mitigation-opportunities-challenges.

terms of overlaps between mitigation options as well as in long-term soil carbon dynamics that can affect the extent of sequestration The outlined carbon sequestration potential is three times greater than Australia's current carbon storage and covers more than half of Australia's total GHG emissions. While Australia's significant agricultural area illustrates high potential from sequestration measures, it's sheer size also poses questions to its implementation. 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.

Feed additives are discussed as one option to reduce emissions from enteric fermentation as they work by inhibiting methane production in cattle. For example, the inclusion of red algae (*Asparagopsis*) has been presented by the Australian government and meat and livestock industry as an innovative, novel scenario that can further reduce enteric fermentation emissions from feedlot or grain-finished cattle. However, its use is not yet commercially viable (Roque *et al.*, 2021). There are also numerous concerns regarding the efficacy, palatability, toxicity, and environmental impacts of feed additives (Nabuurs *et al.*, 2022), which suggest that they should not be promoted as an environmentally sustainable option to reduce livestock emissions. One of the world's longest commercial trials of *Asparagopsis* found significantly lower methane reductions than previous experiments, recording reductions of 28% instead of 80% or as high as 96% (Readfearn, 2023). Given the high uncertainties on efficacy and numerous animal health and environmental drawbacks, relying on technologies such as feed additives will not be sufficient to achieve climate targets and should not replace the deep reductions needed in ruminant meat production.

According to other studies, based on a reference level of 98 MtCO_2e in 2017, AFOLU GHG emissions in Australia could reach a net 103 MtCO_2e under a cost-effective scenario or 56 MtCO_2e under a best practice scenario in 2030 (Meyer *et al.*, 2020). Both scenarios include mitigation options not quantified in this study, such as the uptake of on-farm renewable energy, a reduction in agricultural-related deforestation (cost-effective scenario), 3-nitrooxypropanol (3-NOP) feed additives, precision agriculture, nitrification inhibitors, ceasing overgrazing, and reductions in field burning (best practice scenario). Regarding carbon sequestration specifically, a separate study showed that changing the land use to eucalyptus carbon plantings, or environmental plantings of local native species, on the 85 Mega hectares (Mha) of intensive-use agricultural land in Australia could provide an average annual abatement of 531 MtCO_2e, but would involve trade-offs in biodiversity and water use (Bryan *et al.*, 2015). The mitigation measures outlined in the following sections thus form a part of a broader set of measures that would be necessary to bring Australia's AFOLU sector on track to reaching long-term climate targets.

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 emission reductions in other sectors, and increases reliance on negative emissions technologies (Harwatt, 2019). This is particularly relevant for developed countries such as Australia, which has one of the world's highest meat consumption rates and exports most of their beef production (78%).

2.2 Prioritised mitigation options

2.2.1 Livestock emissions intensity reduction

Measure

The emissions intensity per tonne of meat or milk from cattle can be improved by employing good practices in livestock rearing, including improved health monitoring and disease prevention, breeding optimisation, diet optimisation, herd management, and improvements in manure management and handling. These measures can help to lower the emissions intensity per unit of meat or milk either by reducing absolute enteric fermentation emissions or by improving animal productivity. We assumed that these measures would be applied to existing production systems, and do not involve a shift towards more intensive livestock farming. In Australia, these good practices can primarily be applied to grassland or mixed cattle production systems, since the emissions intensity of feedlot cattle is already quite low (Australian Government, 2022a).

Status

While Australian beef production increased by 40% between 2000 and 2019, the emissions intensity per tonne of beef decreased by 24% in the same time period (Australian Government, 2022a). However, Australia still has a relatively high emissions intensity per tonne of beef (14.6 tCO_2e/tonne of beef) compared to the other high-income countries in this study (9.7–12.9 tCO_2e/tonne of beef), which is likely due to a greater share of grassland systems in Australia which have a higher on-farm emission intensity than feedlot systems (FAO, 2022b).

Potential

Based on our own calculations and national data, Australia's livestock sector emissions could be 6 $MtCO_2e$ lower than 2019 levels (10% reduction in enteric fermentation emissions, 9% in manure management emissions), assuming meat and dairy production remain constant at 2019 levels. This assumes Australia's grassland and mixed systems implement improved feed and lifecycle management strategies to reduce enteric fermentation emissions intensity by 18%, while feedlot cattle enteric fermentation emissions intensity remains the same, since it is already similar to levels across other developed countries (Cusack *et al.*, 2021; Australian Government, 2022a). At the same time, we assumed emissions intensities for beef cattle manure management could be reduced by 20%,

If beef and milk production were to continue to increase following the 10-year historical trend, it would result in a slightly lower magnitude of emissions reductions (3 $MtCO_2e$/year) in 2030 compared to 2019 levels (5% reduction in enteric fermentation emissions, 6% in manure management emissions). The recent historical growth is quite low at 0.6%/year, partly due to recent droughts that have negatively impacted agricultural productivity in Australia. Higher growth rates in beef production, in line with targets to increase total agricultural output (in value) by 50% by 2030 and projections of a return to average seasonal conditions, would result in proportionally higher 2030 emissions for the same mitigation actions (Australian Government, 2019, 2021b).

The estimates outlined above represent a maximum emissions reduction potential based on decreasing the emissions intensity per tonne of beef or milk produced. While our calculations aim not to consider changes to existing livestock production systems, there is a risk that further grain supplementation to achieve higher yields and lower emissions intensities would result in increased indirect emissions from feed production and associated land use change. There are also environmental limitations to consider, including Australia's climactic conditions and low soil fertility, which affect forage quality and can affect the extent of possible emissions reductions (Perroni, 2018).

Co-benefits

Livestock health improvements would result in increased animal welfare and well-being, which has positive implications for food safety and biodiversity conservation (Llonch *et al.*, 2017). Improving manure handling practices can result in reduced odours, reduced pollution, and less nitrogen losses (MacSween and Feliciano, 2018). Improved livestock management will generally increase the sector's adaptive capacity and resilience to climate change impacts (Rojas-Downing *et al.*, 2017).

Barriers

Biophysical/environmental barriers: The impacts of climate change have already affected livestock systems in Australia. Drought conditions have put feed supplies at risk and can negatively affect livestock health, making it more difficult to implement the good practices needed to achieve improved emissions intensities (Forbes, 2019).

Technical barriers: There are practical barriers to applying good practices on extensive, pasture-based systems since cattle move around freely (Kipling *et al.*, 2019).

Economic barriers: Farmers cite a lack of financial resources as a barrier to access the technology and labour needed to improve on-farm livestock management practices. The uncertainty with yields benefits does not financially motivate farmers to change their practices (Özkan *et al.*, 2022).

2.2.2 Silvopastoralism

Measure

Silvopastoral systems integrate tree species with livestock husbandry activities on grassland. The addition of trees on pasture results in increased above-ground carbon sequestration (CIWF, 2017). Silvopastoralism generally also improves animal productivity due to higher-quality forage and increases below-ground soil carbon sequestration (ibid), but this was not quantified.

Status

Australia currently has the largest global land area managed under silvopastoral systems at 200,000 hectares (CIWF, 2017). Northern Australian rangelands, with extensive grazing systems, have large areas of land suitable for silvopastoral plantings, such as eucalyptus tree strips (Donaghy *et al.*, 2009).

Potential

According to our calculations, assuming a 10% increase in Australian silvopastoral area relative to total grassland, implementing silvopastoral systems could result in an additional 150–200 $MtCO_2e$/year of carbon sequestered annually by 2040. This estimate assumes a 51 Mha increase in silvopastoral grassland with an additional carbon sequestration potential of 2.90–3.85 tCO_2e/ha/year (Donaghy *et al.*, 2009; Feliciano *et al.*, 2018). Considering the assumed area is the size of Spain, it is unclear to what extent implementation will be possible to reach the above sequestration potential.

The significant carbon sequestration potential in Australia is relatively in line with Roe *et al.* (2021), who estimate the technical mitigation potential of agroforestry implemented on 50% of Australian agricultural area (incl. cropland and grassland) to be up to 500 $MtCO_2e$/year by 2050.

Co-benefits — Depending on the types of trees planted, silvopastoral systems can provide co-products such as timber, seeds, or food and subsequently increase farm income (FAO and ITPS, 2021a). There are additional economic benefits from improved cattle productivity. In Australian arid- and semi-arid environments, planting drought-resistant trees that have an edible canopy can help prevent land degradation and desertification, while contributing to sufficient fodder supply for livestock during drought periods (MacSween and Feliciano, 2018).

Silvopastoralism has positive implications for animal welfare and adaptation, since trees provide a source of shade and can help mitigate the impacts of high temperatures on livestock (FAO and ITPS, 2021a). In addition, silvopastoral systems increase biodiversity on pastures by providing habitats for birds, bees, and butterflies (CIWF, 2017).

Barriers — **Economical barriers:** Silvopastoral systems are more costly than standard pastures. There are usually high upfront costs from seedling and fencing requirements, and the return on investment is slow to show results and can be uncertain (FAO and ITPS, 2021a).

Technical barriers: The maintenance of trees requires a much different knowledge base than livestock rearing, which may prevent farmers from effectively managing all components of a silvopastoral system (FAO and ITPS, 2021a). Additionally, a 10% increase in silvopastoral area corresponds to an area the size of Spain, or 7% of Australia's total land area, meaning that there are practical barriers to implementing silvopastoralism on such a large scale and achieving the outlined sequestration potential.

2.2.3 Grazing management and improved pastures

Measure — Rotational grazing is a system where livestock are moved from one portion of pasture (paddocks) to another to ensure even grazing and allow paddocks to rest and recover (Sanderman *et al.*, 2015). Controlling the stocking rate, intensity, and duration of grazing has the potential to increase soil organic carbon (SOC) stocks and thereby enhance carbon sequestration on grasslands, since it provides a more favourable environment for vegetation growth and organic matter inputs (FAO and ITPS, 2021b). Rotational grazing can additionally reduce fertiliser inputs on pastureland and improve animal productivity through higher forage quality (ibid).

Status — A high proportion of livestock farmers already apply cell, strip, or rotational grazing practices (61%), particularly in the New South Wales region, to increase resilience against drought conditions.

Potential — Pastureland with rotational grazing could potentially sequester an additional 0.33–0.99 tCO_2e/ha/year in Australia (Gifford, 2010; FAO and ITPS, 2021b). However, this is highly site-dependent and highly uncertain. Evidence of the sequestration benefits of rotational grazing is extremely mixed and at times contradictory (Sanderman *et al.*, 2015; Garnett *et al.*, 2017). Increasing average pastureland carbon sequestration by 0.15 tCO_2e/ha/year over all grazing lands could lead to sequestration of 60 $MtCO_2e$/year (Sanderman *et al.*, 2010).

Co-benefits — Rotational grazing practices have positive implications for soil health, including improved soil structure, protection against soil erosion, and enhanced soil biodiversity (FAO and ITPS, 2021b).

Barriers	**Economical barriers:** Increased labour and infrastructure needs lead to higher maintenance costs, which can deter farmers from implementing rotational grazing practices (FAO and ITPS, 2021b). **Biophysical/environmental barriers:** Disruptive weather patterns and climatic changes can pose challenges to maintaining rotational grazing practices. Several factors need to be considered when implementing rotational grazing practices, including current SOC stocks, topography, vegetation, soil type, etc. (FAO and ITPS, 2021b). **Technical barriers:** The measurement, reporting, and verification (MRV) of emission reductions from gains in soil carbon stocks is challenging due to its uncertainty and complexity. It is difficult to measure small changes in soil carbon relative to total carbon stocks and relative to large areas (OECD, 2019).

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 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 report on barriers mentioned above, 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

The Emissions Reduction Fund (ERF) incentivises farmers and forest growers to reduce emissions from agriculture and deforestation, or to implement sustainable agriculture and land use practices. The ERF and former Carbon Farming Initiative were perceived as bureaucratically complex and stringent, limiting their uptake and success (Kragt *et al.*, 2017). There seems to be a lack of information around potential carbon yields in different regions, with different types of vegetation as well as the impacts of new practices on yields and productivity (Kragt *et al.*, 2017).

Our analysis identified significant emissions sequestration potential from silvopastoral systems. Implementing these systems comes with high upfront costs and also requires farmers to have both knowledge of livestock rearing and maintenance of trees (FAO and ITPS, 2021a).

Past changes in government have led to uncertainty through policies being repealed and changes to the carbon prices. This uncertainty is perceived as a barrier to farmers due to a loss of a confidence in the endurance and consistency of supportive policies (Kragt *et al.*, 2017).

3.2 National level

Current national policies are focused on increasing farm gate output, as proposed by the government and the National Farmers Federation. In most cases, an increase in productivity leads to higher absolute emissions, as overall production rises and herd size is either sustained or increased. Existing policies mostly promote these increases in productivity through technological innovations (e.g. livestock feed supplements, alternative forage feeds, and genetic selection and breeding for low methane), which will likely not hinder emissions from increasing in light of the planned increase of output. For the transition to a more sustainable agriculture sector, substantial system changes and better policy coherence would be required.

Although the government committed to a more ambitious NDC in 2022, there are no explicit targets for the agricultural sector. The absence of a clear goal or vision of what sustainable agriculture means in the national context can act as a barrier to mitigation practices in that no incentives for these practices are available. Moreover, the government committed to reach net zero emissions by 2050, but the planned mitigation measures still fall short of the changes needed to reach this goal in the agriculture sector. The lack of a clear policy and coordination between different governance levels or ministries hinders the implementation of ambitious mitigation action (McRobert *et al.*, 2019).

Agricultural expansion has historically caused dramatic levels of deforestation in Australia. The deforestation rates have decreased in the last decade, but legislation to reduce deforestation has reportedly been weak (no stringent national policies in place) and ineffective (sustained high rates of land clearing for beef production) (Cox, 2022). Clear incentives to reduce deforestation linked to livestock, for example promoting agroforestry systems, are still missing and would need to be put in place to stop currently high deforestation trends.

Regarding monitoring and reporting methodologies, the significant discrepancies between national-level and state-level deforestation estimates represent a major barrier to accurate emissions reporting for the LULUCF sector (Hannam and Cox, 2021). This difference in reporting makes it more difficult to define policies that can address current deforestation rates in the country. This is particularly relevant in the context of forest fires, reporting their impact and the recovery rate over the years, especially as changing climactic conditions and more frequent fires will affect recovery ability of the forest.

3.3 International level

Barriers at the international level largely affect the demand side, not the mitigation options identified as most promising in this report.

Australia's dietary footprint is quite large, with relatively high meat and dairy consumption. While largely plant-based diets are becoming a trend in parts of the population in some countries, there is no international agreement on converging to such diets, where those who overconsume reduce their demand to provide room for those who lack nutrition. Investors in the sector have pointed out that there are no clear signals from the international community to mobilise resources and investment in the transition to less meat consumption.

As Australia continues to respond to the world's growing demand for emissions intensive agriculture commodities (including beef, sugar, wheat, mutton and lamb meat), the supply chains for these products act as indirect drivers of deforestation in the country and to overall livestock emissions with higher livestock numbers. Asia represents half of the export market and its demand is expected to increase in the coming years, driving further deforestation and land use change in the country.

3.4 Consumer level

Australia has one of the highest levels of food waste worldwide, and households account for the majority of it. In general, there seems to be little knowledge in households on how to use food leftovers with most of it ending in the trash. There are also quite strict food regulations on labelling and packaging restrictions (linked to the "best before" and "used by" labelling) which leads to many products being disposed of before the use-by-date (Glover, no date). We have not identified any barriers on the consumer level that would complicate the 3 prioritised mitigation options described in section 2.

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. Australia will need to implement ambitious emissions mitigation measures, including in the agricultural sector, if it wants to comply with its own climate commitments for the medium and long term. The mitigation of climate change is essential to Australian agriculture and forestry, which are increasingly threatened by heat waves, resulting in bush fires and water scarcity. This study identified and quantified three mitigation actions in Australia's agricultural sector that would improve productivity and provide environmental and economic co-benefits: Grazing management and improved pastures, combining agroforestry with livestock (silvopastoral systems) and improving livestock emissions intensity through a set of measures aimed at reducing emissions per unit of product.

To maximise emissions reductions in the agriculture sector, Australia would need to take a multi-faceted approach. The emissions intensity of production can be further improved, including in the livestock sector where additional good practices could be implemented. However, this should not include further intensifying livestock systems. Achieving methane reductions could occur at the expense of increased CO_2 and N_2O emissions from increased reliance on crop-based feed rations and the indirect emissions associated with their production (Ridoutt, 2021).

The Australian meat and dairy industry have set emissions targets, becoming 'carbon neutral' by 2030 and reducing emissions intensity by 30%, respectively. However, the strategies are in part untransparent and considerably rely on carbon sequestration and questionable technologies like feed additives, and they do not bring up reducing livestock numbers or shifting their business models to support more plant-based alternatives (MLA, 2020). Not reducing livestock numbers risks not meeting climate targets, since the global livestock sector could use up to half of the 1.5°C GHG budget by 2030 if emissions are not mitigated (Harwatt, 2019).

This study estimates that good practice measures applied to today's livestock would result in up to 6 $MtCO_2e$ in emissions reductions. However, improvements in emissions intensities could have limited impact on overall emissions if production from the sector increases at a high rate, which is in line with the Australian government's goals to increase total agricultural output in value by 50% by 2030 (Australian Government, 2021b). Taking into account productivity growth and other mitigation options, other studies have identified minimal emissions reduction potential (14 $MtCO_2e$) across all on-farm activities between 2017 and 2030 (Meyer *et al.*, 2020).

At the same time, Australia's extensive land area offers high potential for additional carbon sinks, including through silvopastoral systems and measures to increase soil organic carbon. A carbon sink of up to 150–200 $MtCO_2$/year could be achieved through establishing silvopastoral systems on 10% of grassland area. As the mitigation potential from carbon sequestration is much higher than that for on-farm emissions, it is important to note that the quantification of this potential is difficult, and the outcome is very uncertain (see box above regarding natural carbon sequestration). Estimates of potential carbon sequestration from other studies range from 55 $MtCO_2$/year to over 500 $MtCO_2$/year (Bryan *et al.*, 2015; Meyer *et al.*, 2020).

The combined mitigation potential is more than double the current GHG emissions from the agricultural sector, although sequestration measures should not replace the emissions reduction needed in the sector to meet its climate commitments. Analysis of one of the mitigation areas quantified in this report, i.e. grazing management and improved pastures, led to an unclear picture of whether or not it effectively reduces greenhouse gases. Nevertheless, it is an important tool to increase resilience against climate change impacts.

There are critical barriers that hinder the implementation of measures to exploit the selected potentials, and other activities to reduce GHG emissions in the agricultural sector. Most barriers are on the farm level and the national level, with a lack of comprehensive, unbureaucratic policies to incentivise mitigation action and of knowledge of sustainable practices and their positive effects. The growth of international demand for meat and dairy products and domestic overconsumption and wasteful behaviour drive production up, and while these are not direct barriers to mitigation actions on the production side, they have competing effects on the total amount of GHGs emitted from the sector.

To accelerate the uptake and implementation of the measures described in this report, it is key to 1) more clearly translate national mitigation priorities to the agricultural sector, 2) in turn ensure that all agricultural policies are aligned with mitigation objectives and 3) implement sector policies to comprehensively address the areas where most mitigation is possible. These mitigation policies and incentives should also foster co-benefits between adaptation and mitigation in the agricultural sector.

1. *Translate national mitigation priorities to the agricultural sector*

Australia's NDC does not provide sector-specific targets, nor is there additional national planning that translates the overall target to sectors. The earliest quantitative mitigation goal for the agricultural sector is in the LTS of Australia, a reduction of 2005 emissions levels by 29–36% and reducing the sector's emissions intensity by 40% from 2020 to 2050 (Australian Government, 2021a). This goal is based on national economy-wide modelling and includes substantial additional soil carbon sequestration. More short-term targets for agriculture and anchoring them in the NDC would provide the sector with a clearer sense of direction. A clear vision for the sector could also contribute to the continuity in Australian climate change policies and politics, where a lack of it is a barrier for farmers to adopt new practices.

2. *Probe the agricultural policy framework against climate change mitigation objectives*

Australian agricultural policy is largely set up to increase the output of the sector, with a focus on supplying the Australian population and serving the growing international demand, particularly for meat and dairy products. This growth plan is in conflict with the reduction of GHG emissions of the sector. The agricultural strategy document does not consider the effect on greenhouse gas emissions of the sector at all. The few mitigation policies that cover the agricultural sector, for example, the Emissions Reductions Fund, have not proven very impactful. There is no visible attempt to move the population to a more plant-based diet and avoid overconsumption of animal products.

3. *Selected ideas for improvements, building on existing structures and initiatives, with a focus on the prioritised areas of this report*

Building on existing policy structures and initiatives, the Australian government can foster mitigation in the agricultural sector. Possible activities span promoting research and innovation, providing additional financial incentives, building capacities, and raising awareness to encourage users and consumers to support agribusinesses and initiatives that minimise their climate impacts. Some more concrete ideas are:

- **Foster knowledge on silvopastoralism,** raising attention to its benefits and build capacities around planting and managing trees on pastures.

- **Provide financial support** e.g. in the form of concessional loans with long pay-back periods to support investments in silvopastoral systems.
- **Foster research, innovation and knowledge sharing on improved livestock rearing practices** to decrease emissions from enteric fermentation and manure handling. This includes good practices being employed by other countries, in addition to continued research on red algae as a feed additive to make it a commercially viable mitigation option.
- **Review the accessibility to programmes** like the Emissions Reduction Fund and the Carbon Farming Initiative. Findings could be the necessity to decrease the bureaucratic burden of the programme or to increase farmers' knowledge of mitigation options, including awareness of their benefits.
- **Improve the monitoring and reporting methodologies** of the agricultural sector and land use by reconciling the national and state-level deforestation estimates to reduce discrepancies between emissions reports for the LULUCF sector. Reducing the uncertainty around emissions from the sector allows for more effective policy planning and for monitoring the impacts of new practices on GHG emissions.
- **Avoid food waste** through information campaigns for households and a review of regulations around the use-by dates.

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. For instance, governments could promote dietary guidelines in line with the Planetary Health Diet,[4] which provides consumption recommendations that can feed a growing population while being compatible with planetary boundaries. Discussing alternative narratives next to the current agricultural expansion plans could help understand the implications of a shift to largely plant-based diets and potentially avoid disruptions in the sector in the medium to long term. 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).

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

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