CLIMATE CHANGE
29/2025

Mitigating agricultural greenhouse gas emissions in New Zealand

Status, potential and challenges

by:

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Abstract: New Zealand Country Report

This report describes the current state of agriculture in New Zealand 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: Neuseeland Landesbericht

Dieser Bericht beschreibt den aktuellen Stand der Landwirtschaft in Neuseeland 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. 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
CH_4	Methane
CO_2	Carbon dioxide
CRRF	COVID-19 Response and Recovery Fund
ETS	Emission Trading System
GDP	Gross domestic product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of nature
LULUCF	Land Use, Land-Use Change and Forestry
MAPIP	Māori Agribusiness: Pathway to Increased Productivity
MfE	Ministry for the Environment
MPI	Ministry for Primary Industries
$MtCO_2e$	Mega tonnes of CO_2 equivalents
NDC	Nationally Determined Contributions (in Paris-Agreement)
NIWA	National Institute of Water and Atmospheric Research
N_2O	Nitrous oxide
OECD	Organisation for Economic Cooperation and Development
RCEP	Regional Comprehensive Economic Partnership
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 ideas on how to overcome those barriers. The report begins with a description of the current state of agriculture in New Zealand with regard to the greenhouse gas (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 estimate their mitigation potential. Finally, we identify barriers that act at farm, national, international and consumer level along with possible steps to overcoming those barriers.

New Zealand's agricultural sector shapes not only the country's landscape but also its economy. Arable land represents almost 40% of the total land area, of which the majority is pasture land (FAO 2022). This grassland is foremost used for cattle and sheep farming, which New Zealand is famous for (MfE, Stats NZ 2021). The agricultural sector contributed 6.4% to New Zealand's gross domestic product (GDP) in 2019, which is above the global average (OECD 2021b). The dairy sector is a key industry with dairy products being a major export product. Specifically, New Zealand is the world's largest exporter of whole milk powder and butter (FAO 2020). In 2019, 5.8% of New Zealand's total workforce were employed in the agricultural sector (OECD 2021b, World Bank 2021).

In 2019, about 50% of New Zealand's greenhouse gas emissions were from agriculture, excluding Land Use, Land-Use Change and Forestry (LULUCF) emissions. The high share of agricultural emissions of total emissions reflects the importance of the sector for New Zealand's economy. According to national data, New Zealand agricultural emissions (excl. on-farm energy use and LULUCF) were approx. 41 mega tonnes of CO_2 equivalents ($MtCO_2e$) in 2019 (MfE 2022b).

Emissions from enteric fermentation represent 70% of agriculture-related emissions. Methane from livestock makes up about 90% of national methane emissions, the majority stemming from dairy cattle (MfE 2021d). In the last three decades, all categories of agriculture-related GHG emissions have increased – except for burning biomass, which saw a slight decrease. Also, the contribution of each livestock category to agricultural emissions has changed. Formerly known for having far more sheep than inhabitants, sheep numbers have significantly decreased since 1990 whereas dairy and beef cattle numbers have increased. The reason for the shift from sheep to dairy cattle farming is a rise in milk prices which makes milk production more economically viable (especially on land that was previously considered unsuitable) (MfE, Stats NZ 2021). Consequently, GHG emissions from sheep have decreased by 40% whereas GHG emissions from dairy cattle have increased by 130% since 1990 (MfE 2021a).

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 New Zealand, we selected the following three mitigation measures:

- Reduced nitrogen fertilisation on pastures
- Rewetting of organic soils
- Silvopastoralism.

Regarding mitigation measures for livestock, there is little potential for emission reductions from improving livestock emission intensity from cattle beyond reducing herd sizes and

stocking rates. For the time being, the reduction of synthetic nitrogen application on pastures is thus the only option to reduce emissions from livestock – besides a reduction of livestock numbers. Quantifications of the national nitrogen fertiliser cap show that emissions can be reduced by approx. 72 and 150 ktCO_2e in 2030 and 2035 respectively if synthetic nitrogen fertiliser application is reduced. However, this comprises a very low mitigation potential in relation to total emissions of the agricultural sector (0.4%). A rewetting of 50% of organic soils from grass- and cropland can lead to an emissions reduction of 868 ktCO_2e annually. As rewetting will likely be accompanied by a change of agricultural practices or a reduction of stocking numbers, further emission reductions are linked to this measure. Establishing silvopastoral systems on pastureland could result in additional carbon sequestration, but there are some risks to sequestration, namely uncertainties around the mitigation potential and its permanence/reversibility. The comparatively low mitigation potential of the selected measures shows that a broader set of mitigation measures is required in order to reach the target indicated for the agricultural sector in the national emissions reduction plan (New Zealand Government 2022), particularly including demand-side measures that reduce (not only domestic) consumption of animal products and can thus lead to a reduction in animal numbers, as well as to the increase of carbon sinks. Feed additives are discussed in New Zealand but were not considered in this report due to the uncertainty of animal health impacts, and other potential negative environmental impacts associated with feed additives (ICCC 2019, Nabuurs et al. 2022).

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. On several levels, economic barriers hinder emission reductions in the agricultural sector more generally. Farmers face high transactions cost when switching agricultural practices. The dominance of the dairy sector in the national economy, and the export value specifically, make climate policy interventions difficult. However, the government already tries to address the economic barriers by, for example, the upcoming carbon pricing scheme and several financial support programmes.

To accelerate the uptake and implementation of the measures described in this report, it is key to 1) implement thorough climate policies in the agricultural sector, 2) revise the methodological approach of New Zealand's Nationally Determined Contribution (NDC) and agricultural targets to align them with reporting and accounting methods used under the UNFCCC, 3) take a holistic approach on environmental impacts and a just transition. Mitigation policies and incentives should also foster co-benefits between adaptation and mitigation in the agricultural sector. Diversification of income generation and changing agricultural practices could improve the resilience of New Zealand farmers which rely on wide pasture land that will be impacted by a range of climate change impacts.

Zusammenfassung

Ziel dieses Berichts ist es, mögliche Optionen zur Emissionsminderung im Agrarsektor aufzuzeigen, Hindernisse bei der Umsetzung dieser Optionen zu identifizieren und einige Ideen zur Überwindung dieser Hindernisse zu liefern. Der Bericht beginnt mit einer Beschreibung des aktuellen Zustands der neuseeländischen Landwirtschaft im Hinblick auf die von ihr verursachten 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 lokaler landwirtschaftlicher, nationaler, internationaler und Verbraucherebene wirken, sowie mögliche Schritte zur Überwindung dieser Hindernisse.

Der neuseeländische Agrarsektor prägt nicht nur die Landschaft des Landes, sondern auch seine Wirtschaft. Ackerland macht fast 40% der gesamten Landfläche aus, wovon der Großteil Weideland ist (FAO 2022). Dieses Grünland wird vor allem für die Rinder- und Schafzucht genutzt, für die Neuseeland bekannt ist (MfE, Stats NZ 2021). Der Agrarsektor trug im Jahr 2019 mit 6,4% zum neuseeländischen Bruttoinlandsprodukt (BIP) bei und liegt damit über dem weltweiten Durchschnitt (OECD 2021b). Der Milchsektor ist eine Schlüsselindustrie, wobei Milchprodukte ein wichtiges Exportprodukt sind. Insbesondere ist Neuseeland der weltweit größte Exporteur von Vollmilchpulver und Butter (FAO 2020). Im Jahr 2019 waren 5,8% der neuseeländischen Gesamtbeschäftigten im Agrarsektor tätig (OECD 2021b, World Bank 2021).

Im Jahr 2019 stammten etwa 50% der neuseeländischen Treibhausgasemissionen aus der Landwirtschaft, ohne LULUCF-Emissionen. Der hohe Anteil der landwirtschaftlichen Emissionen an den Gesamtemissionen spiegelt die Bedeutung des Sektors für die neuseeländische Wirtschaft wider. Nationalen Daten zufolge beliefen sich die neuseeländischen landwirtschaftlichen Emissionen (ohne Energieverbrauch in landwirtschaftlichen Betrieben und LULUCF) im Jahr 2019 auf etwa 41 $MtCO_2e$ (MfE 2021b).

Die Emissionen aus der enterischen Fermentation machen 70% der landwirtschaftlichen Emissionen aus. Methan aus der Viehhaltung macht etwa 90% der nationalen Methanemissionen aus, wobei der Großteil von Milchvieh stammt (MfE 2021d). In den letzten drei Jahrzehnten haben alle Kategorien der landwirtschaftlich bedingten Treibhausgasemissionen zugenommen - mit Ausnahme der Verbrennung von Biomasse, die leicht rückläufig war. Darüber hinaus hat sich der Beitrag der einzelnen Tierkategorien zu den landwirtschaftlichen Emissionen verändert. Die Schafbestände, die früher dafür bekannt waren, in ihrer Anzahl die Einwohner*innen Neuseelands zu übersteigen, sind seit dem Jahr 1990 deutlich zurückgegangen, während die Zahl der Milch- und Fleischrinder gestiegen ist. Der Grund für die Verlagerung von der Schaf- zur Milchviehhaltung liegt in den gestiegenen Milchpreisen, die den Betrieb wirtschaftlich rentabler machen (insbesondere auf Flächen, die früher als ungeeignet galten) (MfE, Stats NZ 2021). Infolgedessen sind die Treibhausgasemissionen von Schafen um 40% zurückgegangen, während die Treibhausgasemissionen von Milchkühen seit dem Jahr 1990 um 130% gestiegen sind (MfE 2021a).

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

Für Neuseeland haben wir die folgenden drei Minderungsmaßnahmen ausgewählt:

- Reduzierung von Stickstoffdünger auf Weideland
- Wiedervernässung von organischen Böden
- Silvopastoralismus.

Was die Maßnahmen zur Verringerung der Emissionen aus der Viehhaltung anbelangt, so ist das Potenzial für Emissionsminderungen durch eine Verbesserung der Emissionsintensität von Rindern über die Verringerung der Herdengröße und der Besatzdichte (Tier pro Fläche) hinaus gering. Die Verringerung der Ausbringung von synthetischem Stickstoff auf Weideland ist daher derzeit die einzige Möglichkeit zur Verringerung der Emissionen aus der Viehhaltung - neben einer Verringerung des Viehbestands. Quantifizierungen der nationalen Stickstoffdüngerobergrenze zeigen, dass die Emissionen um ca. 72 bzw. 150 ktCO_2e im Jahr 2030 bzw. 2035 reduziert werden können, wenn die Ausbringung synthetischer Stickstoffdünger verringert wird. Im Verhältnis zu den Gesamtemissionen des Agrarsektors (0,4%) stellt dies jedoch ein sehr geringes Minderungspotenzial dar. Eine Wiedervernässung von 50% der organischen Böden von Gras- und Ackerland kann zu einer Emissionsminderung von 868 ktCO_2e jährlich führen. Da die Wiedervernässung wahrscheinlich mit einer Änderung der landwirtschaftlichen Praktiken oder einer Verringerung des Viehbestands einhergeht, sind mit dieser Maßnahme weitere Emissionsverringerungen verbunden. Die Einführung von silvopastoralen Systemen auf Weideland könnte zu einer zusätzlichen Kohlenstoffbindung führen, aber es gibt einige Risiken für die Sequestrierung in Bezug auf Unsicherheiten in Bezug auf das Minderungspotenzial und die Dauerhaftigkeit/Reversibilität. Das vergleichsweise geringe Minderungspotenzial der ausgewählten Maßnahmen zeigt, dass ein breiteres Spektrum an Minderungsmaßnahmen erforderlich ist, um das im nationalen Emissionsminderungsplan (New Zealand Government 2022) für den Agrarsektor angegebene Ziel zu erreichen, insbesondere einschließlich nachfrageseitiger Maßnahmen, die den (nicht nur inländischen) Verbrauch tierischer Erzeugnisse verringern und somit zu einer Verringerung des Tierbestands sowie zu einer Vergrößerung der Kohlenstoffsenken führen können. Futtermittelzusatzstoffe werden in Neuseeland diskutiert aber in diesem Bericht nicht berücksichtigt aufgrund der Ungewissheit über die Auswirkungen auf die Tiergesundheit und andere potenzielle negative Umweltauswirkungen im Zusammenhang mit Futtermittelzusatzstoffen (ICCC 2019, Nabuurs et al. 2022).

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. Auf mehreren Ebenen behindern wirtschaftliche Hindernisse die Emissionsreduzierung im Agrarsektor im Allgemeinen. Landwirte sind mit hohen Transaktionskosten konfrontiert, wenn sie ihre landwirtschaftlichen Praktiken umstellen. Die Dominanz des Milchsektors in der Volkswirtschaft und insbesondere der Exportwert erschweren klimapolitische Eingriffe. Die Regierung versucht jedoch bereits, die wirtschaftlichen Hindernisse zu beseitigen, z. B. durch das bevorstehende Kohlenstoffpreissystem und verschiedene finanzielle Förderprogramme.

Um die Übernahme und Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, ist es von entscheidender Bedeutung, dass 1) eine gründliche Klimapolitik im Agrarsektor umgesetzt wird, 2) der methodische Ansatz der NDC- und Agrarziele überarbeitet und in Einklang mit den Verfahren zur Berichterstattung dem Accounting unter der UNFCC gebracht wird, 3) ein ganzheitlicher Ansatz bezüglich Umweltauswirkungen und einen gerechten Übergang verfolgt wird. Minderungsmaßnahmen und -anreize sollten auch den gemeinsamen Nutzen von Anpassung und Minderung im Agrarsektor fördern. Eine Diversifizierung von Einkommensquellen und eine Änderung der landwirtschaftlichen Praktiken könnten die Widerstandsfähigkeit der neuseeländischen Landwirte verbessern, die auf große Weideflächen angewiesen sind, die von einer Reihe von Auswirkungen des Klimawandels betroffen sein werden.

1 General characteristics of the agricultural sector and policy landscape

1.1 Characteristics of the agriculture sector in New Zealand

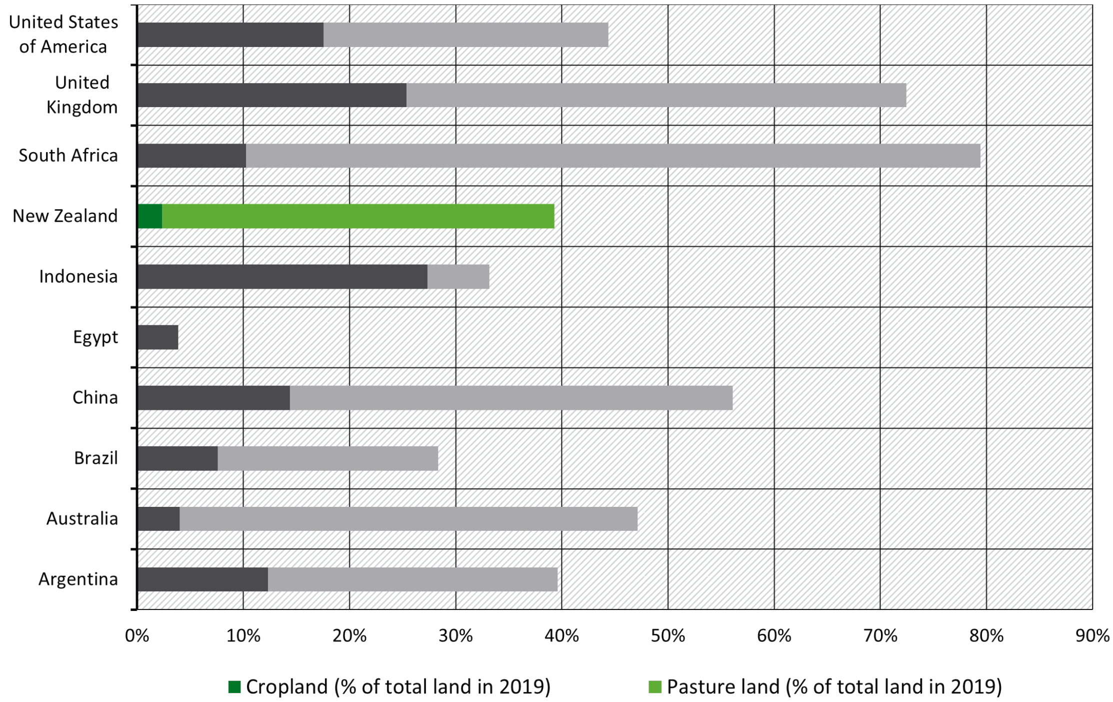
New Zealand's total 27 million hectares of land can be categorised in the following: 54.2% grassland, 37% forest land, 1.8% cropland, 2.8% wetlands and the remainder settlements and other land use (MfE 2022b). The agriculture sector in New Zealand plays a key role in the country's economy and is reflected in the land use: arable land comprises almost 40% of the total land area, of which 2% is dedicated cropland and 37% pasture and range land (FAO 2022). Similar to Australia (Figure 1), pasture is not only the dominant use of agricultural land but also shapes the countries' land cover due to its high relative share of the total land area. The grassland is foremost used for cattle and sheep farming (MfE, Stats NZ 2021). In 2019, more than 13 million hectares were dedicated farmland (MfE 2022b, Stats NZ 2021b). Regions with the largest areas of farmland are Canterbury and Otago (Stats NZ 2021b). The most farms by number are situated in Waikato and Canterbury (ibid). Approx. 9.3% of New Zealand's land area has undergone land-use change in the last three decades (MfE 2022b). The areas of forested land, cropland and settlements have increased whereas grass land areas have decreased (ibid). Overall, the area of agricultural land has decreased by 14% since 2002. In this time period, land used for sheep and beef farming has decreased and pastureland for dairy cattle has increased (Stats NZ 2021a).

While the total area of land used for agriculture as well as the number and size of farms, decreased in the last two decades, the productivity of the farms has increased (ibid). For example, production intensity in dairy farming has increased from an average of about 260kg to 397kg of milk solids production per cow in 1992 and 2020 respectively (LIC, DairyNZ 2021).

The same trends are apparent in the livestock numbers. Traditionally, New Zealand was a country of sheep farms with sheep numbers as high as 70 million in the 1980s (Stats NZ 2021e). This number has decreased significantly to 26.8 million sheep in 2019 – a reduction of over 60%. While beef cattle and sheep numbers decreased in the last two decades, the number of dairy cattle has increased by 82% to 6.1 million since 1990 (ibid). For comparison, New Zealand has 5.1 million inhabitants. The reason for the shift from sheep to dairy cattle farming is a rise in milk prices which makes milk production more economically viable (especially on land that was previously considered unsuitable) (MfE, Stats NZ 2021). The average herd size has steadily increased since 1975 with 444 cows per herd in 2021 (LIC, DairyNZ 2021). The most common herd size consisted of 200 to 249 cows in 2021. Dairy herd numbers have continuously decreased though (ibid). Furthermore, deer farming became popular in the 1990s, but numbers decreased to about 0.8 million deer in 2019 from a peak stock of 1.75 million deer in 2004 (MfE, Stats NZ 2021).

The majority of livestock in New Zealand are fed on grass and are outside on the pasture all year round (MfE 2022a). Feedlots or housing livestock inside is rare. The year-round outdoor farming systems pastoral grazing are more animal-friendly than intensive feedlot, but are also the cause of nitrogen losses to the soil and freshwater system posing a threat to water quality and biodiversity (section 1.5).

Figure 1: Agricultural land as a share of total country area (2019)

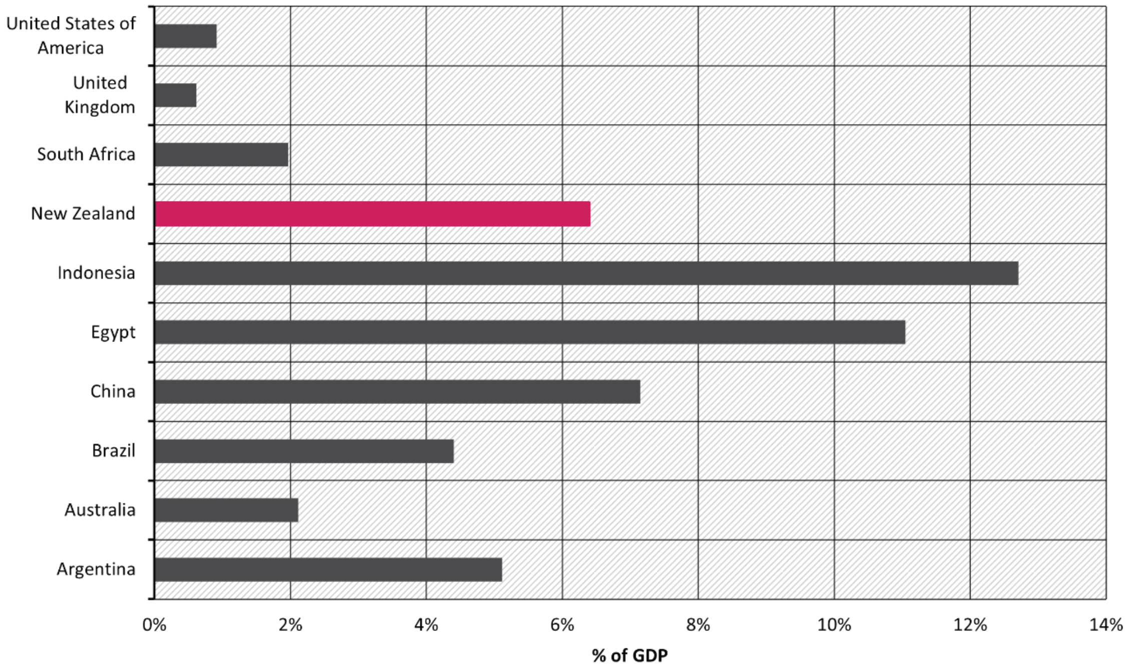


Source: FAO (2022) data for all countries. Data includes "Cropland" and "Land under permanent meadows and pastures"

The agricultural sector contributed 6.4% to New Zealand's gross domestic product (GDP) in 2019, which is above the global average of 3.5% (OECD 2021b). The sector is, for example, more important to the national economy of New Zealand than to its neighbour Australia (Figure 2). New Zealand is a net exporter of agri-food products. Agricultural commodities made up more than 65% of national exports in 2021 (OECD 2021b). The sector generates 35% of the country's total export revenue (ICCC 2019). More than 80% of the livestock products produced nationally and over 50% of horticultural products and wine are exported (OECD 2011). Dairy products comprise the majority of exports by revenue (40%) in the food and fibre sector (including not only agricultural products but also forestry products like timber), followed by meat and wool products (22%) (MPI 2021). New Zealand is the world's largest exporter of whole milk powder and butter (FAO 2020). The main importing country of New Zealand's dairy products is China (ibid). Approx. 11% of New Zealand's imports are agri-food products (OECD 2021b). Additionally, the largest New Zealand company is Fonterra, which accounts for almost a third of global dairy exports.[1]

[1] https://www.gtreview.com/magazine/volume-15issue-5/milk-new-zealands-dairy-exports-conquered-world/

Figure 2: Agriculture, fisheries, and forestry's contribution to GDP (2019)



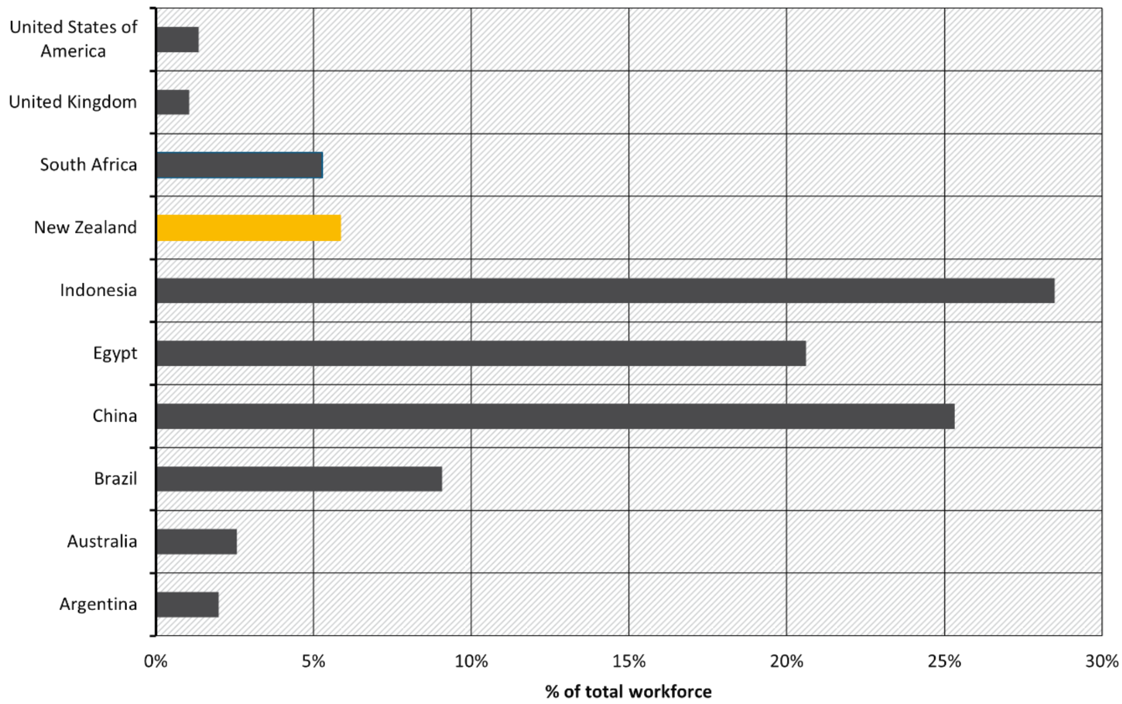
Source: World Bank (2022) data for all countries except New Zealand due to lack of data. Value for New Zealand was taken from OECD (2021b)

Generally, New Zealand's agricultural sector is - for a developed country - very exposed to international trade and global competition since many regulations (e.g. subsidies, tax concessions) were removed in the 1980s (OECD 2021b). New Zealand's big export market is supported by a large number of free trade agreements, including the Regional Comprehensive Economic Partnership (RCEP) with Asia-Pacific countries.

1.2 Socio-economic dimensions

In 2019, 5.8% of New Zealand's total workforce were employed in the agricultural sector (OECD 2021b, World Bank 2021). This comprises a higher share of total workforce compared to other industrialised countries like Australia or the United Kingdom (Figure 3). The Māori have a special connection to land and their economy has a focus on the so-called primary production industries such as dairy farming and horticulture (especially kiwifruit) (MfE, Stats NZ 2021, MfE 2020). The land management of Māori typically includes the sustainable management of soil and other resources (MfE, Stats NZ 2021). Approx. 6% of New Zealand's total land area are Māori freehold land and a significant share of primary industry assets are owned by Māori – for example 40% of forestry and 30% of sheep and beef production (MfE, Stats NZ 2021).

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 ILO (2021)

The number and size of New Zealand's farms has decreased in the last decades (MfE, Stats NZ 2021). An analysis for the years 1972 to 2002 by Mulet-Marquis and Fairweather (2008) showed that the share of smaller (<39 hectares) and larger (>200 hectares) farms increased whereas the medium-sized farms (between 40 to 199 hectares) decreased. The individual farm types differed in their development in the time period under examination. Horticultural farms have increased in all sizes but especially in the smaller farm sizes (ibid). The number of small sheep and beef farms increased while the number of larger farms decreased. The number of small and especially large dairy farm increased whereas the medium-sized farms decreased (ibid). The overall trend of a decrease in the size of sheep farms and an increase in the size of dairy farms continued in the last two decades - with a decrease in farm size and numbers overall in the agricultural sector (MfE, Stats NZ 2021). In line with that, the total area of land used for agriculture and horticulture has been decreasing since 2002 (ibid). In 2019, there were approx. 50,000 farms in New Zealand (Stats NZ 2021b) – mostly small farms.

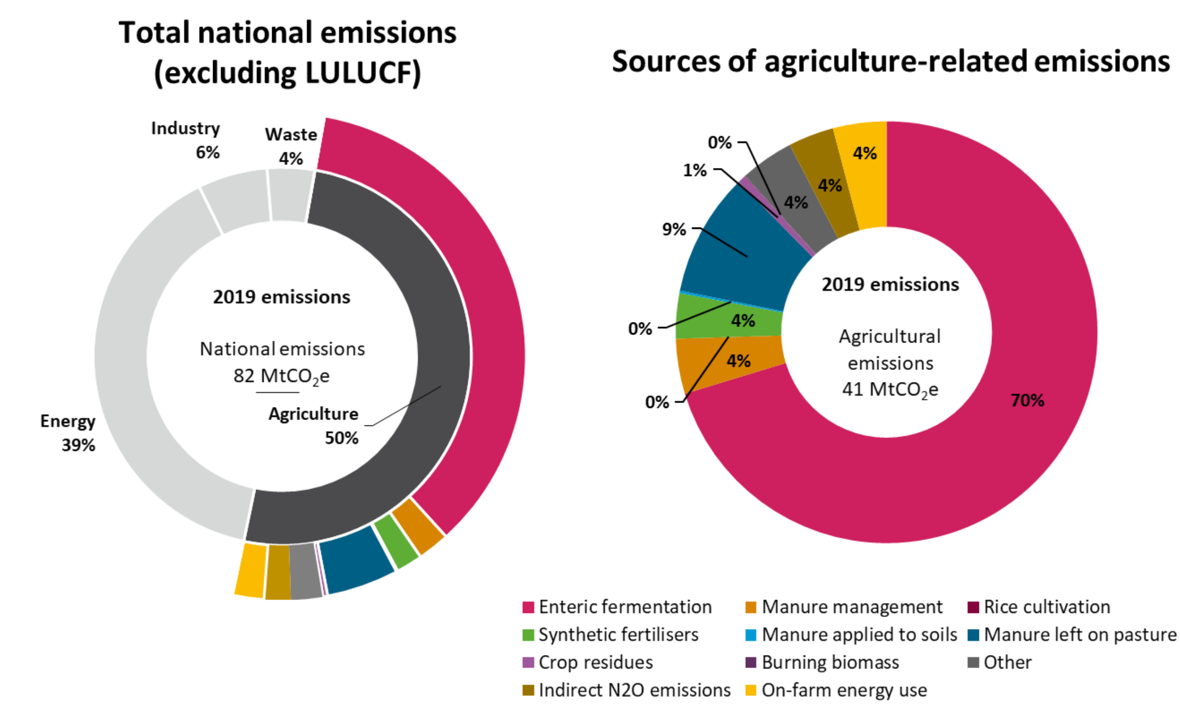
The area of irrigated agricultural land has almost doubled in the last two decades, amounting in total to 1.3% of New Zealand's land area (Stats NZ 2021d). More than half of this irrigated agricultural land is land used for dairy farming (MfE, Stats NZ 2021). In the face of decreasing rainfall or droughts (section 1.6), farmers tend to increasingly irrigate the pasture to increase the quality of the grass and to consequently maintain the productivity of the pasture-based livestock.

New Zealand's agricultural system, and especially the increased use of nitrogen fertiliser, impacts the country's soil, waters and air. Increased nutrients inputs on land can make their way into the ocean and can lead to (harmful) algal blooms. Nitrogen and other nutrients from agriculture can leach into groundwater and freshwater systems. The amount of nitrogen applied to New Zealand soils has increased over 600% since 1991 (Stats NZ 2021c) – dairy farming being the major source of applied Urea fertiliser. Harmful levels of nitrate concentrations were already found in groundwater near areas of intensive cattle farming in New Zealand (MfE, Stats NZ 2021). The management of nitrogen losses, such as fencing streams or timing irrigation and effluent to minimise run-off, was not able to counterbalance the increased nitrogen losses through land conversion to (dairy) farmland and more intense land use between 1995 and 2015 (MfE, Stats NZ 2021). Half of the monitored sites were not within the national target levels for phosphorus levels – especially measurements at dairy, cropping and vineyard sites were above recommended levels (Stats NZ 2021f). Furthermore, there are also indirect impacts of the agricultural sector. Pollution of freshwater systems threatens native freshwater fish and the ecosystem itself in New Zealand (MfE, Stats NZ 2019).

1.3 Greenhouse gas emissions from Agriculture, Forestry and Other Land Use (AFOLU) and the main drivers

In 2019, about 50% of New Zealand's greenhouse gas (GHG) emissions were from agriculture (Figure 4 and Figure 6). These approx. 41 $MtCO_2e$ from agriculture exclude emissions from Land Use, Land-Use Change and Forestry (LULUCF). The agricultural sector is thereby the highest emitting sector. The high share of agricultural emissions of total emissions reflects the importance of the sector for New Zealand's economy (section 1.1). Also, emissions from the power/energy sector are relatively low (39% of the total) for a developed country as hydro power is a large contributor to the national energy sources.[2]

Figure 4: New Zealand's GHG emissions profile, 2019



Source: Nationally reported inventory data (MfE 2022b)[3]

[2] https://ourworldindata.org/energy/country/new-zealand.

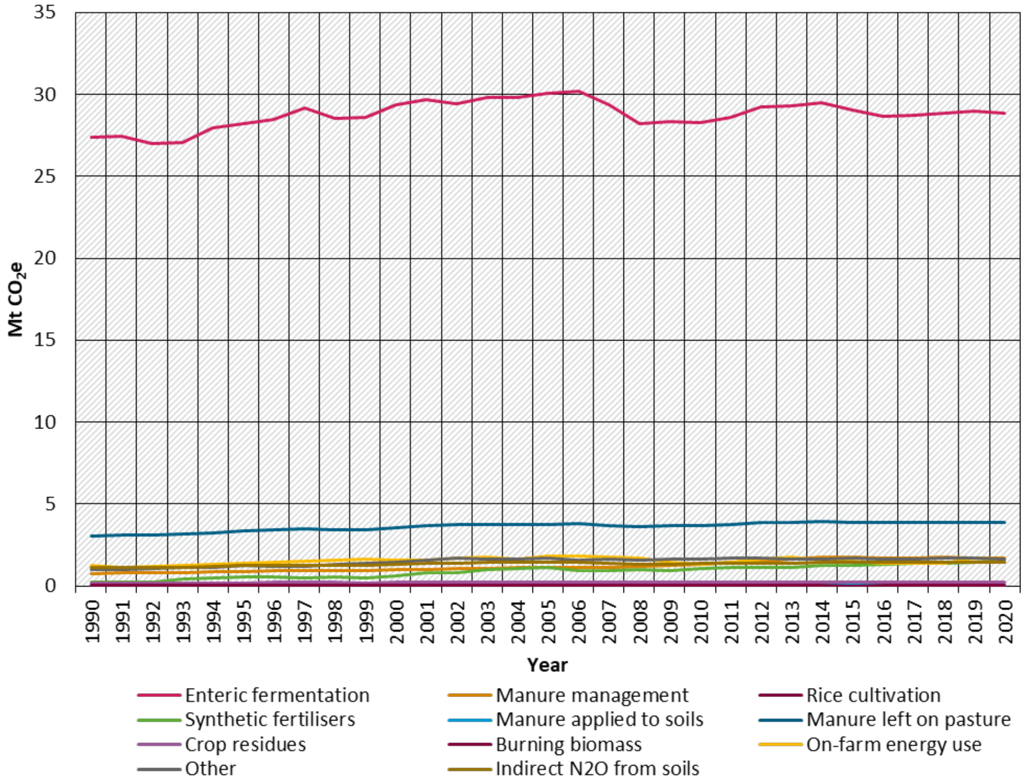
[3] While on-farm energy use is generally reported under energy sector emissions for national data, we include it as an agriculture-related emissions source in this study because of its role in agricultural production (fuel use in harvesters, stable heating, grain drying etc.) and its relevance in several countries in terms of magnitude and mitigation potential. 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.

Since livestock plays a critical and increasing role in New Zealand's agricultural economy, it also plays a critical and increasing role in the sector's GHG emissions. Emission from enteric fermentation represent 70% of agriculture-related emissions (Figure 4). Methane from livestock makes up about 90% of national methane emissions (MfE 2021d). According to the national GHG inventory (MfE 2021b), dairy cattle is the main source of methane emissions from enteric fermentation which corresponds with the high dairy cattle numbers in the country (section 1.1). The shares of the livestock categories in enteric fermentation emissions are as follows: dairy cattle 48%, sheep 29%, beef cattle 20%, deer 1-2% (MfE 2021b, p. 189). The second relevant source of agricultural emissions are nitrous oxide (N_2O) emissions from agricultural soils which encompass: manure left on pasture (9%), synthetic fertilisers (4%), indirect N_2O emissions (4%), crop residues (1%), manure applied to soils (less than 1%) (Figure 4). Emissions from agricultural soils thereby constitute almost 20% of agricultural emissions. Even though emissions from synthetic fertilisers represent a small share of total emissions in comparison to enteric fermentation emissions, the use of synthetic nitrogen fertiliser is of concern as it has increased by more than 600% since 1990 (Stats NZ 2021c). Compared to other Annex I Parties, New Zealand has lower manure management emissions (9%) as manure is deposited directly onto pastures (MfE 2021b).

In the last three decades, all categories of agriculture-related GHG emissions have increased – except for burning biomass which saw a slight decrease of 12% (Figure 5). Emissions from enteric fermentation, as the main source of GHG emissions in the sector, have increased from about 27 $MtCO_2e$ to almost 29 $MtCO_2e$ between 1990 and 2020 - with a particularly steep increase up to the early 2000s (MfE 2022b). Emissions from agricultural soils, the second largest source, increased by 48.5% in the time period between 1990 and 2020 (MfE 2022b). As mentioned above, emissions from synthetic fertilisers have increased since 1990 from 0.23 to 1.55 $MtCO_2e$ in 2020 in accordance with an increase in fertiliser use. Other emission sources, such as emissions from manure management and on-farm energy use have also steadily increased (Figure 5).

While emissions from enteric fermentation have increased overall since 1990, the contribution of each livestock category to these agricultural emissions has changed. Since 1990, GHG emissions from sheep have decreased by 40% whereas GHG emissions from dairy cattle have increased by 130% (MfE 2021a). These trends are caused by the decline in sheep and the increase in dairy cattle numbers in New Zealand (section 1.1).

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

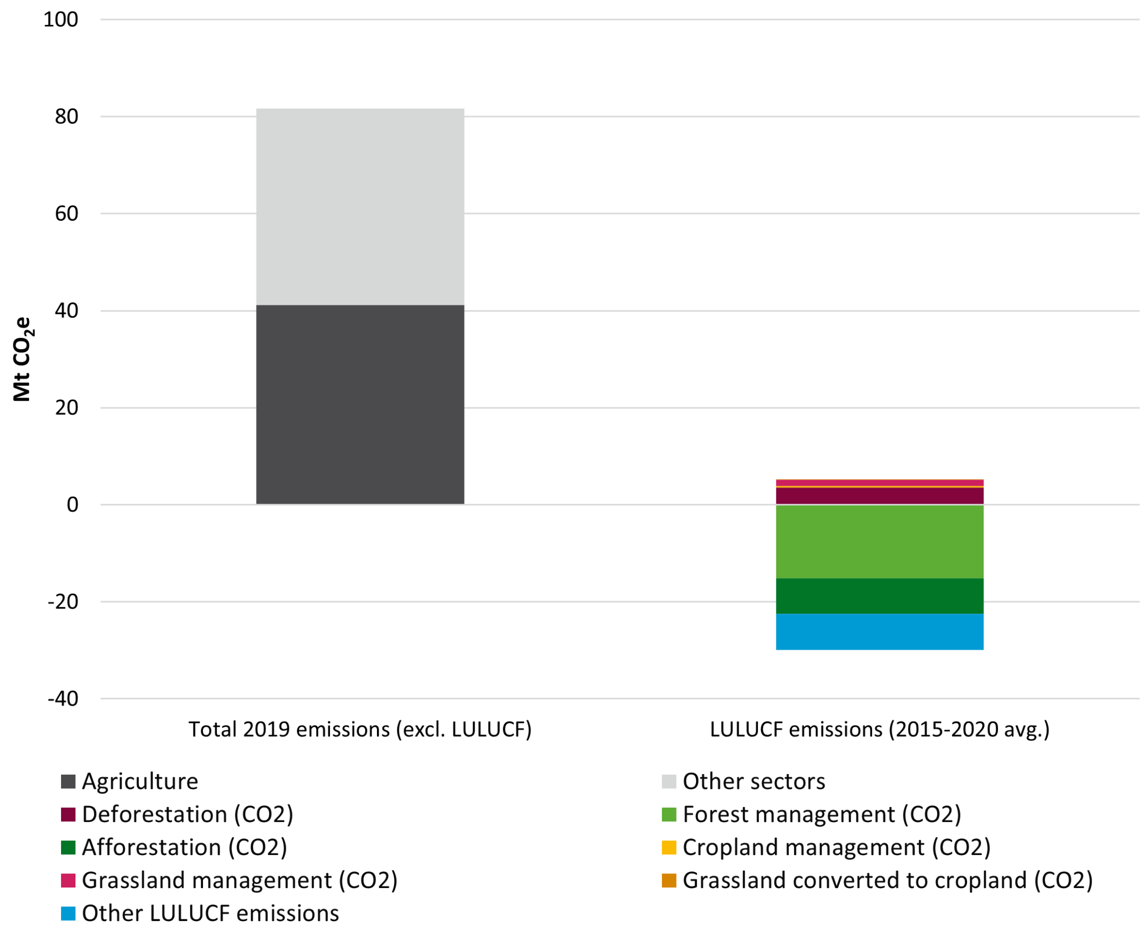


Source: Nationally reported inventory data, as in MfE (2022b)[4]

In terms of the different GHGs, methane is the most important GHG in New Zealand's agricultural sector. Over two thirds of the total agricultural emissions were methane emissions in 2019 (MfE 2021b). The majority of these emissions stems from livestock through enteric fermentation and have increased in the last three decades (ibid). The increase was caused by an increase in livestock numbers and by an increase in livestock productivity (section 1.1) – which requires more feed per animal and thereby increasing methane (CH_4) emissions (MfE, Stats NZ 2020). Sources of carbon dioxide (CO_2) in the agricultural sector are liming and urea application and are negligible compared to agricultural methane emissions (MfE 2021b). While CH_4 emissions have been relatively stable between 1900 and 2019, N_2O emissions – mainly from agricultural soils – have increased from about 5 Mt N_2O to 7.8 Mt N_2O (ibid). Over 90% of New Zealand's N_2O emissions stem from agricultural soils (MfE 2022b).

[4] While on-farm energy use is generally reported under the 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 because of its relevance in several countries in terms of magnitude and mitigation potential. 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 6: New Zealand'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)



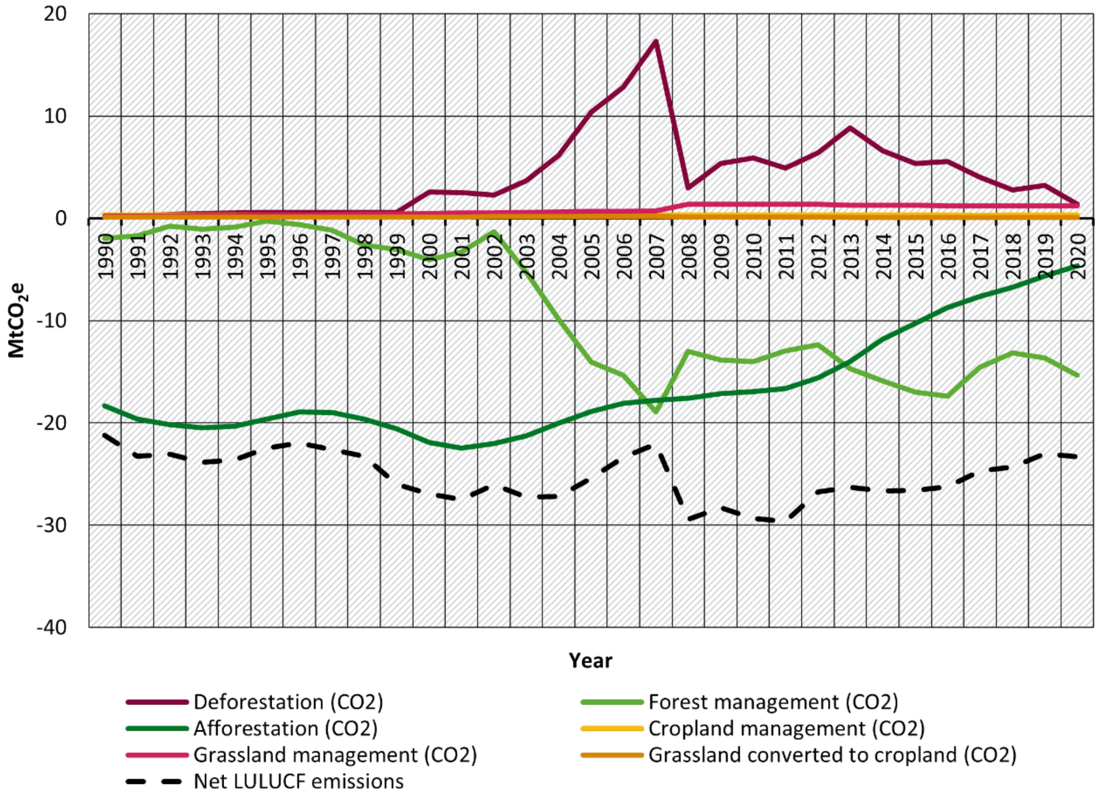
Source: Nationally reported inventory data, as in MfE (2022b). The category "other LULUCF emissions" includes CO_2 emissions from wetlands, emissions from settlements, emissions from other land, and harvested wood products, as well as all non-CO_2 LULUCF emissions, referring to CH_4 and N_2O emissions primarily from organic soils, nitrogen mineralisation/immobilisation, and biomass burning.

The emissions of the LULUCF sector amounted to -24.7 $MtCO_2e$ in 2019, as shown in Figure 6. New Zealand's total GHG emissions were thus 56.9 $MtCO_2e$ in 2019 including LULUCF.

Sources of emissions in the LULUCF sector include (Figure 6): deforestation, cropland and grassland management, and the conversion of grassland to cropland. These emissions are "primarily driven by the harvest of production forests, deforestation, and the decomposition of organic material following these activities" (MfE 2021b, p. 254). Removals in the LULUCF sector are "primarily from the sequestration of carbon that occurs due to plant growth and increases in the size of the harvested wood products pool" (ibid).

Looking at the development over time (Figure 7), emissions from deforestation have varied particularly. The majority of deforestation since 2000 has been due to a conversion to grassland for farming and has decreased in the last years (MfE 2022b). New Zealand's wetlands changed from being a net remover of emissions to a net emitter between 1990 and 2020 due to land-use change (MfE 2021b). Emissions from wetlands are included under cropland and grassland management emissions in Figure 6 and Figure 7. Removals from afforestation have decreased over time. Overall, the LULUCF sector has been a (net) sink for GHG emissions since 1990 (Figure 7). Between 1990 and 2020, the size of the sink in the LULUCF sector varied and has overall slightly increased due to improved forest management practices, variations in afforestation and production of harvested wood products (MfE 2021b).

Figure 7: LULUCF emissions in New Zealand (1990–2020)



Source: Nationally reported inventory data, as in MfE (2022b). This graph 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.

Overall, agricultural GHG emissions (excl. LULUCF) have increased by 16.7% between 1990 and 2020 (MfE 2022b). This increase is mainly caused by an increase in domestic cattle numbers (section 1.1) and an increase in synthetic nitrogen fertiliser application. The decrease in sheep, beef cattle and deer numbers could not offset the emissions increase through the dairy cattle (ibid).

1.4 Government structures and agricultural policy framework

New Zealand committed to the goals of the Paris Agreement. To contribute to the global effort to limit the global average temperature increase to 1.5 °C, New Zealand's Climate Change Response Amendment act of 2019 (also called Zero Carbon Act) sets a legally binding national climate target of achieving net zero GHG emissions in 2050 (New Zealand Parliament 2019). This target, however, excludes biogenic methane for which a separate target was agreed: a reduction of biogenic methane emissions by 10% in 2030 and 24-47% in 2050 (compared to 2017 levels respectively). This target addresses the fact that methane emissions from livestock agriculture ("biogenic methane") are an important source of New Zealand's total emissions (see section 1.3).

Agricultural emissions will thus have to decrease with a view to the national net zero 2050 target and the dedicated biogenic methane target. The Act further establishes a system of emissions budgets and an independent Climate Change Commission for providing expertise and monitoring. Carbon budgets which cap emissions are set in five-year periods (except the first one). The first emission budget for the period 2022 to 2025 permits the emission of 290 $MtCO_2e$ (New Zealand Government 2022). New Zealand Government (2022) outlines sub-sector targets which are not, however, included in legislation. For agriculture, the budget for the period 2022 to 2025 is 159.4 $MtCO_2e$ – which represents the largest sectoral share of the budget in line with the current emissions profile. In its first nationally determined contribution (NDC), New Zealand pledges to reduce net GHG emissions by 50% by 2030 compared to 2005 levels, including LULUCF (New Zealand 2021). CAT (2022) rates this target as insufficient when compared with its fair-share emissions allocation as it would not be consistent with the 1.5°C temperature goal unless other countries achieve deeper emission reductions. The method applied in the NDC has also been criticised (section 3.2).

In terms of institutional arrangements,[5] the Ministry for the Environment (MfE) is the main ministry to administer environmental issue, including climate change mitigation, greenhouse gas monitoring and reporting. The Climate Change Commission's role is to provide independent, evidence-based advice to the government and to help New Zealand transition to a climate-resilient and low emissions future. The Ministry for Primary Industries (MPI) is also contributing to government (climate change) policy for the sectors it covers which include agriculture and forestry. It is important to highlight that agricultural production and trade is basically free from economic regulation in New Zealand (OECD 2021b). Governmental reforms in the 1980s liberalised the country's economy and ended the wide range of incentives (like subsidies) for the agricultural sector (OECD 2011). Since then, the structure and the productivity of the sector has changed a lot (sections 1.1 and 1.2). Nowadays, New Zealand's public agricultural support is below 1% of farm revenues – the lowest level of support to agricultural producers among Organisation for Economic Cooperation and Development (OECD) countries (OECD 2021b). There are some programmes and funds for projects and research on more sustainable farming practices. For example, there is the "Māori Agribusiness: Pathway to Increased Productivity" (MAPIP) funding programme which supports Māori primary sector asset owners in sustainably increasing the productivity of their primary sector assets, such as land, agriculture, horticulture, forestry, and seafood (OECD 2021b). There also programmes targeting the LULUCF sector such as the "One Billion Trees" and the "Sustainable Land Management Hill Country Erosion" programmes (MfE 2022c). With regard to, for example, the supply of woody biomass and the planting of native trees, more funding and research are planned.

After being abolished in 2008, it is now planned to price emissions from agriculture in New Zealand. So far, agriculture is the only sector not included in the national Emission Trading System (ETS). Currently, the agricultural sector must only report but not pay for emissions (MfE 2021c). The "He Waka Eke Noa" partnership[6] between agriculture industry and government has been established to prepare the implementation of a carbon pricing scheme for the agricultural sector. The partnership presented their recommendations in May 2022 and the New Zealand government published a policy proposal subject to public consultation in November 2022. The

[5] The Climate Change Commission's role is to provide independent, evidence-based advice to Government to help New Zealand transition to a climate-resilient and low emissions future.

[6] Primary Sector Climate Action Partnership: https://hewakaekenoa.nz/.

proposal foresees a levy at farm-level pricing CH_4 and N_2O emissions from livestock farming starting in 2025 (New Zealand Government, MfE, MPI 2022).

The government further implemented a limit on synthetic fertiliser use on pasture land. The cap is set at 190 kg/hectare per year.[7] In 2020, the government released a national policy statement on freshwater management which provides policy direction for regional councils.[8] This "essential freshwater package" includes amongst others guidance and provisions regarding agricultural intensification.

Biosecurity is an important topic for New Zealand, also in terms of agricultural pest and diseases, due to its geographical isolation as an island and high level of international trade. A focus of agricultural policies in New Zealand is therefore also animal disease control (OECD 2021b).

1.5 Current developments and trends

The emission intensity has decreased in the dairy, beef and sheep sector since 1990 (ICCC 2019). The main reason for the reductions is the increase in productivity of farms in New Zealand (section 1.1).

Mitigation and adaptation to climate change in the agricultural sector gained increased attention in New Zealand due to several extreme weather events in 2020 and 2023. There was a flooding event in Otago and the Southland and larger parts of the country were affected by drought in 2020. Public and government support for individual farmers and agricultural policies, such as relief payments in the event of disaster, were a consequence (OECD 2021b).

During the COVID-19 pandemic, the agricultural sector has benefited from the governmental COVID-19 Response and Recovery Fund (CRRF) Foundational Package by receiving USD 117 million in funding for individual projects relating to, for example, workforce shortfalls and boosting economic activity and future growth in the horticulture sector. The agricultural sector heavily relies on low-skilled migrant workers (OECD 2022a). As in other countries, the agriculture sector suffered from labour shortages due to travel restrictions limiting the number of overseas and seasonal workers coming to New Zealand during the pandemic (OECD 2021b). Additionally, high freight rates impacted the export of agricultural products (MPI 2021).

New Zealand has a high consumption of meat. In 2018, national beef consumption was more than 11 kg per capita and poultry consumption about 40 kg per capita – resulting in a meat consumption of over 70 kg per capita for beef, pork, poultry and sheep (OECD 2022b). New Zealand thereby ranks among the top ten meat-eating nations in the OECD (VegansocietyNZ 2020). New Zealand's meat consumption is thereby significantly above the recommendation of 15.7 kg per capita from the planetary health diet[9]. According to a recent study by Whitton et al. (2021), meat consumption might have peaked in New Zealand now. Food and organic waste account for 9% of biogenic methane emissions and 4% of total GHG emissions.[10] However, exact numbers on the total volume of wasted food along the supply chain are lacking for New Zealand. A study by Waste Not Consulting (2018) on households finds that about 157,000t of food, which

[7] https://environment.govt.nz/acts-and-regulations/freshwater-implementation-guidance/agriculture-and-horticulture/synthetic-nitrogen-fertiliser-cap-in-place-from-1-july/.

[8] https://environment.govt.nz/acts-and-regulations/freshwater-implementation-guidance/factsheets-on-policies-and-regulations-in-the-essential-freshwater-package/.

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

[10] https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/reducing-food-waste/.

corresponds to approx. 50% of total food household waste, which could have been eaten is wasted annually.

Due to its strong reliance on livestock, and specifically dairy products, New Zealand's agricultural sector might face issues in the future because of shifting consumer preferences towards more environmentally- and climate-friendly diets as well as more sustainable farming practices (OECD 2022a). Considering its high dependency on international trade, New Zealand's agricultural sector may have to adapt to these changing circumstances.

First actions are taken by farmers to address water quality and related biodiversity concerns (section 1.2), such as changing fertiliser practices or converting land back to native forest (ICCC 2019). Since the 1980s, organic farming has an increasing market share in New Zealand. Over 85,000 hectares of land were under organic certification in 2018 (Organics Aotearoa 2021). Approx. 55,000 hectares of the 85,000 hectares is land used for organic livestock farming and the remainder is cropland and land used for horticulture and viticulture. In the dairy sector, organically farmed land makes up only 1% of the total land area used for dairy (ibid). While this is still very small compared to the total area of farmland of over 13 million hectares (of which approx. 7.4 million is farmed grassland[11]), the market grew on average 6.4% per year between 2017 and 2020 (Stats NZ 2021b, Organics Aotearoa 2021).

1.6 Vulnerability and adaptation

It is predicted that the agricultural and forestry sectors in New Zealand will face an increase in extreme events and a continuous gradual change in climatic conditions (MfE 2020). There will be risks of an increased frequency of droughts, water shortages for irrigation and extreme rainfall causing floods and more cyclones (MfE, Stats NZ 2021). New Zealand is already experiencing increased temperatures, changing rainfall and water shortages (MfE, Stats NZ 2021, MfE 2020). The incidence and severity of drought and flooding and extreme weather events have increased across all regions (New Zealand Government 2022). These impacts could decrease agricultural and forestry productivity and output and might increase the spread of invasive species (MfE 2020). As pasture is critical for the agricultural sector in New Zealand, rainfall variability can have a significant effect on productivity (OECD 2011). The quantity and quality of the grass feed depends on consistent rainfall during the summer, but there is also a need for days without rain for silage or hay making (OECD 2011). According to the national GHG inventory report, "the common use of outdoor pastoral grazing systems means New Zealand's agricultural production is more sensitive to climatic events than countries that use intensive grain-fed systems and indoor feedlots" (MfE 2021b, p. 167). The area of irrigated agricultural land has namely almost doubled in the last two decades (section 1.2). Adaptation therefore needs to include efficient water management, increased shelter, and shade in animal farming or "climate-fit" species and grass types. Some regions will, however, experience improved growing conditions for crops as temperatures changes (OECD 2011).

As the Agriculture, Forestry and Other Land Use (AFOLU) sector plays a significant role in the Māori economy, Māori would be especially impacted by reduced productivity and earnings through climate change (MfE 2020). However, Māori and other farmers might not be well prepared for future environmental regulations or climate change impacts on agricultural productivity. A report by the Ministry for Primary Industries (MPI 2019) highlighted the financial vulnerability of the nationally important dairy sector: on-farm bank debt has increased significantly to about NZD 40 billion in 2019 compared to NZD 10 billion in 2003. The "highly

[11] StatsNZ Infoshare: Agricultural data, total grassland: https://infoshare.stats.govt.nz/infoshare/ViewTable.aspx?pxID=23788a7d-2d8b-4d86-8322-5a07258b9951.

indebted sector may constrain the ability of financially vulnerable farms to invest and adapt" (MPI 2019, p. 10) to future regulatory and environmental changes or to change to other less emitting agricultural practices.

New Zealand's National Adaptation Plan is still under development and planned for mid-2022.[12] The Zero Carbon Act (section 1.4) foresees a national climate change risk assessment at least every six years which will be carried out by the Climate Change Commission. The first risk assessment was done in 2020 (MfE 2020).

An analysis with focus on floods by OECD (2021a) shows that the management of risks is mainly the responsibility of individuals and communities because the agricultural sector receives only minimal support from the government (e.g. relief support in case of catastrophic events). Industry groups have therefore an important role in the disaster risk management of the sector. According to the study, the resilience of the sector could be improved – especially the role of the government.

[12] https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/adapting-to-climate-change/first-national-climate-change-risk-assessment-for-new-zealand/

2 Key areas with high mitigation potential

2.1 Introduction

In this chapter, 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 (chapter 1), and the general feasibility for implementation.

2.1.1 Selection of priority mitigation actions

As it can be seen in Figure 4, the two largest sources of emissions are emissions from enteric fermentation and agricultural soils (especially manure left on pasture), both interlinked through New Zealand's dairy industry. Another relevant source of emissions is land use and land use change (Figure 6), also linked to the expansion of pastures for cattle farming by drainage of peatland for farming area and the conversion from forest into grassland. Wetlands have become a net emission source for New Zealand (section 1.3). Livestock farming is by far the largest source of methane emissions in New Zealand. The government has also set clear targets to reduce methane emissions (section 1.4). Regarding mitigation measures for livestock, there is little potential for emission reductions from improving livestock emission intensity from cattle beyond reducing herd sizes and stocking rates. The productivity of New Zealand's pasture-based cattle farming system is already quite high leaving little room for improvement (section 1.1). Other measures to address methane emission, such as on-farm operational and efficiency improvements or the use of feed additives,[13] were not considered in this report. We did not consider feed additives as a mitigation measure to reduce emissions from enteric fermentation (methane) due to the uncertainty of animal health impacts and other potential negative environmental impacts associated with feed additives (Nabuurs et al. 2022). Nitrogen surplus on agricultural land has increased due to livestock farming.[14] For the time being, the reduction of synthetic nitrogen application is thus the only option to reduce emissions from livestock – besides measures to reduce livestock numbers and consumption of animal products.

For New Zealand, we therefore selected the following measures:

- Reduced nitrogen fertilisation on pastures,
- Rewetting of organic soils,
- Silvopastoralism.

Emissions from the livestock sector can be addressed by reducing the amount of applied synthetic fertiliser on agricultural soils. The government has already adopted a cap on synthetic nitrogen fertiliser application (section 1.4). Agricultural use of drained peatlands leads to high CO_2 emissions from soils. Emissions can be further reduced by rewetting the drained organic soils. The role of wetlands for climate change mitigation and adaption is also acknowledged by New Zealand's government and the Climate Change Commissions (New Zealand Government 2022, CCC NZ 2021b). However, rewetted areas are in most cases not compatible with the current agricultural use and lead to a decrease in farmland area available for intensive dairy production (which can act as a barrier to implementation). Finally, the combination of trees and

[13] https://www.agmatters.nz/goals/reduce-methane-emissions/

[14] https://www.ceicdata.com/en/new-zealand/environmental-non-energy-material-productivity-oecd-member-annual/nz-nitrogen-balance-per-hectare

livestock on pastureland (e.g., silvopastoralism) can increase the carbon stock of the land while still allowing for agricultural practices. The report of the Climate Change Commission also mentions the planting of trees on agricultural land to create "diverse silvopastoral landscapes" and to reduce emissions (CCC NZ 2021b, p. 322).

2.1.2 Overall mitigation potential

The three selected measures are described in further detail below. The mitigation potentials from our quantifications[15] and those available in the literature for these measures vary. The three measures encompass options for on-farm GHG mitigation which can be delivered through multiple different measures that contribute smaller amounts of GHG emission reductions. However, their comparatively low mitigation potential shows that a broader set of mitigation measures is required in order to reach the target indicated for the relevant sectors in the national emissions reduction plan (New Zealand Government 2022), particularly including demand side measures that reduce (not only domestic) consumption of animal products and can thus lead to a reduction in animal numbers, as well as increasing of carbon sinks. The following summarises the overall mitigation potentials in the agricultural sector available from the measures for the scope of this paper.

Reducing synthetic nitrogen fertiliser application to agricultural soils can reduce emissions. Quantifications of the national nitrogen fertiliser cap show that emissions can be reduced by approx. 72 and 150 ktCO_2e in 2030 and 2035 respectively. However, this comprises a very low mitigation potential in relation to total emissions of the agricultural sector (0.4%). Studies modelling on-farm emissions (for example, NZAGRC (2017), AgFirst (2019)) show a varying potential for GHG emission reductions from fertiliser reduction whereby high reductions are achieved if fertilizer use is almost eliminated and stocking numbers significantly reduced at the same time.

A rewetting of 50% of organic soils from grass- and cropland can lead to an emissions reduction of 868 ktCO_2e annually. As rewetting will likely be accompanied by a change of agricultural practices or a reduction of stocking numbers, further emission reductions are linked to this measure. NZAGRC (2017) model reductions of cattle herd sizes while also improving productivity and conclude that absolute emission reductions of 3-9% for a 5-15% reduction in stocking rate are possible. This highlights that reducing herd sizes (stocking rates) is an effective measure to reduce absolute emissions in New Zealand, which already has a high livestock productivity. Changes made to the pasture-based livestock systems in New Zealand have already led to substantial improvements in livestock emission intensity over the last three decades and additional potential is marginal (section 1.1).

According to our calculations, if 10% of New Zealand's current grassland area were converted to silvopastoral systems, specifically planting shrubland vegetation (mānuka and/or kānuka) on grassland over the next two decades, it could result in a maximum additional carbon sequestration of 2.5 MtCO_2e/year by 2040. However, there are some risks to sequestration mitigation options that should be considered (see box under 2.2.3 on Natural carbon sequestration: Risks and uncertainties). For comparison, a study by NZAGRC (2018) examined the effects of planting individual trees on small non-productive patches of land on dairy farms and implementing small-scale plantings on sheep and beef farms without significantly affecting farm productivity. The results show that total agricultural GHG emissions can be reduced by

[15] See section 2.2.3. 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.

3.5% (1.3 MtCO_2e) and 3.3% respectively (1.2 MtCO_2e) in 2030 compared to a business-as-usual scenario that reduces emissions by carbon sequestration.

In 2030, under a business-as-usual scenario, livestock emissions are expected to account for half of the 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 the need to rely on negative emissions technologies (Harwatt, 2019). This is particularly relevant for developed countries like New Zealand, which has a high dairy product consumption and is among the top ten meat-eating nations in the OECD (VegansocietyNZ 2020). Furthermore, demand-side mitigation options are of high importance for New Zealand which has a limited potential to further improve livestock productivity and linked emission intensity.

2.2 Prioritised mitigation options

2.2.1 Reduced nitrogen fertilisation on pastures

Measure

While the use of synthetic nitrogen fertiliser has played and continues to play an important role in supplying food for the world's population, its overuse has negative effects on soils, water and air pollution by N_2O, ammonia and NO emissions. Globally, about 50% of applied nitrogen is not absorbed by crops (WRI 2019). Measures to reduce fertiliser use include precision application of fertilisers depending on productivity of fields, and controlled-release fertiliser systems (WRI 2019). Particularly, it is important to ensure that the fertiliser is applied at the right time, in the right location and in the right amount to avoid that nitrogen is lost (Robertson and Vitousek 2009, New Zealand Government 2022). This mitigation option reduces N_2O emissions associated with the overuse of synthetic fertilisers and costs.

Status

The application of synthetic nitrogen fertiliser to New Zealand soils has increased by over 600% since 1991 (Stats NZ 2021c, MfE 2022b), dairy farming is the major source of applied synthetic fertiliser. The fertiliser is used to increase the growth of the pasture which the year-round outdoor pastoral grazing systems of New Zealand depend upon (MfE 2022b). Therefore, the share of these emissions in the agricultural sector has increased from 4% in 1990 to 18.4% in 2019 (MfE 2021b). Previous efforts to manage nitrogen losses (incl. fencing streams or timing irrigation and effluent to minimise run-off) were not able to counterbalance the increased nitrogen losses through land conversion to farmland and more intense land use between 1995 and 2015 and the associated negative impacts on ecosystems (MfE, Stats NZ 2021, 2019).

Against this background, reducing the use of synthetic fertiliser as a result of more precise and more deliberate timing of application is included in a list of measures in the national plan to reduce GHG emissions (New Zealand Government 2022). The Climate Change Commission also recommends a reduction in synthetic nitrogen fertiliser use, together with adjusting supplementary feed use and reduced stocking rates (see above), to decrease on-farm emissions (CCC NZ 2021a). Additionally, the government has a set a cap of 190 kg of nitrogen per hectare per year on synthetic nitrogen fertiliser application on pasture land.[16] Farmers have partially already started to reduce nitrogen fertiliser use by better management practices (New Zealand Government 2022, MfE 2022a).

Potential

The Biennial report of New Zealand (MfE 2022c) provides an indication of the impact of reducing synthetic fertiliser application. The report quantifies the impact of the national synthetic nitrogen fertiliser cap (see above). According to the report, emissions could be reduced by approx. 72 and 150 ktCO_2e in 2030 and 2035 respectively. Compared to synthetic fertiliser emissions of 1,548.2 kt CO_2e in 2020 (MfE 2022b), the impact of the fertiliser cap represents a reduction of about 10% of the 2020 emissions.

NZAGRC (2017) modelled a scenario on farm-level where no synthetic nitrogen fertilisation takes place, stocking numbers are maintained and production is reduced. The study shows that GHG emissions can be reduced by between 6% and 14% compared to the baseline farm practices depending on the region. Emission reductions stem mostly from the reduced production but also from decreases in N_2O emissions from synthetic fertiliser application.

Further, two other studies examined fertiliser reductions while simultaneously reducing stocking numbers which resulted in a larger range of potential emissions reduction. AgFirst (2019) modelled the elimination of synthetic fertiliser in different farming systems, but assumed a reduction in stocking numbers (-12 to -24%) and that the production per cow is maintained. The results showed GHG emission reductions between 10% and 31% depending on the farming region in New Zealand. MPI (2022) modelled on a national scale the impact of different policy options on GHG emissions from dairy farming and the related uptake of different mitigation measures, including reducing fertiliser use, which have been partially assessed in previous studies. Fertiliser reductions of 25%, 50%, 75% and 100% were assumed with simultaneous reductions in stocking rates to match feed supply and demand. Depending on the dairy farming system (varying farming intensity categories based on Djanibekov et al. (2018)), N_2O emission reductions per hectare could be reduced by 9-9.8%, 16.7-19.5%, 24-28.2% and 31.7-40.6% compared to a baseline of 2.5-3.3 tCO_2/hectare. However, it is unlikely that synthetic fertiliser application would be halted completely across the whole country within a short time-frame. For individual farms, avoiding synthetic fertiliser application could be a step towards organic farming.

Co-benefits

Reducing nitrogen surplus has various positive co-benefits for ecosystems and biodiversity.[17] Fertiliser use can negatively affect water quality through nutrient enrichment (eutrophication) resulting in excessive growth of macrophytes and algae which can diminish dissolved oxygen levels. Resulting ammonia emissions also contribute to the acidification of soils (UK Government 2022, 134ff). Reducing fertiliser use can therefore contribute to soil health and protecting biodiversity by avoiding changes in soil pH, and toxicity of soils (Bobbink et al. 2010). Additionally, negative water effects like freshwater acidification and

[16] https://environment.govt.nz/acts-and-regulations/freshwater-implementation-guidance/agriculture-and-horticulture/synthetic-nitrogen-fertiliser-cap-in-place-from-1-july/.

[17] According to a recent report under the Geneva Air Convention of the United Nations Economic Commission for Europe (CCE), a number of ecosystem types are more sensitive to nitrogen surplus than suggested by previously assumed values for critical loads for harmful nitrogen inputs (Aazem et al. 2022).

groundwater contamination can be mitigated if fertiliser use is reduced (Vries et al. 2013). Moreover, saving costs for fertiliser provides socio-economic benefits to farmers. The national nitrogen cap (see above/section 1.4) has also been implemented to limit the impact on freshwater ecosystems. Potential reduction in nitrogen losses through reduced fertiliser application can help New Zealand farmers to comply with regional water quality regulations (NZAGRC 2018). Farmers could also reduce their use of fertiliser to improve their market branding in relation to more environmental-friendly livestock production or transition to organic farming (ibid).

Barriers

Technical barriers: Soil and climate conditions imply uncertainty and heterogeneity for required levels of nitrogen and leaching effects (OECD 2021c).

Economical barriers: New Zealand's dairy sector is dependent on qualitative pasture for grazing (sections 1.1, 1.6). Fewer fertiliser inputs can reduce the on-farm productivity and might thus lead to income losses or increased costs for farmers (NZAGRC 2018). Studies have shown that the impact of such a measure would vary across New Zealand's farms (CCC NZ 2021a). To avoid a loss of income from yield decreases, farmers may tend to over-apply fertiliser as a protective measure. Furthermore, the costs of preparing and updating a nutrient management plan might be an economic barrier for farmers to take action to improve their fertiliser use (SRUC 2020, p. 18).

2.2.2 Rewetting of organic soils

Measure

Peatlands, a form of wetlands, store large amounts of carbon (NWT 2021). Peatlands are freshwater wetlands whose vegetation produces peat (ibid). Peat is a soil rich in organic carbon which builds up over thousands of years. Degraded peatlands are a significant source of GHG emissions globally (Leifeld and Menichetti 2018). Restoring and protecting these organic soils can thus help to mitigate emissions. Previously drained peatland can be rewetted by restoring the waterlogged conditions required for peat formation. Carbon losses and emissions from degraded wetlands can be halted and potentially reversed by adopting carbon-smart wetland management, alternative wetland crop farming practices on drained former peatlands and by restoring these lands (NWT 2021). According to Intergovernmental Panel on Climate Change (IPCC) (2014), rewetting cropland and grassland on drained peat soils in temperate climates has a high GHG reduction potential. The International Union for Conservation of Nature (IUCN) also recommends that "countries should include peatland conservation and restoration in their commitments to international agreements, including the Paris Agreement on climate change".[18]

Status

The majority of New Zealand's wetlands has been lost (90%) since European arrival 150 years ago (Landcare Research Manaaki Whenua 2008). Although there are protection requirements under national law for the remaining wetlands in New Zealand (New Zealand Government 2022, NWT 2020), wetlands continue to be drained (also illegally) - especially for conversion to agricultural usage, mainly to pasture for grazing (NWT 2020). Especially in drained peatlands, carbon stocks are lost (CCC NZ 2021b).

[18] https://www.iucn.org/resources/issues-brief/peatlands-and-climate-change.

According to a study carried out by Ausseil et al. (2015), the conversion of 146,000 hectares of organic soils for agriculture since European settlement currently leads to 0.5 to 2 $MtCO_2e$ per year equivalent to 1-6% of national agricultural GHG emissions. New Zealand's Ministry for the Environment reported a similar number in its emissions reduction plan (New Zealand Government 2022): drained organic soils (excl. mineral wetlands) emit 1.9 $MtCO_2e$ a year based on national inventory data. Given the relatively small share of organic soils in total agricultural area, emissions from drained peatlands are quite high. According to national inventory data, organic soils under grassland represent only 1.2% of total grassland area and organic soils under croplands represent only 2.2% of total cropland area in New Zealand (MfE 2022b).

The New Zealand government acknowledges the role of wetlands and their role for climate change mitigation and adaptation (New Zealand Government 2022). The National Institute of Water and Atmospheric Research (NIWA) also created a guidance on restoring wetlands together with a major dairy industry stakeholder DairyNZ.[19] New Zealand has favourable conditions for carbon sequestration via wetlands due to its low altitudes and moderate climate (Goodrich et al. 2017, Campbell et al. 2014). The national climate change commission recommends that a) a further loss of carbon from organic soils, particularly due to the degradation of drained peatlands and the destruction of wetlands, is prevented, and b) that restoring drained peat soils and wetlands (including on farms) could potentially make a modest contribution to reducing emissions (CCC NZ 2021b, 2021c).

Potential

Mitigation potentials for rewetting of organic soils for New Zealand can be quantified based on the data from the national GHG inventory. Based on the assumption that 50% of organic soils from crop- and grassland (this equals almost 5,000 ha cropland and 84,000 ha grassland) are rewetted, a yearly emission reduction of 868 $ktCO_2$ could be achieved. This calculation is based on an emission factor for grassland on organic soils of 8.2 tCO_2/ha and for cropland on organic soils of 36.5 t CO_2/ha. It is assumed that emissions can be reduced completely by rewetting these areas.

Rewetted areas are in most cases not compatible with the current agricultural use: as the majority of emissions from organic soils stems from highly productive soils used for agriculture, rewetting measures will need to be accompanied by a reduction of stocking rates or by a change of agricultural practices in these rewetted areas. The latter can in turn reduce emissions. Different national studies have shown that reducing stocking numbers can reduce emissions to a varying extent (depending on assumptions of productivity levels, herd size reduction and farm system) (NZAGRC 2017, MPI 2022, Djanibekov et al. 2018). Further, New Zealand's fifth biennial report under the UNFCCC projects that livestock numbers will decline in the future and the dairy industry[20] itself suggests to better match stocking numbers with the pasture production (MfE 2022c)).

Co-benefits

Rewetting drained peatlands can restore ecosystem services and functions. Wetlands are an important habitat for native plant and animal species in New Zealand (New Zealand Government 2022). Beyond carbon sequestration,

[19] https://niwa.co.nz/freshwater/management-tools/restoration-tools/constructed-wetland-guidelines.

[20] https://www.dairynz.co.nz/media/5795018/facts_and_figures_dnz30-001_updated_dec_2021_v6.pdf.

restoring wetlands can improve water quality, increase biodiversity and provide flood and drought protection (ibid). Wetlands are thus important for climate change adaptation (CCC NZ 2021b). The potential benefits for water quality are particularly interesting for New Zealand as wetlands could reduce nitrate and contaminant concentrations (section 1.2). Wetlands are also of cultural, spiritual, historic and economic importance for Māori (Manaaki Whenua – Landcare Research and Waikato Raupatu River Trust 2017). Studies explored the potential of the plant *Typha orientalis* (Raupō) for paludiculture in New Zealand. Rewetting peatlands can provide farmers with an alternative income to traditional farming practices, e.g. paludiculture (NWT 2021).

Barriers

Economic barriers: Reducing stocking rates and agricultural activity as a result of rewetting organic soils, agricultural profits are likely to decrease on restored wetlands. This may disincentivise the implementation of restoration activities. The increasing debt of New Zealand farmers and the dairy sector specifically hamper the transition to other farming practices or the implementation of any measure that impacts profitability of a farm (section 1.6).

Policy/legal barriers: Wetland drainage rules from regional council and authorities vary between regions in New Zealand and so does the level of compliance and enforcement (NWT 2021). This complicates the effective implementation of the measure.

Technical barriers: There are knowledge gaps regarding this measure which need to be filled. Accurate estimates of carbon stocks in existing and former wetlands are needed to improve the assessment of the mitigation potential of New Zealand's wetlands (NWT 2021). There are initial estimates for existing wetlands (Ausseil et al. 2015), but sample sizes are small and some wetland types under-represented (ibid). There is also a lack of GHG emission estimates from drained peatlands and carbon sequestration in healthy (and restored) wetlands (ibid). There are also knowledge gaps regarding emission scenarios/projections for different types of wetlands. This is because different types can store carbon to a varying extent and interact differently with the atmosphere which thus influences their emissions and associated mitigation potentials (Ausseil et al. 2015, Mitsch and Mander 2018).

2.2.3 Silvopastoralism

Measure

Agricultural soils are an important carbon stock. Changing agricultural practices, like switching to silvopastoralism, can increase the soil organic carbon stock (Paustian et al. 2016, Garrett et al. 2017). Adding trees to agricultural land, like pasture land, is considered a significant part of a basket of measures to reduce emissions in projections for the agricultural sector in New Zealand (ICCC 2019, p. 40). Although very little is known about the type of vegetation which is already present on New Zealand farmland (University of Technology Auckland 2020), there is potential in building on the existing vegetation and expand it to increase the carbon stocks of agricultural land. For example, the University of Technology Auckland (2020) found that woody vegetation (forests and shrubs) covers approx. 20% of the land used for sheep and beef farming.

Status

Before any human settlement, New Zealand was forested by about 80% (Easton 2010). New Zealand got largely deforested through early Māori and European

Settlement as well as agricultural expansion. Today, almost 40% of the land is used as farmland (section 1.1). Most of New Zealand's agricultural land (by area) is grazing land of which many locations are steep or hilly (OECD 2011).[21] These locations do not lend themselves well to horticulture, but are suitable for grazing and planting trees or other vegetation. The report of the Climate Change Commission states that land which is less suitable for livestock (like gullies) could be used for planting trees or other vegetation to create "diverse silvopastoral landscapes" and to reduce emissions (CCC NZ 2021b, p. 322). There are also several national programmes that promote tree planting (section 1.4)

Potential

According to our calculations, if an additional 10% of New Zealand's current grassland area were converted to silvopastoral systems, specifically planting shrubland vegetation (mānuka and/or kānuka) on grassland over the next two decades, it could sequester an additional 2.5 $MtCO_2e$/year annually by 2040. This estimate assumes a 1.4 Mha increase in grassland with woody biomass[22] with an additional carbon sequestration potential of 1.72 tCO_2e/ha/year (MfE 2021b). Mānuka and kānuka are both shrubs from the myrtle family and native and endemic respectively to New Zealand. Mānuka is known for its honey made from its nectar.

NZAGRC (2018) examined planting individual trees on small non-productive patches of land on dairy farms and implementing small-scale plantings on sheep and beef farms without significantly affecting farm productivity. The results show that total agricultural GHG emissions can be reduced by 3.5% (1.3 $MtCO_2e$) and 3.3% (1.2 $MtCO_2e$[23]) respectively in 2030 (=compared to a business-as-usual scenario that reduces emissions by carbon sequestration).

Co-benefits

Silvopastoralism increases the carbon stored in the soil which can have several positive environmental impacts, such as increasing biodiversity, improving water quality and increasing the resilience of soils regarding climate change (Paustian et al. 2016, UNFCCC 2019). Although challenging, this mitigation option might benefit from the fact that including emissions sinks on farms is discussed in the proposed ETS for the agricultural sector in New Zealand (section 1.4). Although many farms have smaller patches of trees and vegetation, these areas are currently too small to be accounted for as a sink in the existing New Zealand ETS (ICCC 2019). Especially, the farmers and the industry have demanded that trees and vegetation on farms should be accounted for as one system with sources and sinks (ibid) in any future carbon pricing for the agricultural sector. Introducing trees on pastureland can improve animal welfare and productivity. This mitigation option can also contribute to maintain moisture and nutrients levels in the soil, improving grass quality as the main feed of New Zealand cattle and sheep. Additionally, there is a diversification of products (products from trees & livestock). Income can be generated in the long term through the trees and in the short term with livestock. This diversification can also contribute to the financial resilience of farmers (NZAGRC 2018).

[21] https://www.landcareresearch.co.nz/news/making-un-poplar-decisions-a-framework-for-better-tree-choices-in-our-hill-country/.

[22] The national inventory provides a sequestration rate for "grassland with woody biomass," which consists of "areas of shrubland or scrub less than 5 m tall, as well as sparse, taller woody vegetation, such as found in riparian plantings, shelterbelts, sparse trees within grasslands, and above-treeline shrubland" and consists of 30% or less tree cover.

[23] Based on approx. 37,500 kt of GHG emissions in 2030 in the baseline (NZAGRC 2018, p. 12).

Barriers	**Biophysical/environmental barriers:** In case of switching to other land-uses agricultural land and fresh/groundwater pollution in New Zealand might constrain the (organic farming) production of plants (e.g. oats) as these might not be safe for consumption due to alleviated pollution levels. **Economic barriers:** Transaction costs for farmers to switch to other agricultural/land-use practices might be high and financial benefits might only materialise in the long term. The increasing debt of New Zealand farmers and the dairy sector specifically hamper the transition to other farming practices (section 1.6).

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-permanence 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 chapter, we examine the main barriers identified for the country in the context of the prioritised mitigation options (chapter 2) and discuss some potential actions to overcome them. We hereby build 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 chapter 1 of this report. The analysis of barriers below follows the clustering proposed in Siemons et al. (2023), according to the relevant governance level for taking action, while taking into account the classification from the IPCC Special Report on Climate Change and Land (IPCC 2019) within each of the governance levels.

3.1 Farm level

New Zealand has a long tradition of livestock farming and the agricultural sector is very important for the economy (sections 1.1 and 1.2). Therefore, changing farming practices to reduce GHG emissions face socio-cultural barriers as farmers are hesitant to give up or reduce traditional sheep or cattle farming. According to the Climate Change Commission and the national GHG emission reduction plan (New Zealand Government, MfE, MPI 2022, CCC NZ 2022), there is still a need to increase the awareness of New Zealand farmers of their on-farm emissions and of what options are available to reduce them. Capacity-building is needed to reach the mainly small-sized 50,000 New Zealand farms (section 1.2) and disseminate information on the benefits of changing agricultural practices.

Additionally, investments or high transaction costs for mitigation options in chapter 2 create an economic barrier for farmers who are already largely in debt (section 1.6) and unsure about the associated potential benefits and the return of investment. This is reinforced by the low levels of public agricultural support available to farmers in New Zealand (section 1.4). There might even be a form of lock-in for farmers into high-emission farming, like cattle farming, due to the debt and transaction costs. The upcoming levy to price agricultural emissions is an economic incentive for farmers to change their practices. The proposal additionally foresees several ways of 'assistance' for farmers in the transition of the sector which include incentive payments for the uptake of certain mitigation options (New Zealand Government, MfE, MPI 2022). It has not yet been determined, however, which mitigation measures will be eligible. One aspect to be considered will be the estimated emission reduction of the measure (New Zealand Government, MfE, MPI 2022). The reduction of synthetic nitrogen fertiliser can significantly decrease on-farm emissions (depending on the extend of the reduction) and might thus be eligible for these incentives payments which could reduce the economic barrier faced by this mitigation measure.

3.2 National level

Wetland drainage rules from regional council and authorities vary between regions in New Zealand and so does the level of compliance and enforcement (NWT 2021). Improved integration between councils regarding promotion and enforcement of the rules could provide a better policy framework for this measure (ibid).

Changing the land use on farms by including more vegetation (like silvopastoralism) can lead to additional cost for livestock farmers. The New Zealand government already implemented several national programmes that promote tree planting (section 1.4) and these could be improved or expanded to particularly target vegetation on farms. Further, not all carbon removals by small scale planting, for example from silvopastoral systems, are currently recognised in international and/or domestic accounting (CCC NZ 2021c). There is work underway by the government and industry to assess the potential to measure and account for carbon sequestration of on-farm vegetation (ibid) – which could then be used to provide incentives. The current proposal for the national levy on agricultural emissions actually foresees that farmers would be paid for on-farm carbon sequestration through vegetation from revenues collected through the levy (New Zealand Government, MfE, MPI 2022). This is planned as an interim measure until on-farm carbon sequestration is properly accounted for in inventories and until a sequestration strategy is developed jointly by the government and the industry (ibid).

There might be resistance towards change in the agricultural sector as it is an important part of the economy, and also identity, of New Zealand, which is famously known as having more sheep than inhabitants. For example, Fonterra is a New Zealand cooperative owned by more than 10,000 farmer shareholders and a lead in global dairy exports (section 1.2). The government already engaged the industry proactively in the discussions around a carbon pricing policy in the agricultural sector through the private-public partnership "He Waka Eke Noa," which also encompasses Māori as they have significant role in agriculture and are also particularly vulnerable to climate change impacts on agriculture (section 1.4). The recommendations from this private-public partnership (He Waka Eke Noa 2022) include, however, GHG emission prices far too low compared to carbon prices in the European ETS and considering environmental costs of about 200€$_{2021}$ per tonne of CO_2.[24] A challenge will thus also be to steer the engagement with the industry into a direction with fast and meaningful emission reduction from the agricultural sector.

CAT (2022) find that there are additionally problems with the accounting methodologies used by New Zealand. The Government's "accounting approach overestimates land use sequestration in 2030 compared to the United Nations Framework Convention on Climate Change (UNFCCC) LULUCF, [and] results in allowing higher actual net emissions in 2030" (CAT 2022). Instead of using the accounting approach of the GHG inventory under the UNFCCC, which records emissions and removals as they occur, New Zealand uses a different method for its national ETS and NDC. It is a "modified activity-based" approach which averages out removals and emissions from plantation forests by disregarding CO_2 removals that will become CO_2 emissions when the forest is harvested (CAT 2022). The Lawyers for Climate Change Action New Zealand (LCANZI 2021) argue that this defies the Climate Change Response (Zero Carbon) Amendment Act (section 1.4) which is based on UNFCCC accounting practices. The organisation has actually taken the Climate Change Commission to court over its methodological approach (in its advice regarding the NDC) (ibid). The 2030 NDC target is thus less ambitious with the current method. Furthermore, this could act as a barrier to incentivising and implementing more ambitious agricultural and land-use policies.

3.3 International level

New Zealand's agricultural sector, especially the dairy sector, is very export-oriented (section 1.1). Consequently, New Zealand has signed several trade agreements which facilitate the export of products from New Zealand. Additionally, the largest company in New Zealand is Fonterra, which accounts for almost a third of global dairy exports (section 1.1). Fonterra, and other agri-product exporters, are thus global players which have global influence and drive the food industry in New Zealand and beyond. The export dependency of the agricultural sector makes farmers in New Zealand vulnerable to disadvantages resulting from national environmental regulations in the global competition. For example, the global competition New Zealand farmers face might put additional pressure on the economic barriers identified (like transaction costs,

[24] https://www.umweltbundesamt.de/daten/umwelt-wirtschaft/gesellschaftliche-kosten-von-umweltbelastungen#gesamtwirtschaftliche-bedeutung-der-umweltkosten.

loss of income). As mentioned under 3.1, funding and assistance to farmers during the transition can help to alleviate this pressure.

3.4 Consumer level

The dairy and sheep industry are very important not only to New Zealand's economy but also to the identity of New Zealand's farmers and the population. The food culture centres around products from these industries. For example, New Zealand has one of the highest per capita consumption of fresh milk in the world.[25] As in other countries of the Global North, a shift to plant-based diets is perceived as disruptive. Demand-side measures for consumers to balance out price fluctuations might be needed if agricultural exports decrease due to a reduction of stocking rates/productivity through the presented measures.

[25] https://www.statista.com/statistics/1099604/new-zealand-milk-consumption/.

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. New Zealand 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 New Zealand's agriculture and forestry, which are increasingly threatened by extreme events and a continuous gradual change in climatic conditions. This study identified and quantified three mitigation actions in New Zealand's agricultural sector that would provide environmental and economic co-benefits: reducing synthetic nitrogen fertiliser use, rewetting organic soils, implementing silvopastoralism.

To maximise emission reductions in the agriculture sector, New Zealand would need to take a multi-faceted approach. Reducing synthetic nitrogen fertiliser application to agricultural soils can reduce emissions, which can also result in lower stocking numbers as the pasture land can provide grass/food for fewer animals. Quantifications of the national nitrogen fertiliser cap show that emissions can be reduced by approx. 72 and 150 $ktCO_2e$ in 2030 and 2035 respectively. Based on the assumption that 50% of organic soils from crop- and grassland (this equals almost 5,000 ha cropland and 84,000 ha grassland) are rewetted, yearly emission reductions of 868 $ktCO_2$ could be achieved. If an additional 10% of New Zealand's current grassland area were converted to silvopastoral systems, specifically planting shrubland vegetation (mānuka and/or kānuka) on grassland over the next two decades, this could result in a maximum additional carbon sequestration of 2.5 $MtCO_2e$/year by 2040. However, there are some risks to sequestration, namely uncertainties around the mitigation potential and its permanence/reversibility.

Regarding the mitigation options considered in this study, there are mostly technical and economic barriers hindering the implementation of the measures or limiting their impact. On several levels, economic barriers hinder emission reductions in the agricultural sector more generally. Farmers face high transactions cost when switching agricultural practices. The strong position of the dairy sector in the national economy, and in exports specifically, make interventions difficult.

The emission reductions of the measures analysed in this study represent only a limited potential compared to the total annual GHG emissions of the sector. This highlights the need for other mitigation measures in the agricultural and land-use sector, such as reducing emissions from sheep, reducing stocking rates of cattle, increasing carbon sinks and exploring demand-side options.

To accelerate the uptake and implementation of the measures described in this report and further measures, some key recommendations can be derived:

1. *Implement thorough climate policies in the agricultural sector*

Any mitigation measure would become more attractive if New Zealand started to implement thorough climate policies in the agricultural and land-use sector and thereby acknowledge the significance of these sectors in terms of current and expected future emissions. The clear gap in New Zealand's policy landscape to address all GHG emissions from agriculture will partly be addressed by the proposed levy system (New Zealand Government, MfE, MPI 2022). The design and emission prices are still being debated at the time of writing this report. The government currently favours very low levy prices and a wide-ranging recognition of different kind of on-farm vegetation to count as carbon sequestration within the existing national ETS.[26] An ambitious and well-designed mechanism is needed to quickly reduce New Zealand's highest emitting sector though. For example, if the sector was instead included in the existing ETS, a cap would need to be introduced with no free allocation in the sector (CAT 2022).

The awareness and knowledge gap of farmers can be bridged via targeted policies or programmes which facilitate knowledge transfer. The planned carbon pricing in the agricultural sector in New Zealand can also address this by steering the farmers' choice to implementing these mitigation options. Furthermore, the New Zealand government could support farmers, especially in the dairy sector, to transition to other land-use practices with subsidies or finance schemes. As classical subsidies are almost non-existent in New Zealand's agricultural sector, current funds and tree planting schemes could be extended in this regard (section 1.4). An alternative to conventional subsidies could be targeted support and linking domestic credit lines to policies and best-practice (Siemons et al. 2023). As debts are common in the dairy sector, financial aid and credits for farmers to transition to other farming practices need to be tied to environmental requirements. To ensure that an increase in livestock productivity does not lead to an increase but rather a decrease in absolute livestock emissions (section 2.1), policies might be needed that regulate sectoral emissions (like the planned New Zealand carbon pricing in agriculture) and that better control land use clearing to prevent unchecked production expansion (FAO 2013).

2. Revise methodological approach of NDC and agricultural targets

New Zealand's climate targets and respective policies in its NDC are currently not sufficient to reach the goals of the Paris Agreement (CAT 2022). The country's net zero target needs to be improved as the transparency is poor and international transport is excluded (ibid). There is a separate target for biogenic methane of 24-47% reduction in 2050 (compared to 2017 levels). The national target is oriented at the IPCC report on achieving the 1.5°C temperature goal, which concludes that a reduction of methane emissions from agriculture by 24-47% in 2050 relative to 2010 is required in scenarios limiting the global average temperature to 1.5°C with or no limited overshoot (NZAGRC 2019). By setting a methane reduction target with a range, an overshoot or missing the temperature target becomes more likely if only the lower bound of emission reduction is achieved. A more ambitious methane target (up to 47%) without a range can reduce the uncertainty of the global average temperature development.

Additionally, the accounting methodologies used in New Zealand's GHG inventory and for its NDC are inconsistent, leading to a lower ambition in the country's NDC (see section 3.2). There is also the problem that New Zealand does not include the LULUCF sector in its baseline year (gross) but it does account for net emissions and removals of the sector for the target year (net) (CAT 2022). This so-called gross-net approach allows the country to have higher emissions in the baseline (as the LULUCF sector was a carbon sink). By allowing the sector to count for the target year, the sink of the LULUCF can then be used to compensate for higher emissions in other sectors. These methodological issues and climate targets need to be revised in New Zealand's NDC as the impact and relevance of the agricultural and LULUCF sector is currently not appropriately reflected.

3. Selected ideas for improvements and enabling a just transition

A holistic approach to the negative environmental impacts of the agricultural sector can reap many co-benefits. Climate mitigation options, such as reducing stocking rates, or changing agricultural practices, can also help to reduce the negative environmental impacts of nutrient

[26] https://www.rnz.co.nz/news/national/481197/government-makes-changes-to-farm-level-emissions-pricing-plan.

surpluses. These nutrient surpluses from fertiliser and livestock that lead to pollution of soil, water and air should receive more attention (OECD 2021b). The national synthetic nitrogen fertiliser cap is a first step towards reducing nitrogen surpluses, but could be designed in a more ambitious way. Appropriate regulations and policies need to be found which take into account the rising debt problem of farmers across the country. Special attention needs to be paid to Māori farmers when designing policies as they are especially dependent on agriculture and thus vulnerable to economic risks in the sector. The export dependency of the sector as well as the importance and influence of the dairy sector impede a fast and easy transition of the sector. New storylines that describe change in a positive way might help change the narrative around New Zealand's agriculture and farmer identities. Furthermore, peatlands could be better recognised and accounted for on a national level in New Zealand. The IUCN recommends that national targets for rewetting and restoration of peatlands must be set and that the protection of peatlands should be included in national adaption plans to meet commitments under the Paris Agreement.[27] New Zealand has no national restoration targets for peatlands yet. The Climate Change Commission noted that "carbon losses or gains from peatlands are not currently captured in target accounting" and recommended that methods to include these in the emission budgets should be developed (CCC NZ 2021b, p. 322).

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. 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. With the planetary health diet,[28] a dietary recommendation is available that can feed a growing world population while respecting planetary impact limits and being compatible with climate goals. 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).

[27] https://www.iucn.org/resources/issues-brief/peatlands-and-climate-change.

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

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