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Status, potential and challenges

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Abstract: Mitigating agricultural greenhouse gas emissions in Brazil

This report describes the current state of agriculture in Brazil 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 avoid emissions through deforestation, and estimate the mitigation potential of those options. Finally, we identify barriers to adopting these mitigation strategies and some possible solutions to overcoming those barriers.

Kurzbeschreibung: Länderbericht Brasilien

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

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List of abbreviations

ABC	Low-Carbon Agriculture [Plan]
AFOLU	Agriculture, Forestry and Other Land Use
ASM	Amazon Soy Moratorium
BAU	Business as usual
CH_4	Methane
CO_2	Carbon dioxide
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
$GtCO_2e$	Giga tonnes of CO_2 equivalents
IPCC	Intergovernmental Panel on Climate Change
LTS	Long-Term Strategy
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Measurement, reporting and verification
$MtCO_2e$	Mega tonnes of CO_2 equivalents
NDC	Nationally Determined Contributions (in Paris Agreement)
NUE	Nitrogen Use Efficiency
N_2O	Nitrous oxide
MAPA	Ministry of Agriculture, Livestock and Food Supply
OECD	Organisation for Economic Co-operation and Development
PNMC	National Policy on Climate Change
THG	Treibhausgas
UNFCCC	United Nations Framework Convention on Climate Change

Summary

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

Brazil is a major global agricultural producer and exporter due to its abundant land and water resources. The country accounts for 7.8% of current agricultural land, 13.5% of the world's potential arable land, and 15.2% of global renewable water resources (Arraes Pereira et al., 2012; OECD, 2021). Brazil is also the most biologically diverse country in the world, and is estimated to host between 15-20% of the world's species (CBD, 2022). Brazil is also home to the world's second largest area of forest, which constitutes around 12% of total global forest area (Ritchie and Roser, 2021). However, agricultural expansion, most notably for cattle ranching, has resulted in significant deforestation and corresponding GHG emissions (Butler, 2020). Agriculture plays a considerable role in Brazil's domestic and export economy. The agriculture sector contributed 4.4% to Brazil's gross domestic product (GDP) in 2019, compared to the global average of 3.5% (OECD, 2021).

The agricultural sector accounts for approximately 48% of total national emissions, which corresponds to 540 $MtCO_2e$ (excl. Land Use, Land-Use Change and Forestry (LULUCF)). The largest agricultural emissions sources are enteric fermentation (66%), manure left on pasture (17%), and synthetic fertilisers (5%). Emissions from Brazil's agricultural sector have considerably increased since 1990, primarily due to the 48% growth in animal numbers from 1990 to 2016, 80% of which was cattle for beef production (Government of Brazil, 2020).

The LULUCF sector is a significant emissions source in Brazil and comprises a considerable amount of Brazil's total emissions. The large emission removals from existing forestland are outweighed by the extent of emissions from forest converted into other land uses.

Agricultural expansion and cattle ranching are the most prominent historical drivers of deforestation in Brazil. Some decoupling of agricultural production and deforestation occurred due to internal market regulations, a cracking-down on illegal deforestation, imposed credit barriers, and the creation of more protected areas (Lapola et al., 2014). However, the success in reducing the deforestation rate in Brazil was reversed in recent years. Between August 2019 and July 2020, deforestation in the Amazon increased by 9.5%. In January 2022, Brazil recorded its highest-ever monthly levels of deforestation since its Deter-B satellite monitoring system started in 2015. This equated to 43,000 hectares, which was five times higher than deforestation levels in January 2021 (Spring, 2022).

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:

- The prevention of deforestation due to agricultural expansion
- The restoration of degraded pastures

- Improved nutrient management, to decrease the need for synthetic fertiliser.

These mitigation areas alone could lead to avoided emissions and emission reductions somewhere in the hundreds of megatons, and other areas, for example reductions of emissions from enteric fermentation, could have an additional impact. Of the areas considered here, the reduction of emissions from fertiliser use has the lowest impact on GHG emissions, nevertheless it comes with benefits for farmers and other important environmental benefits.

The overall climate change mitigation potential in the Brazilian agriculture sector is large, although exact data is difficult to obtain and aggregate in a meaningful way. Roe et al. (2021) estimate that Brazil has the largest potential of all countries for mitigation in the land sector of 1.7 ± 0.5 giga tonnes of CO_2 equivalents ($GtCO_2e$) /year, with about 1 Gt/year from restoring and protecting forests, and 0.5 $GtCO_2$/yr from sequestering carbon in agricultural soils. The Brazilian government's sectoral plan (ABC+) assumes a possible reduction of total emissions levels about 1 $GtCO_2e$ in 2030 compared to the year 2020 (MAPA, 2022), of which about half comes from planting forests.

There are critical barriers that hinder the implementation of measures to achieve the outlined mitigation potentials and impair other activities to reduce and avoid GHG emissions in the agricultural sector: The land areas affected are very large and monitoring environmental destruction, as well as the effects of mitigation measures, remains a challenge. International demand for agricultural products and the interests of agribusiness to maximise profits put a high level of pressure on the land area.

To accelerate the uptake and implementation of the measures described in this report, it is key to 1) more clearly translate national mitigation priorities to the agricultural sector, 2) in turn ensure that all agricultural policies are aligned with mitigation objectives and 3) implement sectoral policies to comprehensively address the areas where most mitigation is possible. These mitigation policies and incentives should also foster co-benefits between adaptation and mitigation in the agricultural sector. More specifically, the Brazilian government could foster mitigation through an improved monitoring of agricultural land and forests and governance structures to stop illegal forestation, support for research development and knowledge dissemination on crop intensification and improved nutrient management, and working together with industry and other governments on sustainable supply chains.

Zusammenfassung

Ziel dieses Berichts ist es, Optionen zur Emissionsminderung im Agrarsektor zu identifizieren, die Hindernisse bei der Umsetzung dieser Optionen aufzuzeigen und Empfehlungen zur Überwindung dieser Hindernisse zu geben. Der Bericht beginnt mit einer Beschreibung des aktuellen Stands der Landwirtschaft in Brasilien mit Blick auf die von ihr produzierten Treibhausgasemissionen und den klimapolitischen und sozioökonomischen Kontext. Anschließend werden drei wichtige Optionen zur Verringerung der landwirtschaftlichen Emissionen aufgezeigt und ihr Minderungspotenzial abgeschätzt. Schließlich werden Hindernisse auf betrieblicher, nationaler, internationaler und Verbraucherebene sowie mögliche Schritte zur Überwindung dieser Hindernisse aufgezeigt.

Brasilien ist aufgrund seiner reichhaltigen Land- und Wasserressourcen ein weltweit bedeutender Agrarproduzent und -exporteur. Auf das Land entfallen 7,8 % der derzeitigen landwirtschaftlichen Nutzfläche, 13,5 % der potenziellen Ackerfläche der Welt und 15,2 % der weltweiten erneuerbaren Wasserressourcen (Arraes Pereira et al., 2012; OECD, 2021). Brasilien ist auch das Land mit der größten biologischen Vielfalt der Welt und beherbergt schätzungsweise 15-20 % der weltweit vorkommenden Arten (CBD, 2022). Brasilien beherbergt auch die zweitgrößte Waldfläche der Welt, die etwa 12 % der gesamten globalen Waldfläche ausmacht (Ritchie and Roser, 2021). Die Ausdehnung der Landwirtschaft, vor allem der Viehzucht, hat jedoch zu einer erheblichen Entwaldung und entsprechenden Treibhausgasemissionen geführt (Butler, 2020). Die Landwirtschaft spielt eine wichtige Rolle in der brasilianischen Binnen- und Exportwirtschaft. Der Agrarsektor trug im Jahr 2019 zu 4,4 % des brasilianischen BIP bei, verglichen mit dem weltweiten Durchschnitt von 3,5 % (OECD, 2021).

Der Agrarsektor ist für etwa 48 % der gesamten nationalen Emissionen verantwortlich, was 540 $MtCO_2e$ entspricht (ohne LULUCF). Die größten landwirtschaftlichen Emissionsquellen sind die enterische Fermentation (66%), auf der Weide verbleibender Dung (17%) und synthetische Düngemittel (5%). Die Emissionen aus dem brasilianischen Agrarsektor haben seit 1990 erheblich zugenommen, was in erster Linie auf den Anstieg des Tierbestands von 1990 bis 2016 um 48 % zurückzuführen ist, wovon 80 % auf Rinder für die Rindfleischproduktion entfielen (Regierung Brasiliens, 2020).

Der LULUCF-Sektor ist eine bedeutende Emissionsquelle in Brasilien und macht einen beträchtlichen Anteil an den Gesamtemissionen des Landes aus. Die große Emissionssenke durch bestehende Waldflächen wird durch das Ausmaß der Emissionen aus Wäldern, die in andere Landnutzungen umgewandelt wurden, zunichte gemacht.

Die Ausweitung der Landwirtschaft und die Viehzucht sind die wichtigsten Ursachen für die Entwaldung in Brasilien. Durch interne Marktregulierungen, ein hartes Durchgreifen gegen illegale Entwaldung, auferlegte Bedingungen für Kredite und die Einrichtung weiterer Schutzgebiete konnte die landwirtschaftliche Produktion teilweise von der Entwaldung entkoppelt werden (Lapola et al., 2014). In den letzten Jahren hat sich dieser Erfolg in Brasilien jedoch umgekehrt. Zwischen August 2019 und Juli 2020 nahm die Entwaldung im Amazonasgebiet um 9,5 % zu. Im Januar 2022 verzeichnete Brasilien die höchste monatliche Entwaldungsrate seit Beginn des Satellitenüberwachungssystems Deter-B im Jahr 2015. Dies entsprach 43.000 Hektar und war damit fünfmal höher als die Entwaldung im Januar 2021 (Spring, 2022).

Auf der Grundlage des Beitrags der verschiedenen Emissionsquellen, des Potenzials für sozioökonomische und ökologische Zusatznutzen, des länderspezifischen Kontexts des

Agrarsektors und der allgemeinen Durchführbarkeit wurden drei Minderungsoptionen für eine detaillierte Analyse ermittelt:

- Verhinderung der Abholzung von Wäldern aufgrund der Ausweitung der Landwirtschaft
- Wiederherstellung von degradierten Weiden
- Verbesserte Nährstoffbewirtschaftung, um den Bedarf an synthetischem Dünger zu verringern.

Diese Maßnahmen allein könnten zu vermiedenen Emissionen und Emissionsreduktionen in der Größenordnung von Hunderten von Megatonnen führen, und andere Bereiche, z. B. die Verringerung der Emissionen aus der enterischen Fermentation, könnten zusätzlich Emissionen verringern. Von den hier betrachteten Optionen hat die Verringerung der Emissionen aus dem Düngemitteleinsatz die geringsten Auswirkungen auf die Treibhausgasemissionen, sie bringt jedoch finanzielle Vorteile für die Landwirte mit sich und verringert die Umweltverschmutzung.

Das gesamte Potenzial zur Minderung des Klimawandels im brasilianischen Landwirtschaftssektor ist groß, auch wenn es schwierig ist, genaue Daten zu erhalten und sinnvoll zu aggregieren. Roe et al. (2021) schätzen, dass Brasilien mit 1,7 ± 0,5 $GtCO_2e$/Jahr das größte Minderungspotenzial aller Länder im Landwirtschaftssektor hat, wobei etwa 1 $GtCO_2$/Jahr auf die Wiederaufforstung und den Schutz von Wäldern und 0,5 $GtCO_2$/Jahr auf die Kohlenstoffbindung in landwirtschaftlichen Böden entfallen. Der Sektorplan der brasilianischen Regierung (ABC+) geht von einer möglichen Verringerung des Emissionsniveaus von etwa 1 $GtCO_2e$ im Jahr 2030 gegenüber dem Jahr 2020 aus (MAPA, 2022), davon etwa die Hälfte durch die Aufforstung von Wäldern.

Es gibt kritische Barrieren, die die Umsetzung von Maßnahmen zur Erreichung der skizzierten Minderungspotenziale behindern und andere Aktivitäten zur Reduzierung von THG-Emissionen im Agrarsektor beeinträchtigen: Die betroffenen Landflächen sind sehr groß, und die Überwachung der Umweltzerstörung sowie der Auswirkungen von Minderungsmaßnahmen bleibt eine Herausforderung. Die internationale Nachfrage nach landwirtschaftlichen Produkten und das Interesse der Agrarindustrie an Gewinnmaximierung üben einen hohen Druck auf die Landflächen aus.

Um die Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, ist es entscheidend, 1) die nationalen Klimaschutzprioritäten klarer auf den Agrarsektor zu übertragen, 2) im Gegenzug sicherzustellen, dass alle agrarpolitischen Maßnahmen mit den Klimaschutzzielen in Einklang gebracht werden, und 3) sektorbezogene Maßnahmen zu ergreifen, um die Bereiche, in denen der größte Klimaschutz möglich ist, umfassend zu berücksichtigen. Diese Minderungsmaßnahmen und -anreize sollten auch Synergien zwischen Anpassung und Minderung im Agrarsektor fördern. Konkret könnte die brasilianische Regierung landwirtschaftlichen Flächen und Wäldern sowie durch Governance-Strukturen zur Unterbindung illegaler Aufforstung besser überwachen, Forschung fördern, Wissen über die Intensivierung von Nutzpflanzen verbreiten, das Nährstoffmanagement verbessern sowie die Zusammenarbeit mit der Industrie und anderen Regierungen bei nachhaltigen Lieferketten fördern, um den Klimaschutz voranzutreiben.

1 General characteristics of the agricultural sector and policy landscape

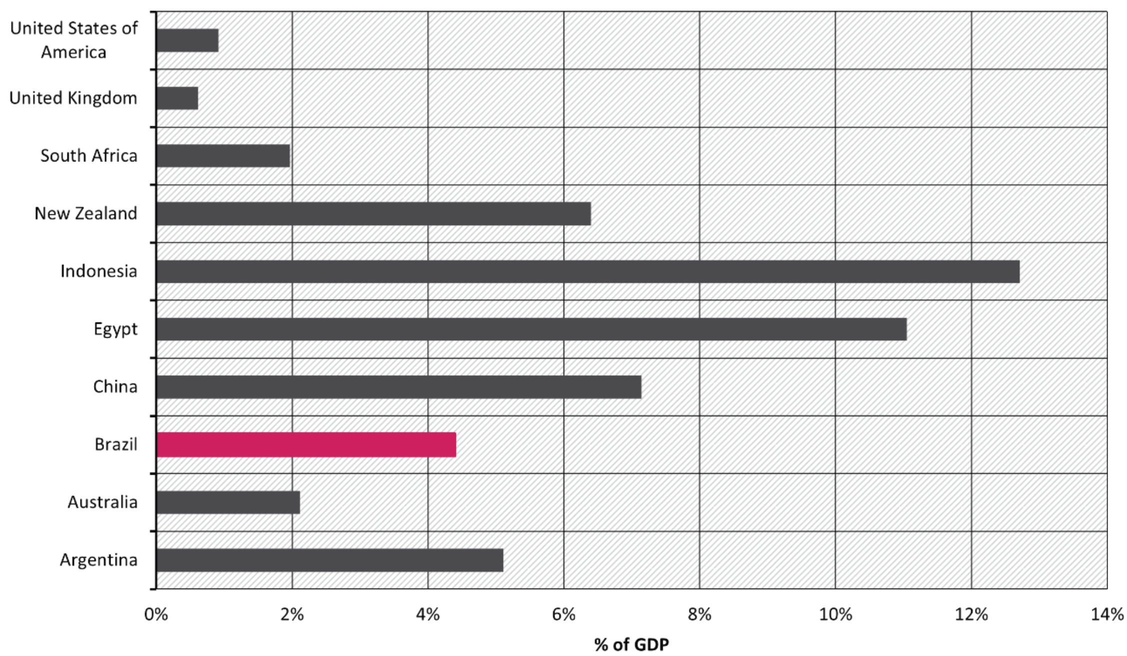
1.1 Characteristics of agriculture sector

Brazil is the largest country in Latin America and has the 6th largest population in the world. The country is a major global agricultural producer and exporter due to its abundant land and water resources. Brazil alone accounts for 7.8% of current agricultural land, 13.5% of the world's potential arable land, and 15.2% of global renewable water resources (Arraes Pereira et al., 2012; OECD, 2021). Brazil is also the most biologically diverse country in the world, and is estimated to host between 15-20% of the world's species (CBD, 2022).

Brazil is home to the world's second largest area of forest, which constitutes around 12% of total global forest area (Ritchie and Roser, 2021). However, agricultural expansion, most notably for cattle ranching, has resulted in significant deforestation and corresponding GHG emissions (Butler, 2020).

Agriculture plays a considerable role in Brazil's domestic and export economy. The agriculture sector contributed 4.4% to Brazil's GDP in 2019, compared to the global average of 3.5% (Figure 1; OECD, 2021).

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



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

Brazil is a world-leading beef producer, accounting for 17.3% of global agricultural exports and 14% of global beef output. The country hosts the world's second largest cattle herd, most of which are brought up on tropical pasture grazing systems rather than feedlots, with important implications in terms of land use and land use change (World Bank Group, 2021; Zilli et al., 2020).

Brazil also leads the world in soy cultivation, and produces roughly 30% of global soybean supply (Stabile et al., 2020). The growth of the beef and soybean sectors has come at the expense of forest and savanna ecosystems. Since 1985, over 65 million hectares of native ecosystems have been cleared for pastureland and cropland expansion (ibid).

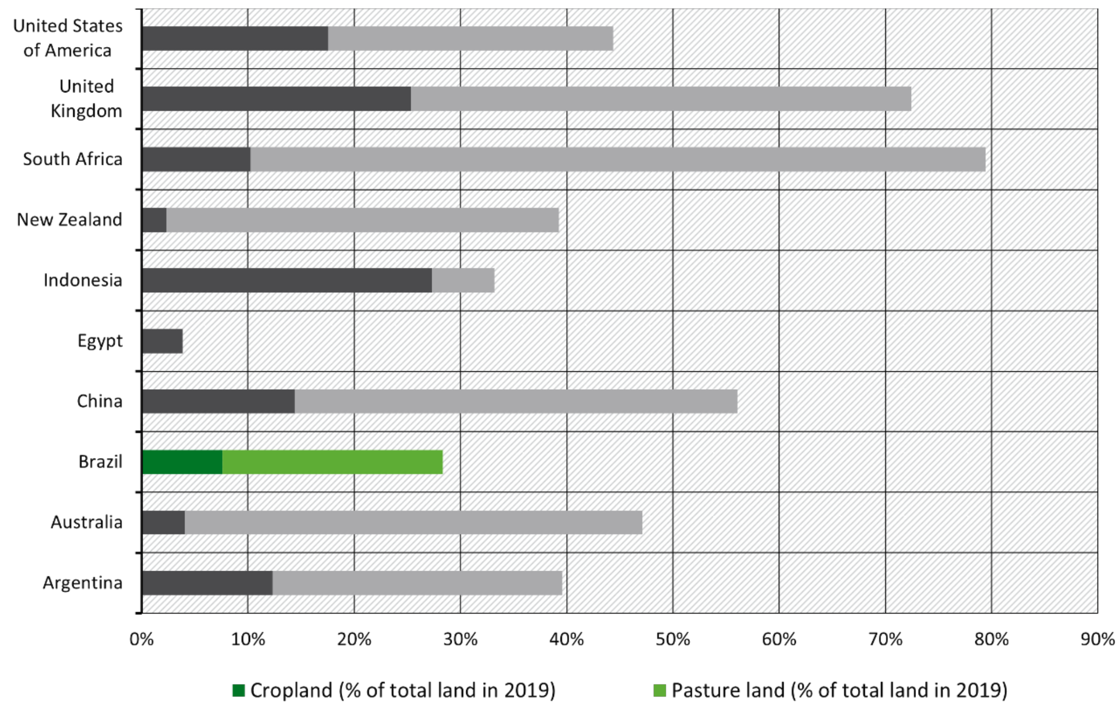
Brazil is in the top three largest global exporters of beef, broiler chicken, soybean, sugar, coffee, and orange juice (Arraes Pereira et al., 2012). Agricultural exports represent 36.1% of Brazil's total exports, making the country the third largest exporter of agricultural products after the U.S. and European Union (OECD, 2021). The main export commodities are corn, sugar cane, and soybeans, the latter of which accounts for almost half of agricultural exports. 41% of Brazilian agricultural exports go to China (ibid).

Brazil is expected to contribute a significant share of future food production, given rising demand, due to its potential for yield improvements and large arable land availability (Lapola et al., 2014), although even in Brazil land for agriculture competes with areas for environmental services. Improving the productivity of the land is necessary so that Brazil meets future domestic and export demand for meat, crops, wood, and biofuels, without the conversion of natural ecosystems (Strassburg et al., 2014).

Agricultural biomass is an important contributor to Brazil's energy supply. Ethanol derived from sugarcane by-products contributes to 17.5% of the country's national energy supply (Antunes et al., 2019). While zoning regulations initially only permitted sugarcane expansion on degraded land and cattle pasture, this was recently revoked, putting the Amazon at risk of deforestation directly or indirectly caused by sugarcane cultivation (Hofmeister, 2019). Renewable energy expansion, namely the construction of large hydropower dams, has also been linked to deforestation and forest degradation (Assunção et al., 2017).

Brazil's agricultural sector accounts for approximately 29% of the country's land use, with pasture making up 21% of total land area and cropland 8% (Figure 3).

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



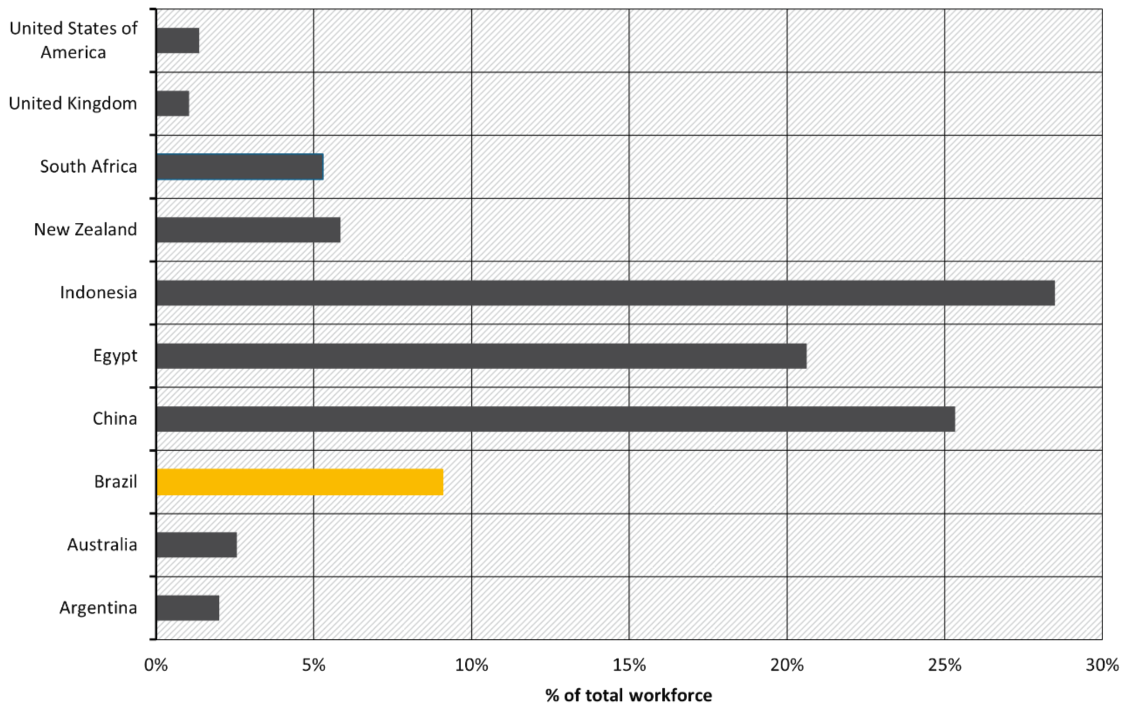
Source: FAO (2022b) data for all countries. Data includes "Cropland" and "Land under permanent meadows and pastures".

1.2 Socio-economic dimensions

Brazil has relatively high rates of income inequality, land distribution inequality, and nutrition inequality, which is further exacerbated by its agricultural system (Martinelli et al., 2010). Industrial agricultural operations, which make up 15% of farms in Brazil, occupy 75.7% of the country's agricultural land (Gross, 2019). This inequity is even more pronounced when considering the top 1.5% of rural landowners (by revenue) occupy more than half of all agricultural land (ibid). There has been a decrease in the number of small farms due to competition from large-scale producers. The correlated rural migration has led to unprecedented urban growth that has caused severe environmental and public health problems from growing slum populations (Lapola et al., 2014).

Around 9.1% of the workforce in Brazil works in the agricultural sector (Figure 3). On average, the labour productivity in Brazil is relatively low. There are capital-intensive large-scale farms where the required labour input is small, but also a large share of traditional farms focused on self-sufficiency and local markets, where labour input for an equivalent output is high (OECD, 2015). Small family farms comprise around 85% of farmers (World Bank Group, 2021).

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



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

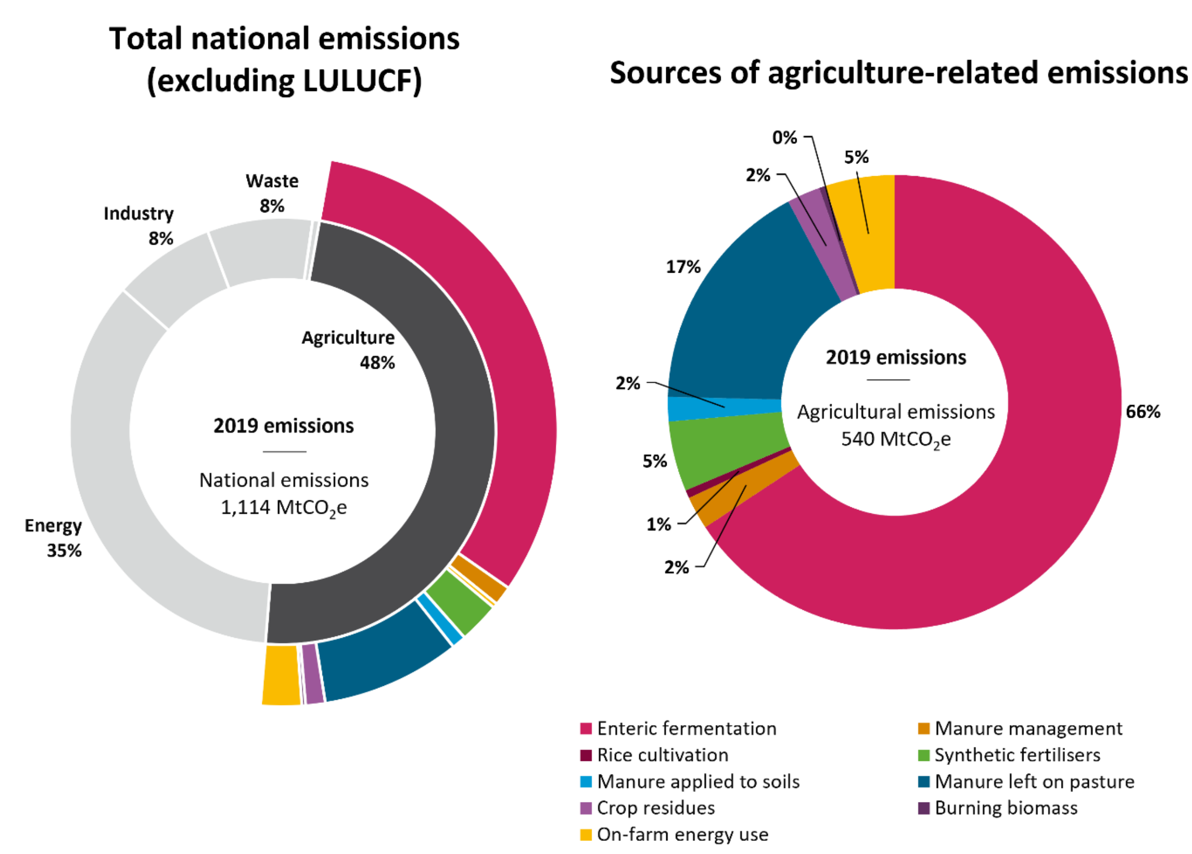
Although Brazil's agricultural production is enough to meet both domestic and export demands, nearly a third of Brazil's population remains food insecure (USAID, 2021; World Bank Group, 2021). More value-added agricultural activities (e.g. equipping sugar cane farms with mills for bioethanol production) can improve social welfare, food security, and income inequality, provided there are improved land title and land distribution systems in place (Martinelli et al., 2010).

Although Brazil holds 12% of the world's freshwater resources, these resources are unevenly distributed across the country, posing issues for water allocation and scarcity (OECD, 2015). Increasing levels of irrigation and cattle ranching are putting added pressure on water resources, which is exacerbated by deforestation and subsequent atmospheric feedback altering local water cycles (Lathuillière et al., 2018).

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

Agriculture makes up a large portion of Brazil's national emissions. The agricultural sector accounts for approximately 48% of total national emissions, equating to 540 $MtCO_2e$ (excl. LULUCF) (Figure 4). The largest agricultural emissions sources are enteric fermentation (66%), manure left on pasture (17%), and synthetic fertilisers (5%).

Figure 4: Brazil's GHG emissions profile (2019)



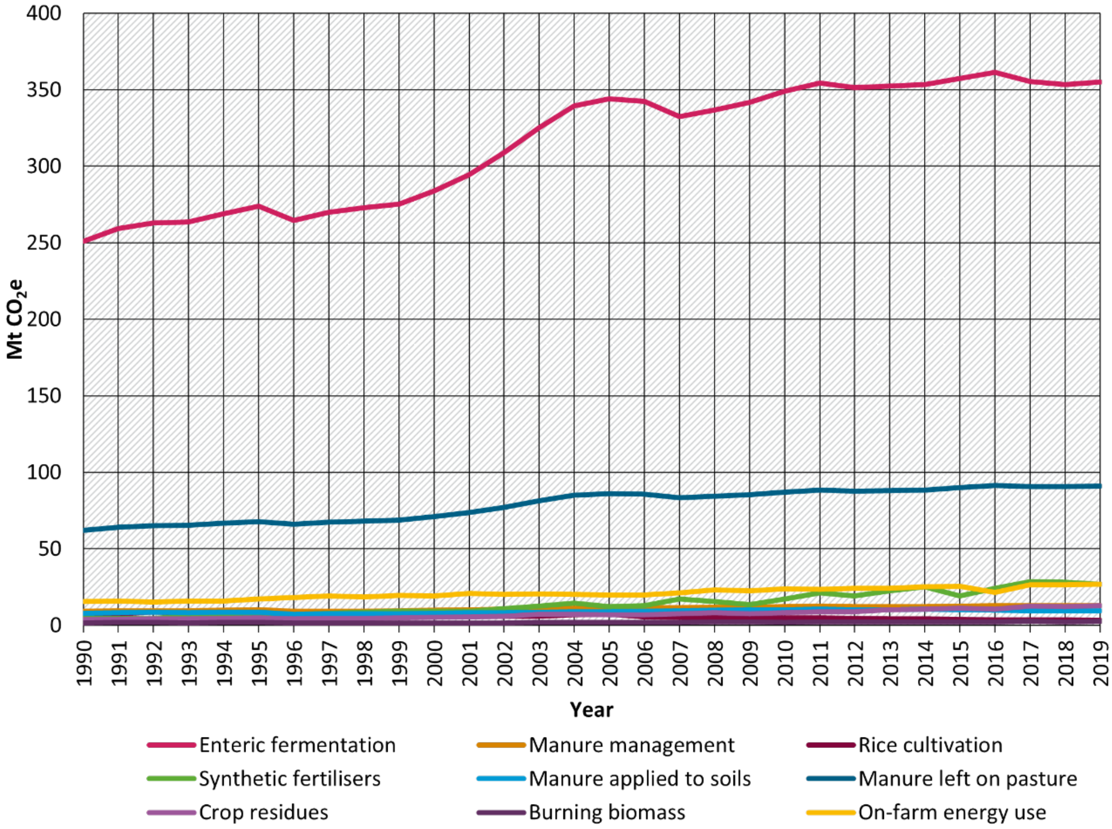
Source: **Gütschow et al. (2021)** for energy (excl. on-farm energy use), industry, waste, and other sectors. **FAO (2022a)** for agriculture and agriculture-related emissions.[1,2]

[1] The PRIMAP-hist dataset used for all non-agriculture-related emissions combines multiple datasets but prioritises country-reported data (Gütschow et al., 2016, 2021). FAO data may differ from nationally reported agricultural emissions under the UNFCCC, and thus agricultural emissions reported under PRIMAP-hist, as a result of data uncertainties and differing methodological approaches to reporting emissions in this sector. We use FAO for these graphs for non-Annex I countries since it includes a complete time series from 1990 to 2019, has a higher level of detail for non-Annex 1 countries (e.g. enteric fermentation emissions per category of animal), and to maintain consistency across the assessed countries.

[2] While on-farm energy use is generally reported under the energy sector emissions for both PRIMAP-hist (Gütschow et al., 2021) and national data, we include it as an agriculture-related emissions source in this study because it is part of 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.

Emissions from Brazil's agricultural sector have considerably increased since 1990 (Figure 5). This is primarily attributed to the 48% growth in animal numbers from 1990 to 2016, 80% of which was cattle for beef production (Government of Brazil, 2020). While enteric fermentation emissions per head of beef cattle have decreased by 8.2% from improvements in forage digestibility in the same time period, there was an absolute increase in emissions due to the larger herd size (ibid).

Figure 5: Agriculture-related emissions in Brazil (1990–2019)



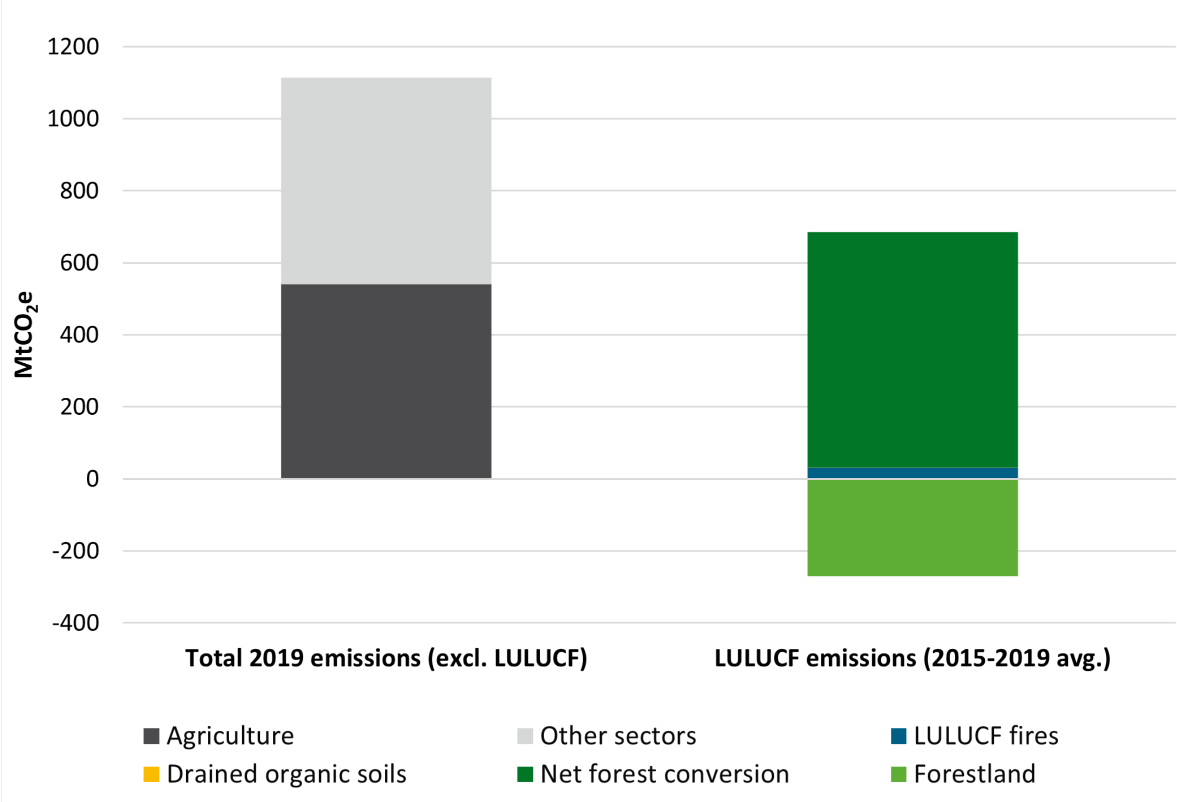
Source: **FAO (2022a)**.

Due to limited financial and technical capacity and poor management practices, current cattle productivity is at 80 kg of beef per hectare of land per year, which is well below its potential of 300 kg per hectare per year from improved pasture conditions. The low productivity is compensated for via forest clearing (Garcia et al., 2017). The low productivity of the Brazilian cattle industry is seen as a concern for greenhouse gas emissions, and is further exacerbated by the region's increased temperatures that reduce the carrying capacity of pastures by 25% (McManus et al., 2016). The current productivity of pasturelands is 32–34% of its potential. Increasing pasture productivity to 49–52% of its potential would meet demand for meat until at least 2040 without further conversion of natural ecosystems, pasture degradation, or the need for supplementary feed (Strassburg et al., 2014). This calculation, however, does not yet consider that current agricultural areas could contribute to carbon sequestration even more effectively if Brazil decided to convert them back to forests.

Brazil has the second largest amount of fertiliser use per hectare globally, at 305 kilograms per hectare of arable land, which includes nitrogen, phosphorus, and potash inputs (Ritchie et al., 2022). The low cost of nitrogen fertilisers results in overapplication, with the result that the crops can only take up a fraction of the nitrogen provided (Pires et al., 2015), while the rest is released into the environment causing GHG emissions and local pollution. There have been substantial increases in the extent of livestock manure left on pasture or applied as fertiliser in Brazil, with corresponding emissions increasing by 120% since the 1980s, in part due to an increase in livestock numbers (Tian et al., 2020).

The LULUCF sector is a significant emissions source in Brazil and comprises a considerable amount of Brazil's total emissions (Figure 6). The large emissions removals from existing forestland are outweighed by the extent of emissions from forest converted into other land uses (ibid).

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



Source: **Gütschow et al. (2021)** for emissions from 'Other sectors' (energy excl. on-farm energy use, industry, waste, and other emissions). **FAO (2022b)** for agriculture-related and LULUCF emissions. LULUCF fires includes the FAO categories "Forest fires," "Fires in humid tropical forests," and "Savanna fires"[3]. Emissions from LULUCF have high interannual variability so average emissions over 5 years (2015 - 2019) is presented to avoid outliers.

Historically, Brazil's LULUCF sector has been a major emissions source (Figure 7). While deforestation levels, and corresponding land use change emissions, had considerably decreased in the past decade, emissions are once again on the rise (ibid).

Agricultural expansion and cattle ranching are the most prominent historical drivers of deforestation in Brazil, with peaks in cropland area and herd size coinciding with peaks in

[3] In some countries, "Savanna fires" (which includes the prescribed burning of grassland) is accounted for in agricultural emissions under the burning biomass category instead of in the LULUCF sector. In this case, we followed national accounting standards based on UNFCCC reports to allocate the "Savanna fires" category under agriculture or LULUCF emissions. Savanna fires are reported under LULUCF for Australia, Brazil, New Zealand, and the United States, while they are reported under burning biomass for China and Indonesia. South Africa and Argentina report CO_2 emissions from savanna fires under LULUCF, but CH_4 and N_2O emissions under burning biomass. Since all emissions from savanna fires in both countries are non-CO_2 gases, they are accounted for under burning biomass.

deforestation rates, although this correlation weakened between the years 2004 and 2012 (Lapola et al., 2014; Schielein and Börner, 2018). The decoupling occurred due to internal market regulations, a cracking-down on illegal deforestation, imposed credit barriers, and the creation of more protected areas (Lapola et al., 2014).

However, the success in reducing the deforestation rate in Brazil has been reversed in recent years. Between August 2019 and July 2020, deforestation in the Amazon increased by 9.5% and covered an area three times larger than the 2020 deforestation target set by the National Policy on Climate Change (Nelson, 2020). In January 2022, Brazil recorded its highest-ever monthly levels of deforestation since its Deter-B satellite monitoring system started in 2015. This equated to 43,000 hectares, which was five times higher than deforestation levels in January 2021 (Spring, 2022).

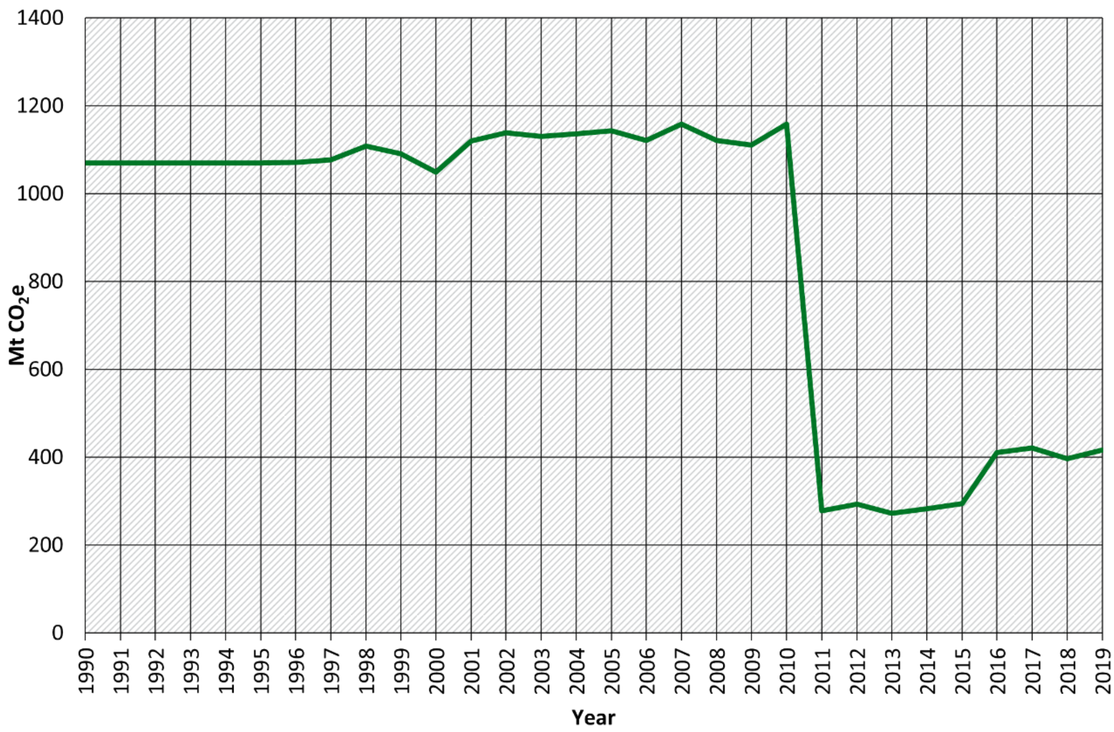
Pasture expansion drove about 74% of recent forest loss and soy 20%, primarily due to soy production displacing pastures and shifting livestock expansion further into the Amazon (Dummett and Blundell, 2021). This has been exacerbated by laws exempting punishment for deforestation in protected areas and giving amnesty for land seizures, and the dismantling of environmental protections under the Bolsonaro regime (ibid).

Deforestation is a large source of emissions in Brazil and illegal deforestation is concentrated on a few properties: Only 2% of properties in the Amazon and Cerrado account for 62% of potentially[4] illegal deforestation (Rajão et al., 2020). Different factors play into this, such as the size of those properties, but it seems interesting that targeting those specific properties and ownership structures behind them could solve an important share of the issue.

Trade acceleration and liberalisation has played a significant role in deforestation and environmental degradation (Balogh and Jámbor, 2020). For instance, 32% of land use change emissions in Brazil in 2007 were attributed to exports (Saikku et al., 2012). In 2020, 20% of soybeans and 17% of beef exported to the EU from the Amazon and Cerrado regions potentially came from illegally cleared land (Rajão et al., 2020).

[4] The boundary between non-compliance to protect or reforest areas and illegal deforestation is not fully defined and the different behaviours are difficult to monitor (see Rajão et al. (2020)).

Figure 7: LULUCF emissions in Brazil (1990–2019)



Source: **FAO (2022a)**. Includes FAO categories “Forestland,” “Net forest conversion,” “Forest fires,” “Fires in humid tropical forests,” “Forest fires,” “Savanna fires,”[3] and “Drained organic soils”. Note that FAO data differs from national data and uses forest activity data in 5-year intervals, meaning data is averaged over the 5-year periods and can highly fluctuate between those intervals. This report uses FAO data for consistency with the other non-Annex I countries in this report series. National data on emissions from LULUCF is available at **(Observatório do Clima, 2022)**.

1.4 Government structures and agricultural policy framework

The stated role of the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) is to promote the sustainable development and competitiveness of agribusiness by increasing agricultural production to meet demand while contributing to an exportable surplus (ABC, 2022). They are also responsible for formulating and carrying out the measures outlined in the country’s Low Carbon Agriculture Plan.

The Brazilian Forestry Service, originally linked to the Ministry of Environment, has come under the control of the Ministry of Agriculture. The move by Bolsonaro has mainly benefited the country’s powerful agribusiness sector, and led to protected areas opening up for commercial activities including cattle ranching and agricultural production, oil and gas exploration, and new hydroelectric dam projects (Climate Action Tracker, 2020).

Brazil’s first Nationally Determined Contributions (in Paris Agreement) (NDC) set a target to reduce total greenhouse gas emissions by 37% below 2005 levels by 2025 and by 43% by 2030, reaching an emissions level of 1,307 MtCO_2e in 2030, excluding LULUCF (Climate Action Tracker, 2022). In April 2022, following an announcement at COP26, Brazil submitted an updated NDC and set a 50% emissions reduction target by 2030 compared to 2005 (Federative Republic of Brazil, 2022). Brazil’s climate target is currently deemed to be highly insufficient and is not a 1.5°C compatible target in line with the Paris Agreement. An initial assessment of the updated target indicates that Brazil has not raised its ambition beyond its first NDC (Climate Action Tracker, 2022).

Brazil's National Policy on Climate Change (PNMC) outlines many potential actions for reducing emissions in the AFOLU sector. This includes restoring 15 million hectares of degraded pasture, expanding integrated crop-livestock-forestry systems by 4 million hectares, applying no-till practices to over 8 million hectares of cropland, applying biological nitrogen fixation to 5.5 million hectares, planting 3 million hectares of forest, and treating 4.4 million cubic meters of animal waste (Government of Brazil, 2018). The plan also committed to reducing deforestation by 80% from 1996-2005 levels by 2020 (ibid).

While there was progress towards the targets under the Low Carbon Agriculture Plan, the deforestation target under the PNMC was far from being reached. Although Brazil had reached their 2020 pledge on deforestation reductions in 2012, deforestation rates and LULUCF emissions have started to increase again, setting up Brazil to miss its 2020 target (Climate Action Tracker, 2022).

Brazil's Low Carbon Agriculture (ABC) Plan is the sectoral plan aimed at mitigating and adapting to climate change that is managed by the Ministry of Agriculture (Agroicone and GTPS, 2015). The mitigation actions outlined in the plan are the same as those in the PNMC. Between 2010 and 2020, the measures related to the plan were estimated to mitigate 170 $MtCO_2e$ of emissions and provided 52 million hectares of farms with modernised production technology (Agência Brasil, 2021). However, Brazil fell short in reaching the targets for re-forestation and rehabilitating degraded pastureland included in the plan (Aquino, 2021).

ABC+, the second iteration of the plan for 2020–2030, aims to reduce net-agricultural GHG emissions levels by 1,100 $MtCO_2e$, which is seven times more than originally planned (MAPA, 2021). This would be achieved by expanding the areas on which different mitigation measures are applied, such as increasing the extent of integrated crop-livestock-forestry systems from 4 to 10 million hectares and expanding the number of grain-finished cattle by 5 million (Agência Brasil, 2021; Wiese-Rozanova et al., 2021).

The revised Forest Code, passed in 2012, defines a percentage of farmland area that must be preserved as natural vegetation. This ranges from 20% in most parts of Brazil to 80% in the Amazon (Sparovek et al., 2015). However, this requirement can be reduced from 80% to 50% depending on the extent of designated public land in the territory, which would increase the extent of legal deforestation based on the provisioned public protected areas (Freitas et al., 2018). The revised Forest Code has been criticised for amnestying illegal deforestation before 2008 and its weaker requirements on natural vegetation restoration (Freitas et al., 2017; Sparovek et al., 2015).

Brazil's weakened institutional and legal frameworks have paved the way for illegal deforestation and land grabbing. Insufficient land tenure laws have enabled land grabbers to occupy and deforest undesignated public land, contributing to 35% of deforestation in 2019 (Climate Action Tracker, 2022). A new proposed measure would allow speculators to declare ownership of public land grabbed before 2018, which would likely trigger significant amounts of conflict and deforestation in protected forestland and indigenous reserves (ibid). The Bolsonaro administration has exacerbated the issue by continuing to cut budgets for environmental monitoring and enforcement (ibid).

1.5 Current developments and trends

Brazil has adopted integrated crop-livestock-forestry systems, also known as silvopastoral systems, as a means of increasing crop and pasture productivity through a synergistic approach that includes techniques such as crop rotation, no-till, intercropping with forage, and planting tree rows (Pacheco et al., 2013). This practice has several co-benefits including improved soil health, minimised agrochemical use, and the reduced need for agricultural expansion, in addition to improved yields (ibid; Arraes Pereira et al., 2012). The higher forage quality facilitated by this system can also contribute to lower methane emissions per unit of livestock (ibid).

Brazil's New Forest Code (2012) requires farms to protect or restore a certain extent of its natural vegetation. The code allows family farmers to use agroforestry systems to restore these designated permanent protected areas or legal reserves, provided it preserves the basic ecological functions and structure of the natural vegetation (Miccolis et al., 2019). Agroforestry has been cited as a viable option for achieving Brazil's targets of restoring 15 million hectares of degraded forests and 12 million hectares of degraded pastures while providing socioeconomic and financial benefits to smallholders. However, agroforestry implementation faces challenges with complexity, access to knowledge, and the labour inputs and management required (ibid).

No-till agriculture is a common practice in Brazil and is applied across small and large farms alike. More than 33 million hectares of agricultural land, or 61% of total cropland, in Brazil applied no-till techniques in 2017 (Fuentes-Llanillo et al., 2021). This practice was prompted by the extreme soil degradation and loss of agricultural productivity experienced in the 1960s and 1970s. First deployed by small and medium farms, the rise in genetically modified crop varieties facilitated the adoption of no-till practices on large-scale farms, who are now the predominant users of no-till methods (ibid).

While no-tillage has positive implications for soil health and conservation, it is usually still coupled with unsustainable practices such as monocultures and intensive pesticide, herbicide, and fertiliser application (Ofstehage and Nehring, 2021). The motivation to apply no-till is primarily linked to profitability rather than sustainability, especially in the case of large-scale, industrialised farms. The adoption of no-till is correlated with expansion of the soy frontier in the fragile Cerrado ecosystem since the practice reduces costs and minimises the agroecological limitations of farming in the region (ibid).

1.5.1 Diets and food waste

In addition to supply-side measures, Brazil's agricultural landscape has been shaped by demand-side and external factors. Food waste, dietary habits, the COVID-19 pandemic, and climate change impacts all influence agricultural processes and related emissions. Brazil has a substantial dietary ecological footprint due to its high levels of meat consumption. The average Brazilian diet is influenced by socio-cultural factors, since eating meat is often linked to traditions and social gatherings in the form of churrascarias (barbeques) (Happer and Wellesley, 2019).

Brazil is estimated to waste an average of 82 million tonnes of food per year, which amounts to 422 kilograms per capita and 42% of the food supply (Dal' Magro and Talamini, 2019). Most losses occur at the production and processing stages of the food supply chain (ibid). The reasons for high pre-consumption waste include poor post-harvest management and handling, a lack of logistics infrastructure, and inefficient processing and packaging practices (ibid).

1.5.2 Recent developments in national context

The COVID-19 pandemic has accelerated the rampant illegal deforestation occurring in the Amazon due to a lack of enforcement from environmental agencies, whose field operations have been shut down or constrained by budget (Brancalion et al., 2020). Between January and April 2020, there was a 55% increase in tree cover loss compared to the previous year; many illegal logging operations and criminal organisations have taken advantage of the fragility of the situation and are operating more openly and intensely (Londoño et al., 2020).

The elections in late 2022 led to a government change, and President Lula has promised to reverse and eventually stop deforestation of the Amazon (Mathiesen, 2023).

1.5.3 Selection of priority mitigation actions

Cattle cause, by far, the most emissions in the agricultural sector in Brazil, through enteric fermentation and manure, as well as through increased deforestation for pasture and soy feed expansion. The livestock sector is also of high economic importance, which stresses the importance of a sustainable approach to it. The past decades of conventional agriculture and unsustainable practices have left a large amount of area degraded, which causes farmers to further expand agricultural land. Brazil has a very high fertiliser use per land area, ranking second globally. The use of synthetic fertilisers has caused increasing emissions, and in 2019 caused about 5% of Brazil's agricultural emissions (see Figure 3).

For Brazil, we therefore stress the importance of the following measures which are discussed in more detail in the following sections:

- The prevention of deforestation due to agricultural expansion
- The restoration of degraded pastures
- Improved nutrient management, to decrease the need for synthetic fertiliser.

One area not described in detail in this report, but nevertheless important, is the reduction of GHG emissions of cattle production. D'Aurea et al. (2021) observe strong variations between farms and suggest that improved animal management strategies can reduce the GHG emissions intensity from the sector.

1.6 Vulnerability and adaptation

Brazil's variety of climactic regions means that climate change impacts differ across the country. For example, total annual precipitation is projected to increase in the western Amazon and southern regions, while decreasing in other major agricultural areas (Zilli et al., 2020). Climatic changes could reduce the extent of area suitable for soybean production by 65.7% and corn by 84.9%, displacing production to other regions, while improving sugar cane suitability and yields due to lower frost frequencies (ibid).

Warmer temperatures would significantly affect crop and livestock productivity. In a worst-case scenario, soybean yields could decrease by 44%, while pasture productivity could be reduced by 10% due to heat stress (Lapola et al., 2011). The increased need for cropland and pastureland expansion due to reduced productivity could further drive deforestation in the Amazon and Cerrado regions (ibid).

Declines in productivity are also expected to impact commodity prices. The lower supply would result in significantly increased food prices, especially for staples like rice, beans, and meat. These price changes can further exacerbate poverty and food insecurity in Brazil (Assad et al., 2013). At the same time, the reductions in agricultural income in poor municipalities would reinforce their socio-economic vulnerability (Giannini et al., 2017).

Brazil published their National Adaptation Plan for climate change in 2016. The country's Agricultural Adaptation Programme focuses on ensuring efficient access to information and new technologies for farmers while significantly increasing yields via sustainable production methods (MMA, 2016). Adaptation measures include emphasising decentralised production systems, diversifying local food supply, developing genetically drought-resistant cultivars, and expanding irrigation technology (ibid). However, the outlined technological solutions are time-intensive and require high investments, which can be outside the reach of smallholder farms if not properly implemented (Zilli et al., 2020).

The second iteration of the Low Carbon Agriculture (ABC+) Plan places importance on the synergy of adaptation and mitigation strategies. This includes the adoption and maintenance of conservation agriculture practices and integrated production systems, as well as genetic improvements and biodiversity recovery to build resilience while simultaneously reducing sectoral emissions (MAPA, 2021).

2 Key areas with high mitigation potential

2.1 Introduction

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

2.1.1 Selection of priority mitigation actions

Cattle cause, by far, the most emissions in the agricultural sector in Brazil, through enteric fermentation and manure, as well as through increased deforestation for pasture and soy feed expansion. The livestock sector is also of high economic importance, which stresses the importance of a sustainable approach to it. The past decades of conventional agriculture and unsustainable practices have left a large amount of area degraded, which causes farmers to further expand agricultural land. Brazil has a very high fertiliser use per land area, ranking second globally. The use of synthetic fertilisers has caused increasing emissions, and in 2019 caused about 5% of Brazil's agricultural emissions (see Figure 3).

For Brazil, we therefore stress the importance of the following measures which are discussed in more detail in the following sections:

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One area not described in detail in this report, but nevertheless important, is the reduction of GHG emissions of cattle production. D'Aurea et al. (2021) observe strong variations between farms and suggest that improved animal management strategies can reduce the GHG emissions intensity from the sector.

2.1.2 Overall mitigation potential

The overall mitigation potential in the Brazilian agricultural sector is large, although exact data is difficult to obtain and aggregate in a meaningful way[5]. Roe et al. (2021) estimate that Brazil has the largest potential of all countries for mitigation in the land sector with an estimated 1.7 ± 0.5 $GtCO_2e$/year, with about 1 $GtCO_2e$/year from restoring and protecting forests, and 0.5 $GtCO_2$/year from sequestering carbon in agricultural soils. The Brazilian government's sectoral plan (ABC+) assumes a possible reduction of emissions levels about 1 $GtCO_2e$ in 2030 compared to the year 2020 (MAPA, 2022), of which about half comes from planting forests. The three focus areas of this report alone could lead to avoided emissions and emission reductions somewhere in the hundreds of megatons, and other areas, for instance reductions in emissions from enteric fermentation, could have an additional impact. Of the three mitigation options considered here, the reduction of emissions from fertiliser use has the lowest impact on GHG

[5] As opposed to some other countries in this series, the analysis for Brazil is entirely literature-based.

emissions, nevertheless, it comes with economic benefits for farmers and other important environmental benefits.

2.2 Prioritised mitigation options

2.2.1 Preventing deforestation due to agricultural expansion

Measure	Through intensifying the use of existing land, meaning increasing the output per hectare, production can be guaranteed even without converting additional forest areas into agricultural land. At the same production rates, less land area is needed and forests can recover the lost area (Köberle et al., 2020). In the case of crops, farmers can adopt integrated systems that cultivate more than one crop, apply crop rotations or use fertiliser in a more targeted manner.
Status	The Amazon Soy Moratorium (ASM), first implemented in 2006, is "an agreement by grain traders not to purchase soy grown on recently deforested land" and has contributed to the reduction of expansion of agricultural land into forests (Heilmayr et al., 2020). For soy bean production, research suggests that a process from extensification to intensification already has happened to some extent in the first decade of this century (Gama-Rodrigues et al., 2022). However, the production area for soy is continuing to grow (Marin et al., 2022). For cattle ranching, the intensity of production varies a lot by farm, meaning that on average, further intensification is likely possible.
Potential	Marin et al. (2022) estimate a mitigation potential of about 150 $MtCO_2e$ on average per year until 2035 for soybean production, compared to a BAU. An older study from 2014 estimates possible avoided emissions of 14.3 $GtCO_2$ until 2040 (we assume this is the cumulative value across all years) (Strassburg et al., 2014). In the case of beef production, studies have found that an intensified use of the land can even lead to an, at least temporarily, increased sequestration of carbon in the soil (Bragança et al., 2022), but we have not found reliable data on the overall potential for emissions reductions of this element.
Co-benefits	Stopping or limiting agricultural expansion into forest areas decreases the pressure of land use change on Brazil's indigenous population and additionally contributes to biodiversity.
Barriers	**Institutional barriers:** The interests of agribusiness have influenced policy making in the past or undermined the policies through non-compliance. The rising global demand for Brazilian agricultural products (e.g. soybeans, corn, sugarcane) and its synergies with development objectives can further influence decisions towards agricultural expansion (Valdez, 2022). In addition, despite the new president Lula's pledge to end deforestation, Brazil's enforcement agencies against deforestation lack significant capacity to effectively enforce laws (Spring, 2023). **Policy/legal barriers:** Under the ASM and the Forest Code, deforestation and agricultural expansion has shifted into grasslands, including the highly-vulnerable and carbon-rich Cerrado ecosystem (Conant et al., 2017; Spring, 2022). **Economic barriers:** Intensifying production can require high amounts of capital and the adoption of new technologies, which poses challenges to smallholders

with low investment capacity, or is contrary to the economic interests of agribusinesses (Soares-Filho et al., 2012).

2.2.2 Restoration of degraded pastures

Measure

Restoring degraded pastures not only leads to increased carbon sequestration on grassland, but can also decrease the pressure to expand agricultural area into native forests (see previous mitigation option). Measures to restore pastures include, for example, cattle management and pasture rotation, and reducing input waste to limit the extra resources (e.g. feed) needed, all of which thus can alleviate pressure on the degraded land (Feltran-Barbieri and Féres, 2021). Managing cattle covers many aspects; examples for activities related to restoring pastures include defining the calving season (different seasons offer different feed on pastures) and supplementary feed that supports the growth of cattle while allowing pastures to recover from grazing. For a sustainable approach, two points are critical: During the recovery, ensure that the cattle do not expand into other areas. And after the intervention, to maintain an intact recovered pasture, limit the number of cattle.

Status

Brazil has accumulated about 100 Mha of degraded pastures (Feltran-Barbieri and Féres, 2021). According to the same study, these pastures are concentrated around a few municipalities, meaning that the efforts for improvements can effectively be focused on those areas.

Potential

The potential of the measure is uncertain. A critical assumption is what land use type the degraded land is restored to; reforestation could lead to much higher sequestration of emissions[6] than restoration of the pastures for agricultural use (e.g. cattle grazing). A relatively old source estimates a sequestration rate of 0.61 MgC/ha/year (Maia et al., 2009) for improved management of pastures. Assuming about 17 Mha of pasture area were to be restored (De Oliveira Silva et al., 2018), this leads to a rough sequestration potential of about 38 $MtCO_2$/year in the near term, assuming that restored pastures are again suited for cattle grazing. If the same factor of improvement were applied to the full area of degraded pastures, the potential could be about five times higher. The government's ABC+ plan assumes a potential of reducing emissions levels by 114 $MtCO_2e$ by 2030 compared to 2020 (MAPA, 2022). In addition to increasing the carbon stock, well-managed pastures for cattle can lead to lower emissions from enteric fermentation and manure (Gama-Rodrigues et al., 2022).

Co-benefits

Restoration of degraded pastures can increase the income of farms on land which currently has low productivity. It also contributes to avoiding the expansion of agricultural areas (focus area described above).

Barriers

Institutional barriers: Even with restored pastures, farmers would still expand into native forests (for economic reasons) if the enforcement of the Forest Code is too low, which has been the case historically.

Technical barriers: Limited knowledge on the location of degraded pastures and good practices on restoration is a barrier to implementation, which is exacerbated by a lack of access to rural advisory and credits services (Feltran-

[6] Another important factor is also the level of degradation. Strongly degraded and depleted soils may not always be able to support forests due to a lack of key nutrients.

Barbieri and Féres, 2021). Degradation can also be severe with the result that improvement measures may not be very successful. Furthermore, the measurement, reporting, and verification (MRV) of gains in soil carbon stocks and corresponding increased sinks is challenging due to its uncertainty and complexity (OECD, 2019). Regional climate change and climate impacts may result in less favourable natural conditions for pasture regrowth.

Economic barriers: Pasture restoration via rotational grazing involves increased labour and infrastructure needs, which may result in high upfront and maintenance costs that deter adoption (FAO and ITPS, 2021).

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 carbon dioxide (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 decarbonisation 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.

2.2.3 Improved nutrient management

Measure

Measures to reduce fertiliser use include precision application of fertilisers depending on productivity of fields, and controlled-release fertiliser systems (Searchinger et al., 2019). The inclusion of legumes in grasslands or integrated production systems can also reduce the need for fertilisers[7].

Status

Where the Nitrogen Use Efficiency (NUE) is too low, it means that too much nitrogen is lost and not absorbed by the crops, causing environmental damage. Where the efficiency is too high, lands get degraded over time. The NUE varies greatly throughout Brazil, but lies outside the desirable range in many regions (Tôsto et al., 2019). In 2022, the government announced a National Fertilizer Plan to reduce the dependency on fertiliser imports. Brazil is responsible for 8% of global fertiliser consumption (Caetano, 2022).

Potential

The Brazilian ABC+ plan assumes a reduction potential of about 23 $MtCO_2e$ in 2030 compared to the year 2020 (MAPA, 2022). Griscom et al. (2020) estimate a reduction potential of about 10 $MtCO_2e$ in 2030. A report financed by the International Fertiliser Association finds only a few megatons of reduction potential, assuming that additional fertiliser is needed in regions with a currently

[7] The use of organic fertilisers can also reduce GHG emissions, particularly on the production side. The measures described here focus on managing nutrient balances on farmland, which is also critical for organic fertiliser to avoid overfertilisation and nutrient deficiency.

	too high NUE. However, it states that the decreasing pressure to deforest would make the overall impact of those measures net-positive (i.e. decrease national emissions in total) (Systemiq, 2022).
Co-benefits	A reduced need for synthetic fertiliser reduces costs for the farmers and the dependency on fertiliser imports. Avoiding overuse of nitrogen improves the water and soil quality. Well-managed soils in terms of nutrients provide yield benefits over the long term, thus decreasing the risk for the farmer and the need to expand agricultural land.
Barriers	**Technical barriers:** There is lack of granular data on soil quality and soil nutrient status, which varies on a farm-to-farm scale, leading to uncertainty about the optimal fertiliser amounts. **Economic barriers:** Some nutrient management measures require up-front investments, while others are more labour-intensive than conventional systems. Farmers also overuse fertiliser to ensure their yields do not decrease. Brazil imports most of its fertiliser supply, meaning prices are highly dependent on global circumstances. Recent high crude oil prices and supply chain disruptions have led to higher fertiliser prices, meaning farmers may be forced to apply less fertiliser than what is required to reach an optimal NUE (Valdez, 2022).

3 Barriers to implementing mitigation potential

In this section, we look into the main barriers to mitigation of agricultural emissions identified for the country, building on the findings of a report on general barriers prepared under this research project[8] and the country-specific circumstances described in Section 1 of this report. The analysis of barriers below follows the clustering proposed in WP2 report, according to the relevant governance level for taking action, while taking into account the classification from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (IPCC, 2019) within each of the governance levels.

3.1 Farm level

The lack of access to technical assistance and financial credits complicates the implementation of low-carbon agriculture for small farmers (Gama-Rodrigues et al., 2022). For agribusiness, measures to increase productivity may not completely offset the demand for additional area, if there is sufficient demand for more agricultural products. The fear of economic losses is another challenge to change practices.

3.2 National level

The late 2022 change in government improves the chances for climate change mitigation action in the agricultural and forestry sector drastically. The new government has promised to enforce and improve existing laws on the protection of native land areas.

Still, the competition of large-scale commercial agriculture versus the rights of indigenous people and the protection of the environment, including some of the world's most important carbon sinks, remains and the lobby of agribusiness to continue to expand land area for agricultural production is still strong. Another threat is a change in government in the future that could roll back the current administration's efforts.

Data availability on deforestation and land use has improved but is still somewhat patchy. Further improved monitoring could support targeted measures and financing mechanisms.

3.3 International level

International demand for agricultural products is one driver of expansion. Researchers express concern that the trade agreement between the EU and the Mercosur (Brazil, Argentina, Paraguay and Uruguay) may threaten sustainability and increase deforestation (Kehoe et al., 2020).

Finance lags behind in forest area, with specific finance instruments targeted at the sector missing, despite relatively low mitigation costs (Boehm et al., 2022) and increasing international interest to support the sector through climate finance. The new Brazilian government aims to attract additional international climate finance, particularly for the protection of forests.

3.4 Consumer level

Per capita consumption of animal products, including beef and dairy, is very high in Brazil, and the cultural preference of animal products is a barrier to changing towards a sustainable food system. Changing demand patterns is not the focus of this report, but it should be stressed that a decrease in domestic demand could either free more products for export or decrease the pressure for expanding agricultural land.

[8] See https://www.umweltbundesamt.de/publikationen/barriers-to-mitigating-emissions-from-agriculture.

4 Recommendations

In a world compatible with a Paris Agreement, the agricultural sector will need to meet the growing food demand of people and animals, while contributing to other equally relevant climate and development objectives and adapt to a changing climate. Mitigation action in Brazil, one of the large emitters globally, is essential for limiting global temperature increase, including in the agricultural sector. Ending deforestation is not only important for a sustainable and just development of Brazil – protecting the amazon as a large carbon sink is critical to avoiding temperature increases. The quality of the land in Brazil highly varies, and there are concerns about soil mining, i.e. an overexploitation of the nutrients. Measures to reduce GHG emissions that also address this concern can support sustainable agriculture in the long-term, benefiting not only Brazil but also the countries that profit from imports of Brazilian agricultural products.

This study identified and quantified three mitigation actions in Brazil's agricultural sector that would improve productivity and provide environmental and economic co-benefits: Preventing deforestation due to agricultural expansion, the restoration of degraded pastures, and improved nutrient management, which leads to reduced fertiliser use.

To minimise emissions and enhance sinks in the sector, Brazil would need to take a multi-faceted approach. Ending deforestation due to agricultural expansion and the restoration of degraded pastures would lead to hundreds of megatons of avoided GHG emissions. The potential emissions reductions from fertiliser are a magnitude smaller, yet the measures to pursue them are equally important for its other benefits. Minimising emissions and enhancing sinks from land use in Brazil are critical for the success of global climate action due to the magnitude of the overall potential, which we estimate to be higher than 1 $GtCO_2e$ in 2030 (based on ABC+, (MAPA, 2022)) and potentially up to 2 $GtCO_2e$ (based on (Roe et al., 2021) including restoration and protection of forests), based on the literature analysed in this report.

The measures to leverage these potentials provide benefits beyond the reduction of net-emissions levels: Decreasing deforestation lowers pressure on the land of indigenous populations and supports biodiversity. Restoring degraded pastures increases the productivity of the land and can increase smallholders' incomes. Improved nutrient management leads to lower environmental impacts and pollution, reduces fertiliser costs for farmers and decreases the import dependency of the Brazilian economy.

The implementation of more sustainable practices in the sector currently faces various challenges: The land areas affected are very large and monitoring environmental destruction, as well as the effects of mitigation measures, remains a challenge. International demand for agricultural products and the interests of agribusiness to maximise profits put a high level of pressure on land.

This report recommends various actions the government could take to foster climate change mitigation in the agriculture sector:

1. Enhancing the national climate mitigation framework in agriculture

The Bolsonaro administration did not prioritise mitigation actions in the AFOLU sector and deforestation rose during those years (2019–2022). The newly elected government now has the challenge of re-establishing and enforcing the policy framework to stop deforestation and agricultural expansion and safeguard the rights of indigenous people. With the ABC+ Plan, Brazil already has a comprehensive sectoral mitigation approach. Important for its success is a wide-spread implementation of mitigation measures on large land areas to leverage the potential and ensure the enforcement of the protection of forests.

2. Align overall agriculture framework with climate mitigation objectives

The Brazilian NDC requires the country to reduce economy-wide emissions compared to today. The NDC does not provide sectoral targets, with the result that the expected contribution of agriculture and forests is unclear.

Policy making for the agricultural sector falls under the responsibility of the Ministry of Agriculture, Livestock and Food Supply (MAPA), which promotes the sustainable development and competitiveness of agribusiness by increasing agricultural production to meet demand while contributing to an exportable surplus. The different objectives are potentially at conflict, and the new government will need to strike a balance between increasing production and environmental protection. With this in mind, the sustainable intensification of agricultural land will be one important contribution.

3. Selected ideas for how mitigation could be strengthened

Building on existing policy structures and initiatives, the Brazilian government can foster mitigation in the agricultural sector. Many activities are already in place and can be complemented, expanded, and potentially improved. Some more concrete, non-exhaustive ideas are:

- **Improve the monitoring of agricultural land and forests** to avoid deforestation and improve management of the land. Better data on land use changes and productivity of areas allows for authorities to react quickly to illegal deforestation. For agricultural lands, a better understanding of productivity patterns allows more effective interventions to improve the output of the land, for example through targeted application of fertiliser.

- **Support research, development and spreading knowledge on crop intensification and improved nutrient management.** Studies show large variations in yield across the country, but estimate that with interventions the output in low-yield areas can be increased, for example through "judicious choice of sowing dates and cultivars, the application of nutrient fertiliser, better crop protection, improved soil and water management and the use of cover crops" (Marin et al., 2022). Developing further methods that address specific geographical and cultural circumstances and spreading information on them can foster their application.

- **Improve national and subnational enforcement and governance structures** to avoid illegal deforestation (Boehm et al., 2022). A shift in the negative trend observed under the previous government is required and is promised by the new government. This area of action should also include an increased budget for authorities on the national and subnational level for monitoring and reporting land area conversions.

- **Work together with industry partners and other governments on sustainable supply chains** to create demand for sustainably grown agricultural products. This provides an incentive for agribusiness to invest in the sustainability in the long term. Through the inclusion of other countries in this process, and anchoring it in international supply chains, these structures would run a smaller risk of being put on hold in case of another drastic change in the government.

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 could help understand the implications of a shift to largely plant-based diets and potentially avoid disruptions in the sector in the medium to long term. International research reports that demand-side measures, such as shifting to less meat-intensive diets and reducing food waste, have a high mitigation potential while contributing to other co-benefits at relatively lower costs (Roe et al., 2021).

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