

CLIMATE CHANGE MITIGATION OPTIONS FOR ARGENTINA'S AGRICULTURAL SECTOR

A2A PHASE II



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KEY FINDINGS

The Argentinian agricultural sector plays a critical role for the country's economy and its development trajectory. The expansion of the sector, in particular for high-value commodities, such as bovine meat, is an important facet of Argentina's development strategy but also an important source of emissions.

In 2018, the agriculture and land use sector represented 37% of national greenhouse gas (GHG) emissions or close to 135 MtCO₂e per year. At the same time, Argentina's NDC aims at limiting total net GHG emissions to 349 MtCO₂e by 2030 and to develop a long-term low-emission development strategy with the objective of reaching climate neutrality by 2050.

This report provides an overview of a range of potential climate change mitigation measures in the agriculture sector in Argentina that were prioritised in close consultation with experts from the National Institute of Agricultural Technology (INTA), based on available literature to support calculations, perception of feasibility of implementation, relevance in the national context and potential additional benefits.

The mitigation measures analysed included: feed optimisation through the use of deferred forage and improving nitrogen use efficiency, extending grain finishing time for livestock already in intensive systems, improving livestock health and reducing the incidence of reproductive diseases, incorporating cover crops, crop rotation practices, improving synthetic fertiliser management, and expanding silvopastoral livestock systems on forest land.

According to our findings, the implementation of these measures could reduce emissions by up to 14% in 2030 (~28 MtCO₂e) compared to a reference scenario. Over 80% of the potential emissions reduction comes from implementing

silvopastoral systems and their influence in halting deforestation for pastureland expansion. We also found that measures to improve livestock productivity (those that reduce emissions intensity per unit of product) can likely lead to an increase in absolute emissions levels unless the size of the herd is reduced. This highlights the importance of reducing land use change and deforestation, and makes evident the comparatively limited potential to reduce emissions through other technical measures that increase efficiency in existing livestock and crop production practices.

Even with a successful implementation of the measures evaluated in this report, the agriculture and land use sector would still represent a large share of the country's emissions in 2030, leaving other sectors to make much more significant reductions in order to still meet the NDC target. The gap is more evident when we compare the mitigation scenario with a climate neutrality one: **the sector's emissions pathway under the mitigation scenario is completely misaligned with where it should be in 2030 to reach climate neutrality by 2050.**

Argentina will need to drastically cut the GHG footprint of its AFOLU sector to align sectoral development with the country's stated climate ambition and to safeguard the sector's economic sustainability and the competitive advantage of export-oriented producers in carbon-constrained markets. By considering further mitigation measures that explore more fundamental transformations in the sector, Argentina could strengthen its position to reach its international climate commitments. Mitigation measures such as shifting to more sustainable diets (i.e. with lower meat consumption) and reducing food waste reportedly have a higher mitigation potential and are likely to provide significant co-benefits at relatively lower costs.

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ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
BMU	Federal Ministry of the Environment, Nature Conservation and Nuclear Safety
CAT	Climate Action Tracker
CO₂	Carbon Dioxide
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	German Corporation for International Development
IKI	International Climate Initiative
INGEI	National Inventory of Greenhouse Gases
INTA	National Institute of Agricultural Technology
IPCC	Intergovernmental Panel on Climate Change
LTS	Long-Term Strategy
LULUCF	Land Use, Land-Use Change, and Forestry
MAGyP	Ministry of Agriculture, Livestock, and Fisheries
MAYDS	Ministry of the Environment and Sustainable Development
MBGI	National Plan for Forest Management with Integrated Livestock Production
NDC	Nationally Determined Contribution
N₂O	Nitrous Oxide
NUE	Nitrogen Use Efficiency
OECD	Organisation of Economic Co-operation and Development
SGAyDS	Government Secretariat of Environment and Sustainable Development
SPIPA	Strategic Partnerships for the Implementation of the Paris Agreement
USD	United States Dollar

1 INTRODUCTION

The Argentinian agricultural sector plays a critical role for the country's economy and its development trajectory. As a major producer of agricultural commodities, Argentina is one of the main global suppliers of soybean and soy derivatives, bovine meat, cereals, and dairy products. Agri-food exports are a crucial source of foreign earnings, making up 65% of Argentina's total export revenues in 2020 (INDEC, 2021).

The expansion of the agricultural sector, in particular for high-value commodities for which demand is growing, such as bovine meat, is an important facet of Argentina's development strategy. However, the Argentinian agricultural sector must also play a considerable role to achieve the country's emissions reduction targets since it represents 37% of national annual greenhouse gas (GHG) emissions or close to 135 MtCO₂e per year (Moreira Muzio, 2019). Argentina has pledged to limit total net GHG emissions to 349 MtCO₂e by 2030 and to present a long-term low-emission development strategy with the aim of achieving climate neutrality by 2050 (Government of Argentina, 2021b).

Argentina's export-dependent economy could face significant risks as climate-progressive countries and economic unions consider introducing stricter environmental requirements and taxation schemes for emissions-intensive trade commodities (Marquardt, Gonzales-Zuñiga, et al., 2022). The introduction of even a moderate EU carbon tariff would incur significant economic losses and employment impacts for Argentina. An EU carbon price of USD 50 per tonne of CO₂e would reduce agricultural GDP by 7.9 % and job years by over 40,000 due to decreased demand for Argentinian beef and soybean exports and lower commodity price levels (ibid).

In addition to facing economic transition risks from climate action, Argentina's agricultural sector is highly vulnerable to physical climate change impacts, which has implications for producers' livelihoods, food security, and further environmental degradation (World Bank Group, 2021). For these reasons, improvements in agricultural productivity should coincide with efforts to reduce emissions from agricultural production to ensure the sector's future development while maintaining alignment with their climate commitments.

The objective of this study is **to identify and quantify potential GHG emissions mitigation measures that can be adopted by the Argentinian government and producers to reduce emissions from livestock and crop production**, while also providing economic and environmental co-benefits. Finally, the mitigation potential of this set of measures is compared to Argentinian climate targets for the medium- and long-term, as well as with independent studies that modelled potential pathways to reach net zero emission by 2050 in the Agriculture, Forestry and Other Land Uses (AFOLU) sector in Argentina (INTA; Fundacion Bariloche; Fundacion Avina, forthcoming).

2 ARGENTINA'S AGRICULTURE SECTOR

2.1 GENERAL CHARACTERISTICS

The Argentinian agriculture sector plays an important role in both a national and global context. In 2018, the sector contributed 6.1% of the country's gross GDP, which is well above the global average of 3.6% (OECD, 2019). Agriculture is an important source of foreign earnings, and accounted for more than 51% of total exports in 2018. The main export commodities are soy, maize, wheat, fruits and vegetables, beef, and wine (ibid).

Globally, Argentina is the third-largest exporter of soy and processed soy products, which made up 26% of total exports in 2019 and close to half of all agricultural exports (INDEC, 2019; OECD, 2019). The majority of soy is exported to China (Silveyra, n.d.). The Argentine agri-food market has faced high levels of government intervention in order to raise revenues and avoid defaulting on significant levels of sovereign debt (Heath & Bronstein, 2019). This has included raising export taxes on soy, wheat, corn, and beef despite stark opposition from farmers, who claim to already struggle with high financing costs, inflation, and production dry spells (ibid).

Argentina is the world's fifth-largest beef exporter and exports around a quarter of domestic production (Wyatt, 2021). Exports are predicted to considerably increase in the coming decade (OECD, 2019). The beef market in particular has been subject to high levels of government intervention. In June 2021, President Fernández instated a month-long beef export ban in order to stabilize domestic supply and price inflation (Wyatt, 2021). A similar, two-month long export ban was instated on corn in early 2021 to ensure there was enough raw material to use as livestock feed (Heath, 2020).

The Pampas region, a temperate zone, produces most of Argentina's export crops, hosts more than half of the country's beef cattle herd, and contains the country's main economic provinces of Buenos Aires, Córdoba, and Santa Fe (Munoz et al., 2021). It is also considered one of the most important grain-producing regions of the world (FAO & ITPS, 2021).

Despite extensive agricultural production systems and corresponding land, the share of agricultural employment in relation to the total workforce is quite low at 2%, attributed to the country's high rate of informal employment and high degree of mechanization (OECD, 2019; OIT, 2021).

2.2 LIVESTOCK PRODUCTION SYSTEMS

Livestock activity in Argentina is concentrated in the Pampas Region, followed by the northeast of the country. Livestock composition is predominantly bovine, followed by sheep, and to a lesser extent, swine, horses and goats, among others. The number of cattle (for both meat and milk) in the country increased steadily until the late 1970s and has remained relatively stable at around 50 million heads ever since (FAO, 2021).

As expected, livestock production plays a critical role in Argentina's economy and in promoting development. The Argentinian government planned to increase beef production by 46% by 2020 compared to 2010 levels, primarily by improving productivity (MAGyP, 2012). Although this target was not reached, meat production still increased about 22% in the same timeframe (Agrofy News, 2021; MAGyP, 2012). Livestock production is also responsible for a large share of Argentina's agricultural GHG emissions. The high GHG footprint of livestock production in Argentina presents an opportunity to improve herd management, nutrition (e.g. access to better quality fodder and forage), reproductive efficiency and growth rates, while reducing emissions at the same time (FAO & NZAGRC, 2017).

To meet growing demand for beef, intensive cattle farming systems have considerably expanded in Argentina. Around half of slaughtered cattle originate from feedlots, where they are fattened up in cramped conditions in the period before slaughter (Hartmann & Fritz, 2018). Despite feedlot cattle producing less methane from enteric fermentation than grass-fed cattle, feedlots account for additional GHG emissions from feed production and transportation and manure management (AWA, 2013). The overall emissions balance of each of these systems can significantly vary depending on a series of farm-specific factors; however, other more recent drivers such as animal welfare concerns, may increasingly counter the trend to intensify meat production, potentially diverting some of the demand towards higher quality meat (Marquardt, Woollands, et al. (2022).

It is in Argentina's own economic interest to address climate change, since beef producers have already begun to experience climate variability and more frequent and intense climatic events. In 2008/09, a severe drought in the North-central provinces caused over 700,000 livestock deaths, impeding production and resulting in a 70% decrease in exports and 15% decrease in consumption. Likewise, the 2016 El Niño event reduced milk production by 25% (FAO & NZAGRC, 2017).

2.3 CROP PRODUCTION SYSTEMS

Around 40 million hectares of land in Argentina are used for cropping systems. The predominant crops are soybean, wheat and maize, which made up 85% of total crop area in 2020 (MAYDS, 2020). Soybean production dominated Argentina's agricultural landscape in the past decades, using up to 59% of Argentina's total arable land in 2009 (Catacora-Vargas et al., 2012). In 2021, however, the soybean area reached its lowest in the past 15 years, covering 16.5 million hectares or 46.3% of the total planted area (Agroinforme, 2021). Meanwhile, the planted area of corn made up 7.3 million hectares or around 20.5% of total planted area in the same year (ibid).

Only a fraction of total cropland is irrigated, meaning favourable conditions for rainfed crop production. More than half of cropland is leased to producers (GYGA, n.d.). Most farms are small-scale family-operated farms (75%); they represent only 18% of agricultural land and 27% of agricultural output (FAO, n.d.). While cropland area has dramatically increased, the amount of small- and medium-size producers has decreased by around 40% (Hiba, 2021). Currently, 1% of producers control about 40% of productive land (ibid).

The increasing extent of rented farms has had some negative implications for soil and ecosystem health, since farmers are not incentivised to ensure the long-term health of their land (ibid). Despite that, no-till farming has been increasingly and steadily adopted since its introduction 30 years ago, and its practice remains high at 90% average nationwide. Some parts of the country reported increasingly lower rates in this practice, mostly due to the need to control highly resistant weeds (Brihet et al., 2021b).

In general, no tillage practices require a higher use of herbicides and lower use of fertilizers. Thus, Argentina has a comparatively low use of synthetic fertilizer than other countries. For example, in 2017, Argentina applied approximately 24 kilograms of nitrogen fertilizer per hectare. In contrast, Brazil applied around 82 kilograms of nitrogen fertilizer per hectare and Uruguay 63 kilograms per hectare (Ritchie & Roser, 2013). The southern part of the Pampas region shows higher rates of fertilizer application, attributed to lower phosphorus levels in those soils (Brihet et al., 2021b). However, on a national level, fertilizer is being underapplied in part due to short-term land tenures, which is affecting soil fertility (Tan, 2018). On the other hand, Argentina has one of the highest consumption rates of agrochemicals (mainly pesticides and herbicides), in part supported by the lack of a national law regulating their use and application (Belada, 2017).

2.4 IMPACTS ON LAND USE AND DEFORESTATION

Over the past 30 years, Argentina has significantly expanded the extent of land used for agricultural purposes from 26.5 million to just over 39 million hectares (World Bank Group, 2022). The land dedicated to soybean production has increased threefold, from close to 5 million in 1990 to 16.5 million hectares in 2020; wheat crops went up from 5 million to 6.5 million hectares, while corn plantations increased from 1.5 million to almost 8 million hectares in the same timeframe (FAO, 2021). The dramatic increase in agricultural land came in its majority at the expense of pastures and, to a lesser extent, forest land.

Between 2001 and 2014, Argentina lost 12% of its forest area (World Bank Group, 2016). The primary driver of deforestation has been industrial-scale land expansion for soy that is eventually exported, used as livestock feed, or grown for biofuels, while cattle production has played a secondary role. Typically, soybean expansion replaces existing pastureland, which pushes the cattle frontier further into forest land (ibid).

Argentina instituted its Native Forest Law in 2007, which required provinces to zone where forest could be cleared for agriculture, where forest could not be cleared but managed, and forest areas dedicated to conservation (Volante et al., 2016). However, favourable agricultural expansion conditions such as high commodity prices have outweighed the regulatory power of the Native Forest Law due to insufficient funding and a lack of enforcement (ibid). In 2018, 40% of deforestation occurred in designated conservation areas laid out by the Forest Law (Greenpeace, 2019).

3 ARGENTINA'S CLIMATE COMMITMENTS

3.1 AGRICULTURE AND LAND USE EMISSIONS

The agriculture and land use sector constitutes one of Argentina's most significant sources of GHG emissions. According to its Fourth Biennial Update Report to the UNFCCC, in 2018, Argentina emitted about 366 MtCO₂e, with agriculture and land use representing the second largest source at 143 MtCO₂e or 39% of total emissions (see Figure 1). Within the sector, the largest identified source of emissions is livestock at 57 MtCO₂e, mostly due to enteric fermentation methane emissions. Non-CO₂ emissions primarily from soil management constitute about 49 MtCO₂e. These include emission sources like the use of manure and synthetic fertilizers, as well as crop residues. Finally, land use related emissions are estimated at 37 MtCO₂e, with just over two thirds of that coming from deforestation (forest land converted to cropland and pastureland) and one third from cropland converted to pastures (Government of Argentina, 2021a).

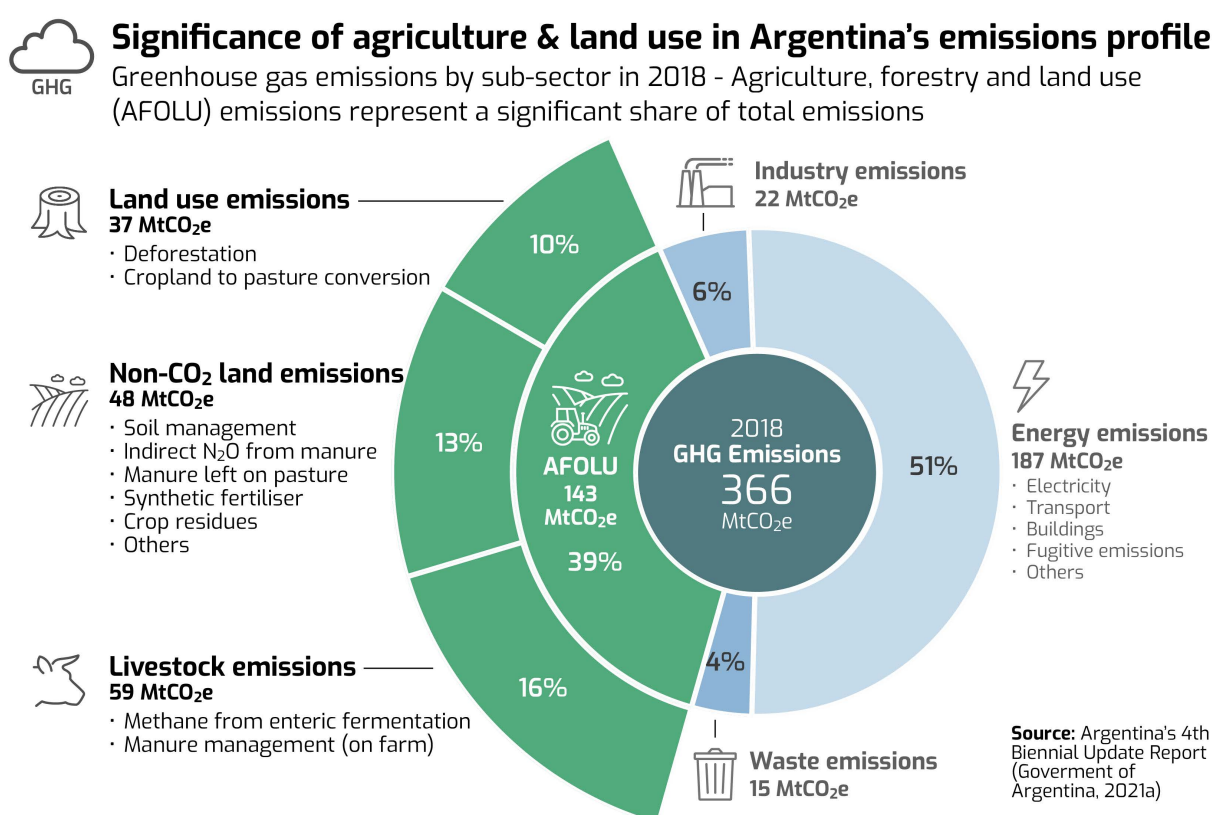


Figure 1. Emissions profile by sector for Argentina (2018).

In 2016, Argentina ratified the Paris Agreement and submitted its first Nationally Determined Contribution (NDC) to the UNFCCC. That same year, Argentina established a National Climate Change Cabinet (GNCC) by Executive Decree to facilitate the adoption of climate change policies and the achievement of its climate commitments under the Paris Agreement. In 2019, the cabinet was institutionalised by the National Climate Change Law and played an important role in the preparation of the country's second NDC submission in 2020 (Moreira Muzio, 2019).

In 2019, Argentina's Ministry of Agriculture, Livestock and Fisheries (MAGyP) published its National Plan for Agriculture and Climate Change which, in the context of the NDC, aims to prioritise adaptation, strengthen the role of the agro-industry as a source of solutions to climate change, integrate agro-industrial production into the context of the ecosystems on which it depends on for its sustainability, and encourage the development of technologies. The implementation of the plan will be coordinated between the

Sustainable Production Directory at MAGyP, and the National Climate Change Directory at the Secretariat for Environment and Sustainable Development (SGAyDS), and operated by several public and private entities (MAGyP, 2019). The National Plan for Agriculture and Climate Change includes several adaptation measures and three mitigation measures that are to be implemented by 2030:

1. Increased afforestation, expected to have an emissions mitigation contribution of 18 MtCO_{2e}
2. Improved crop rotation, expected to reduce emissions by 4.3 MtCO_{2e}
3. The use of biomass for energy generation, expected to reduce emissions by 3.4 MtCO_{2e}

According to the National Plan, the total mitigation potential of 25.7 MtCO_{2e} represents an additional reduction beyond Argentina's NDC commitment (MAGyP, 2019). This reduction represents about 15% of agricultural emissions in 2018 (Government of Argentina, 2021a), noting that the emissions reduction from the use of biomass for energy generation would actually be accounted for under the energy sector.

3.2 NDC

Argentina's second NDC, submitted in December 2020, includes an unconditional, absolute emissions reduction goal, applicable to all sectors of the economy and limiting GHG emissions to 359 MtCO_{2e} by 2030 (Government of Argentina, 2020). In April 2021, Argentina's President announced at the Leaders' Summit on Climate that they would further increase their climate action by 2% beyond what was submitted in December 2020 (Climate Action Tracker, 2021). This announcement was followed by an official submission to the UNFCCC in November the same year, to formalise the new goal to not exceed 349 MtCO_{2e} per annum nationally by 2030 (Government of Argentina, 2021b).

Argentina's NDC includes a vision for the agriculture sector to sustain its significant contribution to its GDP. Cereal production is projected to increase based on yield improvements and using limited additional land. Meat production is also foreseen to grow by increasing productivity through genetic improvements and good practices, rather than expanding pastureland or livestock population. In the forest sector, the NDC highlights plans to substantially reduce deforestation through sustainable forest management, to be achieved through the implementation of the National Plan for Forest Management with Integrated Livestock Production (MBGI) (Government of Argentina, 2020).

3.3 LTS AND CLIMATE NEUTRALITY

During the Climate Ambition Summit held in December 2020, President Alberto Fernández announced the country's commitment to reach climate neutrality by 2050. This was later included in the country's official submission of their second NDC which states that the Argentina is committed to prepare and submit a long-term low-emissions development strategy (LTS), with the goal of achieving climate-neutral development by 2050 (Government of Argentina, 2020). The Government is currently working on the LTS submission, which will provide further details as to how this target will be reached in their national circumstances, while acknowledging that achieving this target requires structural long-term changes and a gradual action plan in the short-term (Climate Action Tracker, 2021).

In this context, the project titled "Towards a national strategy for long-term low greenhouse gas emissions development in the AFOLU sector" looked into what would be the role of the Agriculture, Forestry and Other Land Uses (AFOLU) sector in achieving climate neutrality by 2050. This project was supported by the Strategic Partnerships for the Implementation of the Paris Agreement (SPIPA) project; financed by the European Union and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU); and implemented by INTA (National Institute of Agricultural Technology), Fundación Avina, Fundación Bariloche and GIZ. The project found that the climate neutrality goal, while still feasible, would require a significant increase in natural and planted forest areas (11% and 300%, respectively), halting deforestation, restoring and recovering native forests, doubling crop and livestock productivity without land expansion, and increasing protected areas (to at least 30%

of the territory) to prioritise the convergence between carbon conservation, biodiversity and water sources (INTA; Fundacion Bariloche; Fundacion Avina, forthcoming).



A pathway towards carbon neutrality in agriculture & land use

Independent modelling of a Paris Agreement compatible scenario for the AFOLU sector in Argentina 2000–2050

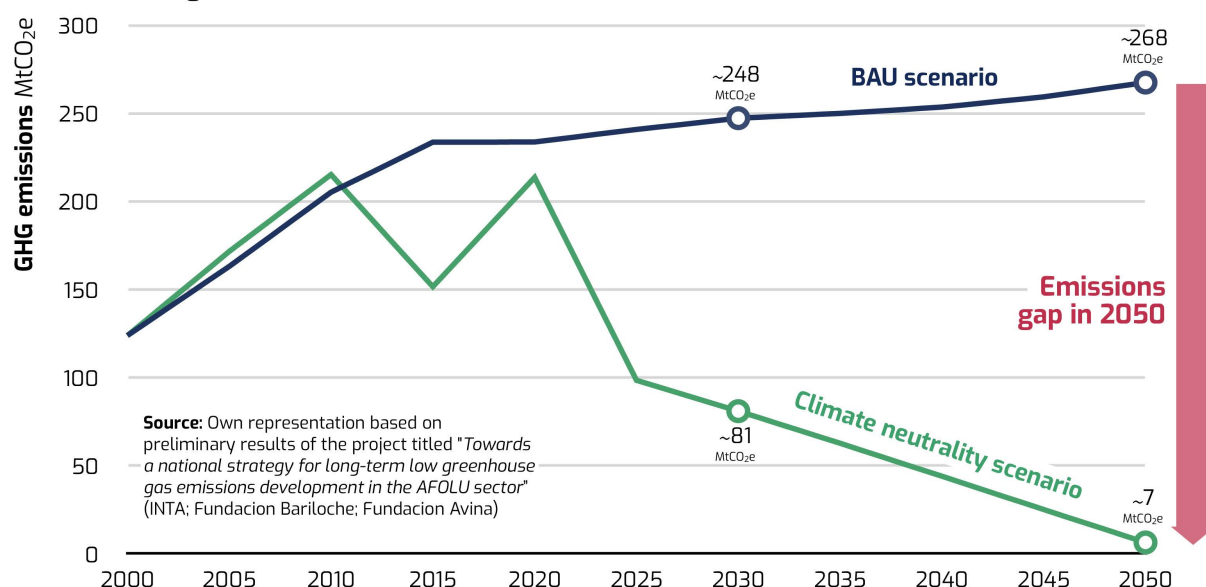


Figure 2: A pathway towards carbon neutrality in agriculture and land use.

Figure 2 shows the emissions gap between a business-as-usual or reference scenario and the results of a modelled pathway to reach climate neutrality in 2050. The reference scenario is built on the assumption that the sector will continue to grow and develop as in the last three to five years, without significant changes in technology or additional policy implementation. The climate neutrality scenario is taken from the preliminary results of the exercise of developing the long-term low-emission development strategy for the agriculture and land use sector (INTA; Fundacion Bariloche; Fundacion Avina, forthcoming).

4 MITIGATION OPTIONS FOR ARGENTINA'S AGRICULTURE SECTOR

This section provides an overview of a range of potential climate change mitigation measures in the agriculture sector in Argentina. The evaluation includes a brief description of each measure and its current state of implementation in the national context, an indication of the mitigation potential, as well as other co-benefits from its implementation. The eight mitigation measures evaluated for this report were prioritised from a longer list of mitigation options based on available literature to support calculations, perception of feasibility of implementation, relevance in the national context and potential additional benefits. The prioritisation process was done in close consultation with experts from the National Institute of Agricultural Technology (INTA).

To quantify the potential GHG emissions reduction from each of the prioritised measures, we developed an agricultural extension of the PROSPECTS+ tool; a bottom-up, Excel-based tool that calculates a complete time series of GHG emissions for the Argentinian agriculture sector from 1990 to 2050. We use relevant activity and emissions intensity data for livestock, crops, land use, and land use change to estimate emissions in a business-as-usual or reference scenario. We also divided the country into three geoclimatic regions: arid and semi-arid region, temperate region, and subtropical region, broadly following the approach taken by FAO & NZAGRC (2017). The potential changes in activity or emissions intensities are based on national and international literature review and are then used to estimate the GHG emissions reduction potential of each of the mitigation measures presented below.

4.1 LIVESTOCK-RELATED MITIGATION MEASURES

4.1.1 Feed optimisation - Use of deferred forage

Measure	Feed optimisation measures are commonly explored to increase productivity and profitability, while also reducing methane emissions from enteric fermentation. Some studies identified the use of deferred forage as one of the measures with the highest potential to balance increases in productivity and emissions reduction (FAO & NZAGRC, 2017). The use of deferred forage entails the conservation of forage in times of surplus, to then be used to fill feed-gaps in periods of deficit. This increase in forage supply and quality, leads to higher final weight at finishing or lower finishing age and lower enteric fermentation emissions due to the improved digestibility of the forage, effectively reducing emissions intensity of meat production (ibid).
Status	Forage availability in Argentina is heavily influenced by seasonality. The seasonal nutrient deficiencies in pastures lead to low growth rates of cattle, i.e. animals need to be retained longer in farms to be able to reach their target weights. There are, however, important variations in practices and emissions intensities across the different regions of the country. In the temperate region, where most of Argentina's cattle is, the average emissions per live weight is close to 20 kg CO ₂ e/kg lw; the subtropical region has higher emissions intensity at 31 kg CO ₂ e /kg lw (FAO & NZAGRC, 2017).
Potential	The quantification of the emissions reduction potential from the use of deferred forage was based on FAO & NZAGRC (2017), which estimates the reduction in enteric methane emissions intensity at 15 kg CO ₂ e /kg lw in the temperate region, and at 19 kg CO ₂ e /kg lw in the subtropical region. The study also reports a potential increase of 30% and 65% of productivity in the temperate and subtropical regions, respectively. We assumed this measure would be applied to 50% of the beef herd in the temperate and subtropical regions by 2030. Under these assumptions, we estimate that the use of deferred forage in beef cattle would lead to an increase of ~2.5 MtCO₂e in Argentina by 2030. While this measure reduces emissions intensity per kilogram of meat produced, increasing feed intake per animal will always result in higher absolute emissions, unless the herd size is reduced.
Co-benefits	The improved nutritional quality from deferred forage increases livestock productivity, resulting in positive economic benefits for farmers. However, it must be noted that unless the number of animals is reduced, implementing this measure will result in an increase of absolute emissions , which contradicts other efforts in the sector to reduce emissions in line with international mitigation commitments. These findings are in line with recent national studies exploring increases in beef production through efficiency, concluding that no scenario produced an increase in production without increasing environmental impacts (including emissions, biodiversity, ecotoxicity and erosion) in absolute terms (Gonzalez Fischer & Bilenca, 2020).

4.1.2 Feed optimisation – Improved nitrogen use efficiency on dairy cattle

Measure	Nitrogen use efficiency (NUE) refers to an animal's capacity to convert nitrogen in their diets, into milk and meat. Generally, a higher NUE represents higher animal productivity and lower nitrogen losses (European Commission, 2015). The protein content of animal diets is the most relevant factor in determining the NUE, and consequently, nitrogen emissions from livestock (i.e. direct and indirect N ₂ O emissions from manure). Studies show that diets for dairy cattle with lower than recommended protein levels can lead to higher NUE levels in Argentina, reducing the amount of nitrogen released to the environment in manure, without affecting milk production levels (Tier, 2021). At the same time, high protein content in diets is usually associated with a reduction in enteric emissions (due to increased digestibility). Reducing protein content can thus -in some cases- lead to an increase in enteric methane emissions.
Status	The average protein content in Argentina's dairy cattle diets is close to what is internationally recommended (18%). However, the NUE levels for Argentina's dairy cattle are below optimal, which highlights the potential to improve diets and NUE levels in the country's dairy industry (Tier, 2021).
Potential	To quantify the emissions reduction potential of altering cattle's diets to improve nitrogen use efficiency, we assumed the protein levels of dairy cattle's diets would be lowered to 13% (from 18%, currently). This is based on studies that indicate that altering diets to this level of protein content would increase NUE levels in Argentina's dairy cattle, lead to about 43% reduction in nitrogen emitted from manure and a negligible increase in methane emissions (Tier, 2021). Under these assumptions, we estimate that improving nitrogen use efficiency in dairy cattle could contribute emissions reductions of ~0.5 MtCO₂e in 2030. It must be noted that, although this measure results in an important reduction of manure related N ₂ O emissions, manure related emissions from dairy cattle are not significant emissions sources for Argentina. Under a baseline scenario, manure related N ₂ O emissions from dairy cattle could reach about 1 MtCO ₂ e in 2030; therefore, its reduction potential is also limited in absolute terms.
Co-benefits	Improved livestock nitrogen use efficiency will increase productivity while lowering costs for farmers and producers.

4.1.3 Health monitoring and reproductive disease prevention

Measure	Monitoring and improving the health and reproductive status of livestock can decrease the rate of disease and output loss, thus improving productivity and decreasing the emissions intensity of production. This can be achieved through strategic feed supplementation to improve nutritional management and reproductive status, accelerate growth and weight-gain, and correct dietary imbalances (FAO & NZAGRC, 2017). Reducing the extent of reproductive diseases and its negative impacts on cow fertility can reduce calf losses during gestation, resulting in a greater number of calves produced and weaned (ibid).
Status	The weaning rate in the temperate zone is quite low at 68%, meaning around 32% of cows do not produce a weaned calf (FAO & NZAGRC, 2017). The fertility rate in the temperate zone is around 80%, which could be improved by 5–10% by addressing seasonal nutrient deficiencies and supplementation during periods of low nutrient uptake, allowing cows to rebreed more readily (FAO & NZAGRC, 2017; P.J. Gerber et al., 2013). The death rate of cattle in Argentina is rather low at 2%, meaning most mitigation potential is derived from reduced breeding overhead and improved health and nutritive conditions (FAO & NZAGRC, 2017).
Potential	The quantification of the emissions reduction potential from health monitoring to reduce reproductive diseases was based on FAO & NZAGRC (2017), which estimates the reduction in enteric methane emissions intensity, as well as the increase in productivity for three geoclimatic zones in Argentina (temperate, subtropical and arid and semi-arid zones). We assumed this measure would be practiced in 50% of the beef herd in the temperate and subtropical regions by 2030. Under these assumptions, we estimate that the monitoring and reduction of reproductive diseases in beef cattle would lead to an increase of ~3 MtCO₂e in Argentina by 2030. While this measure reduces emissions intensity per kilogram of meat produced, its implementation results in higher absolute emissions, unless the herd size is reduced.
Co-benefits	Improved livestock health and disease monitoring will greatly benefit animal welfare and well-being, which will have positive impacts on food safety and biodiversity conservation (Llonch et al., 2020; OIE, 2017). At the same time, the increase in productivity will result in positive economic returns for farmers (FAO & NZAGRC, 2017). However, it must be noted that unless the number of animals is reduced, implementing this measure will result in an increase of absolute emissions , which contradicts other efforts in the sector to reduce emissions in line with international mitigation commitments. This findings are in line with recent national studies exploring increases in beef production through efficiency, concluding that no scenario produced an increase in production without increasing environmental impacts (including emissions, biodiversity, ecotoxicity and erosion) in absolute terms (Gonzalez Fischer & Bilenca, 2020).

4.1.4 Extended grain-finishing times

Measure	Intensified livestock systems can help meet growing demand for beef without expanding to more land or increasing cattle numbers (Modernel et al., 2016). Pasture grazing that is complemented by grain supplementation can improve weight gains, which increases animal productivity and reduces the emissions intensity per unit of product (Pierre J. Gerber et al., 2013). Extending the grain finishing time of cattle, for example, by 40 days can reduce the extent of enteric methane emissions while also reducing emissions from managed feedlot manure due to improved feed digestibility (Pierre J. Gerber et al., 2013).
Status	Currently, Argentina faces a low supply of high-quality pastures, and a large extent of feed rations have poor digestibility (55%) and low levels of crude protein (FAO & NZAGRC, 2017). In 2014, the number of cattle on a high-grain diet that were finished in confinement accounted for 23–25% of the total population (Rearte & Pordomingob, 2014). This has increased over time to up to half of slaughtered cattle originating from feedlots today (Hartmann & Fritz, 2018).
Potential	To quantify the emissions reduction potential of extended grain finishing, we assume this measure would be applied to beef cattle in the temperate zone (region Pampeana), which hosts 52% of the beef herd in Argentina. We assume this measure would only be implemented in cattle that is currently grain-finished, which we assume to be 75% of the Pampeana herd (FAO & NZAGRC, 2017). We assume a 2% reduction in the enteric fermentation emissions intensity of beef cattle production from extended grain finishing and an 11.3% reduction in manure methane emissions based on (Pierre J. Gerber et al., 2013). Under these assumptions, we estimate extended grain-finishing time can contribute emissions reductions of ~0.5 MtCO₂e in Argentina by 2030.
Co-benefits	Optimizing livestock feed via greater grain supplementation can improve the productivity of Argentinian livestock systems, resulting in higher net economic returns, lower labour costs, and increased regional development (Pereira et al., 2018). However, extending cattle's finishing time in intensive systems could have trade-offs with animal welfare and well-being which should be carefully assessed before the measure is implemented.

4.2 CROPLAND-RELATED MITIGATION MEASURES

4.2.1 Cover crops

Measure	Cover crops are grown on soils which otherwise would be bare in the winter season, and are planted in order to protect soil against erosion and nutrient losses through surface runoff. The inclusion of cover crops leads to an average increase in soil organic carbon (SOC) stocks, which increases carbon sequestration rates on cropland (Poeplau & Don, 2015). Cover crops also decrease soil Nitrate-N levels, contributing to reduced emissions from managed soils (Alvarez et al., 2017).
Status	Cover crops have not been widely implemented in Argentina. In 2018, approximately 2% of national cropland implemented cover crop practices (Brihet et al., 2021a). The area under cover crops reportedly doubled in 2019, reaching 4.7% of the total cropland and again in 2020, where it was reported to be applied to 9% of all cropland. In many regions, cover crops (whether for harvesting or non-harvesting purposes) are included to help control weeds and improve soil quality (Brihet et al., 2021a).
Potential	To quantify the emissions reduction potential of planting cover crops, we assumed cover crops practices will continue to pick up and will be implemented on 40% of cropland by 2030 (compared to 9%, currently). We also assume the implementation of cover crops will lead to added carbon sequestration rates of 0.45 tCO ₂ /ha on cropland soils (FAO & ITPS, 2021). Cover crops are also assumed to reduce soil nitrate levels by up to 30% (Alvarez et al., 2017), impacting indirect emissions from managed soils. Under these assumptions, we estimate cover crops could contribute emissions reductions of ~1.5 MtCO₂e in 2030.
Co-benefits	Cover crop practices increase and improve the functioning of soil roots, microorganisms and fauna. They promote infiltration and enhance percolation of water into the soils, reducing surface runoff and loss of nutrients (FAO & ITPS, 2021). In addition, the use of cover crops can greatly reduce the extent of wind and water erosion of soil particles, while retaining nitrogen (N) and phosphorus (P) in the root zone, which is highly beneficial for the following crop (MacSween & Feliciano, 2018). The enhanced soil quality can result in higher cash crop yields, most reliably if the cover crops used are legumes (ibid).

4.2.2 Crop rotation

Measure	Crop rotation is the practice of planting different crops sequentially on the same plot of land to improve soil health, optimize soil nutrient content, and combat pest and weed pressures. A simple rotation involves two or three crops, while complex rotations may incorporate a dozen or more (Rodale Institute, n.d.). Carrying out crop rotations can potentially increase the rate of soil organic carbon (SOC) storage, thereby sequestering more CO ₂ from the atmosphere (West & Post, 2002), and also decrease the extent of nitrate leaching, reducing N ₂ O emissions from managed soils (De Notaris et al., 2018).
Status	The shift to soybean becoming Argentina's most widely planted crop initially resulted in a lack of crop rotation, which has led to a significant depletion of agricultural soil fertility (Bronstein, 2013). Today, combining soybean with cereal crops is much more widely adopted. According to recent studies, in 2016, the share of cereal crops being used in crop rotations reached 40%. This practice continued increasing and reached almost 45% by 2019 (Brihet et al., 2021b).
Potential	To quantify the emissions reduction potential of crop rotation practices, we take into account only soybean, wheat and maize crop rotations and we use the share of cereal crops being used in crop rotations as reported by Brihet et al. (2021b), as a proxy to the share of land applying crop rotation. Following the historical trend in this practice, we assume up to 60% of soybean, wheat and maize crops could implement crop rotation by 2030. We take 0.26, 0.27 and 0.06 tCO ₂ /ha as average carbon sequestration rates for soybean, wheat and maize rotations, respectively (West & Post, 2002). Crop rotation is also assumed to reduce nitrogen leaching by up to 60%, reducing indirect N ₂ O emissions from managed soils (De Notaris et al., 2018). Under these assumptions, we estimate crop rotation could contribute emissions reductions of ~0.5 MtCO₂e in 2030.
Co-benefits	Soil quality can be significantly enhanced through crop rotation. Diverse crop rotations can enhance overall soil health and biodiversity, increase resistance to soil-borne pathogens, and improve soil structure, which in turn improves soil fertility, nutrient efficiency, and water conservation (FAO & ITPS, 2021; Shah et al., 2021).

4.2.3 Synthetic fertiliser (nutrient) management

Measure	Improved nutrient management achieved through a reduction in synthetic fertilizer use, for example through more precise application of fertiliser amounts and more deliberate timing of application, can significantly reduce nitrous oxide emissions associated with the overuse of synthetic fertilisers. The overuse of synthetic fertilisers does not derive productivity benefits, but rather results in greater costs and environmental degradation (Andersen & Bonnis, 2021; MacSween & Feliciano, 2018).
Status	Compared to other countries, the use of synthetic fertilizer is relatively low in Argentina. In 2018, Argentina applied on average around 28 kg/ha of nitrogen fertilizer while Brazil applied about 81 kg/ha (FAO, 2020). Wheat and corn are the two crops with higher need for fertilizer. Close to 85% of these crops depend on the application of synthetic fertilizer while only about 55% of soybean crops do (Tan, 2018). Since 2015, there's been a continuous growth in fertilizer use, coinciding with increased technification of the sector and increased production of both wheat and corn (Terré & Treboux, 2020). In 2019, fertilizer use increased by 9% (4.6 million tonnes of fertiliser) compared to the previous year, setting an all-time record for the country (ibid).
Potential	To quantify the emissions reduction potential of improved synthetic fertilizer management, we take the share of producers adopting nutrient management practices as reported by Brihet et al. (2021b), as a proxy to the share of land applying best practices for fertilizer use. This was reported to be 35% in 2016 and increased to 37% by 2019 (Brihet et al., 2021b). Following the historical trend, we assume good practices in fertilizer use could be applied on up to 50% of cropland by 2030. We also assumed a nitrogen emissions reduction factor of 0.44 tCO ₂ e/ha/year from improved fertilizer use (Project Drawdown, n.d.). Under these assumptions, we estimate that improved synthetic fertiliser management could contribute emissions reductions of ~0.5 MtCO₂e in 2030.
Co-benefits	Improved nutrient management can reduce the extent of eutrophication and water pollution caused by synthetic fertilizer overapplication, which has positive implications for both ecosystem and human health (Andersen & Bonnis, 2021). Integrated nutrient management can also result in cost savings for farmers due to decreased nitrogen fertilizer requirements (MacSween & Feliciano, 2018).

4.3 LAND USE-RELATED MITIGATION MEASURES

4.3.1 Silvopastoral systems

Measure	Silvopastoral farming is a practice that combines forestry, forage plants and livestock. It involves either planting trees on grazing land or rearing cattle in pre-existing native or managed forest, the latter being most relevant for Argentina. These systems combine tree species with farming activities, allowing the production of both timber and livestock products on the same unit of land. In this way, they reduce pressure on forests and avoid emissions from deforestation caused by the expanding livestock frontier.
Status	In Argentina, there is a wide range of silvopastoral systems that have been established across the country. However, those established in the northeast and northwest of the country (subtropical region) are of most relevance, as this is where livestock farming continues to expand and drive land use change. In particular, in the regions of Misiones, Corrientes and Chaco, silvopastoral systems currently represent 8%, 11% and 30% of the region's forest plantation area, respectively (Embrapa, 2021). This amounts to close to 30% of the subtropical region area already implementing this practice.
Potential	To quantify the emissions reduction potential of expanding silvopastoral systems, we limit the scope of their application to the subtropical region (including the regions of Misiones, Corrientes and Chaco) and we look only at systems combined with beef cattle livestock. Following the historical trend in implementing these systems, we assume up to 60% of the region's plantation area would be under silvopastoral systems by 2040 (compared to 30%, currently). We also assumed a load factor of 1.5 animals per hectare throughout the region (Embrapa, 2021). Under these assumptions, we estimate silvopastoral systems could contribute emissions reductions of ~24.5 MtCO₂e in 2030. Native forest loss in this region represents almost 90% of the country's overall forest loss (Mónaco et al., 2020). Under the above assumptions, native forest loss would be significantly reduced and the mitigation potential refers mostly from avoiding forest conversion to grassland.
Co-benefits	Well-managed silvopastoral systems increase soil and biomass carbon, improve production efficiency, and conserve water and biodiversity resources (Ibrahim et al., 2010). In addition, the diversification of products from cultivating timber and livestock products and increased livestock productivity from silvopastoralism can aid in alleviating poverty and improving the livelihoods of cattle producers (ibid). Preventing land use change via silvopastoralism can also reduce the extent of land degradation from overgrazing (FAO, 2006).

5 AGRICULTURE EMISSIONS TRAJECTORIES

Over the last two decades, emissions from livestock (i.e. enteric fermentation and manure management emissions) have consistently increased, although at low growth rates. Emissions related to crops and managed soils had a similar development. Land use change emissions on the other hand, have been consistently spiking and sharply decreasing over the years, although mostly remaining at high levels (see Figure 3).

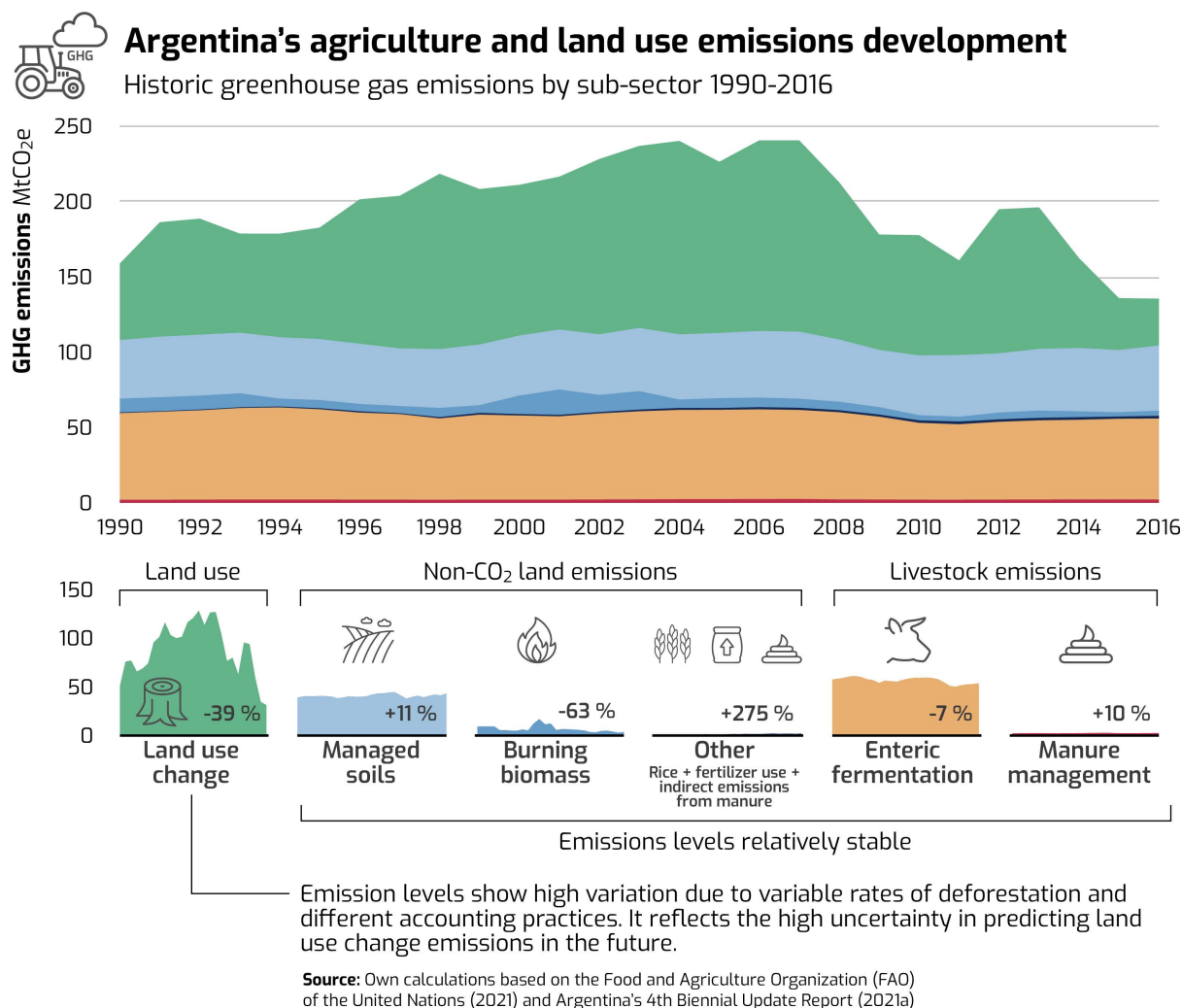


Figure 3. Emissions development for AFOLU sector in Argentina (1990 – 2016).

In 2016, livestock emissions represented 36% of the AFOLU sector emissions; cropland 31% and land use change made up the other 32% of sectoral emissions, in a record-low of emissions contribution (MAyDS, n.d.). In comparison, in 2013, emissions from land use change amounted to 54% of the AFOLU sector's emissions (ibid). This highlights their erratic and unpredictable behaviour (making it difficult to model them into the future) and their significant contribution to overall national emissions.

To analyse the mitigation potential of the prioritised measures, we developed a **reference scenario**. The reference scenario represents a conservative estimate of emissions development into the future, broadly following growth rates of the past three to five years and assuming no implementation of new policies or technologies. General assumptions behind this scenario are listed below (see Annex: PROSPECTS+ extension for the agriculture sector for more details):

- Livestock population will continue to increase over time, with growth rates below 1% per year; the emissions intensity per type of animal will remain the same as 2016 levels.

- Changes in land use followed a similar trend as that from the preliminary results of the project looking at developing the long-term low-emission development strategy for the agriculture and land use sector, which included a modelling exercise combining the use of FABLE and GLOBIOM models (INTA; Fundacion Bariloche; Fundacion Avina, forthcoming); the emissions intensity of each type of land use change will remain the same as 2016 levels.
- Crop-related activities will continue to increase over time, with growth rates of close to 1.5% per year; the emissions intensity of soil management will remain the same as 2016 levels.

According to our projections, under a reference scenario, AFOLU emissions in Argentina could reach 212 MtCO₂e in 2030 and up to 234 MtCO₂e in 2050, as shown in Figure 4.

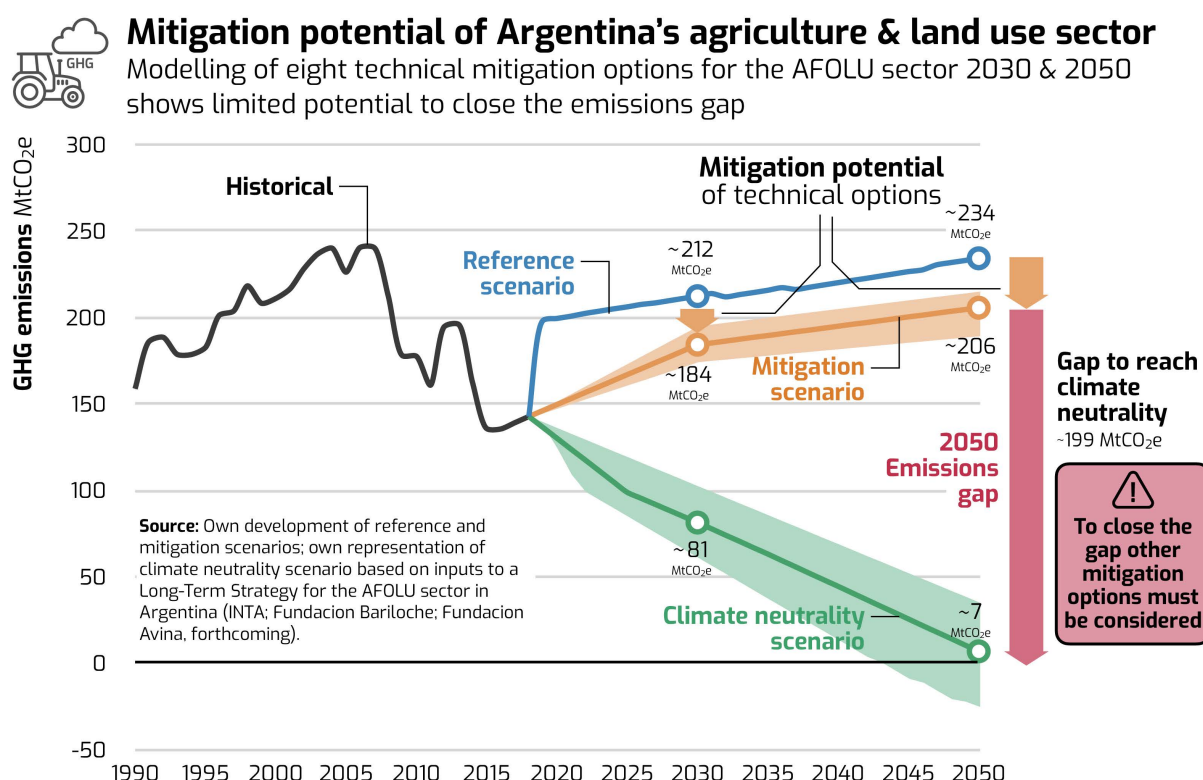


Figure 4: Reference, mitigation and climate neutrality scenarios for the AFOLU sector in Argentina

For the **mitigation scenario**, we aggregated the mitigation impact of eight measures that were prioritised in close consultation with colleagues from the National Institute of Agricultural Technology (INTA), taking into account available literature to support calculations, perception of feasibility of implementation, relevance in the national context and potential additional benefits (see Section 4 of this report and Annex: PROSPECTS+ extension for the agriculture sector or more details on the assumptions for each measure):

- Livestock related mitigation measures could reduce emissions by about 1 MtCO₂e in 2030
- Cropland related mitigation measures could reduce emissions by about 2.5 MtCO₂e in 2030
- Land use related mitigation measures could reduce emissions by about 24.5 MtCO₂e in 2030

According to our calculations, AFOLU emissions in Argentina could decrease to close to 183 MtCO₂e in 2030 and up to 206 MtCO₂e in 2050 under a mitigation scenario (see Figure 5). This represents a reduction of ~14% of emissions by 2030 compared to the reference scenario.



Mitigation potential and emissions gap in AFOLU sector in Argentina

AFOLU emissions expected to continue rising until 2030. Implementing technical mitigation options will reduce emissions but the gap to climate neutrality is still significant

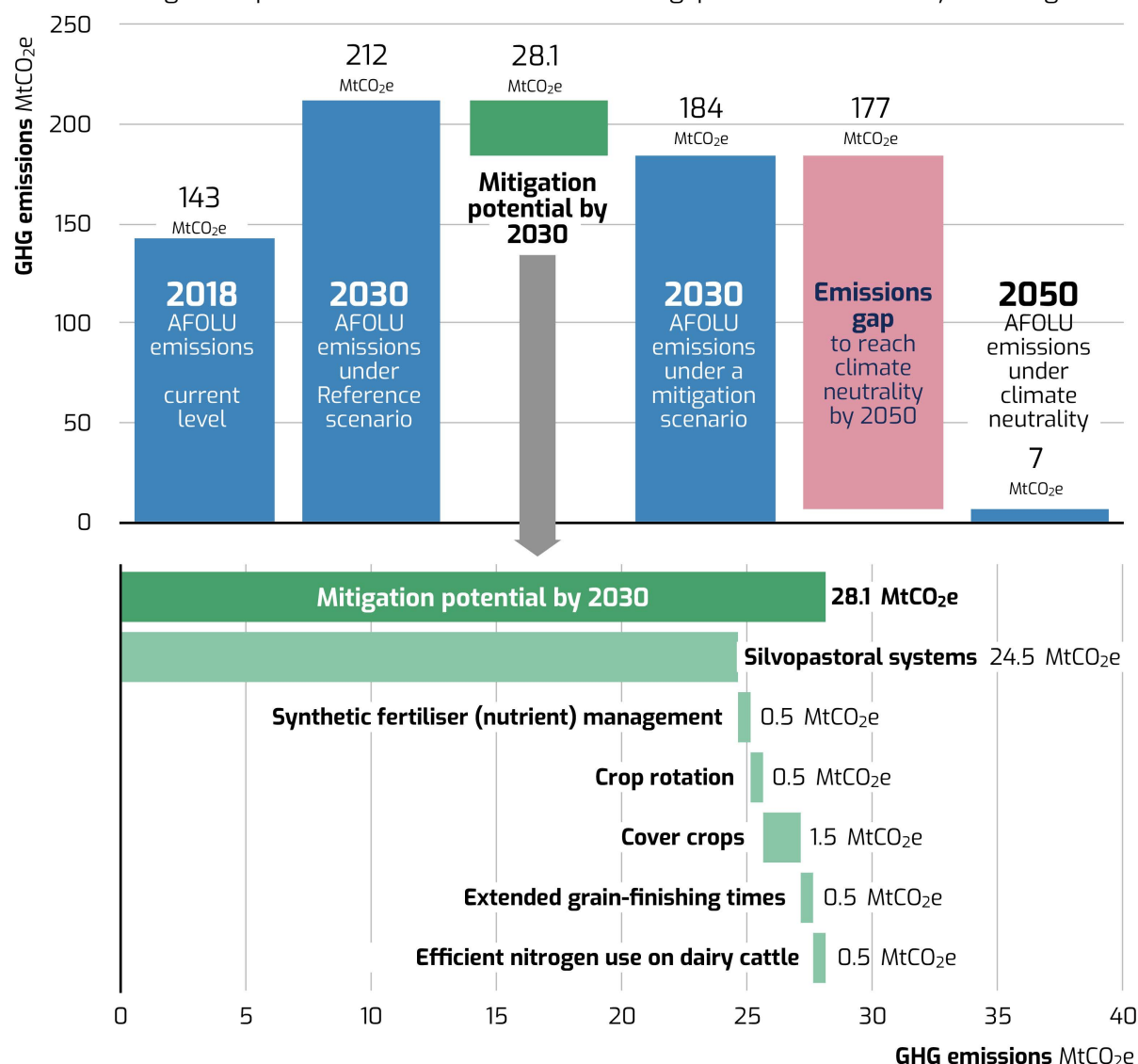


Figure 5: Mitigation potential and emissions gap in the AFOLU sector in Argentina

As it can be seen, over 80% of the potential emissions reduction is linked to the implementation of silvopastoral systems and, consequently, halting deforestation for pastureland expansion. Two of the prioritised measures to reduce emissions from livestock were focused on improving productivity, thus reducing emissions intensity per unit of product. According to our assessment, these two measures could rather lead to an increase in absolute emissions levels unless the size of the herd is reduced. Based on literature review and expert consultation, a reduction in the number of animals was considered unrealistic, especially in the context of higher productivity and profitability. We reported a potential increase of absolute emissions from the implementation of these measures (see Section 4.1) but we did not include them in the mitigation scenario described above.

The calculated mitigation potential of each measure assumes it is introduced in isolation to the other measures, but the combined implementation of these measures may lead to a degree of overlap in the mitigation outcome, leading to a potential overestimation of emissions reductions under this scenario. Thus, the final emissions reduction estimate under the mitigation scenario is meant to be taken only as a first order estimate, to illustrate the order of magnitude of the potentials and limitations of implementing these mitigation measures.

The third pathway is a **climate neutrality scenario**, developed based on preliminary results of modelled pathways to reach net zero emission by 2050 in the AFOLU sector in Argentina. These modelled pathways were developed outside this project in the context of preparing inputs to a Long-Term Strategy for the sector in Argentina (INTA; Fundacion Bariloche; Fundacion Avina, forthcoming). According to that modelling exercise, a climate neutrality scenario would reach total emissions levels of ~7 MtCO₂e in 2050, as shown in Figure 4 and Figure 5.

In their recent NDC submission, the government of Argentina committed to not exceeding net GHG emissions of 349 MtCO₂e in 2030 (Government of Argentina, 2021b). In comparison, the mitigation scenario would lead to AFOLU emissions of 183 MtCO₂e by 2030, which represents just over half (52%) of the emissions budget planned for that year under the NDC (see Figure 6). This leaves the remaining 48% (166 MtCO₂e) for all other sectors, including energy, which already emitted more than that (186 MtCO₂e) in 2018 (Government of Argentina, 2021a). Thus, drastic additional measures would need to be put in place in the energy, transport, industry, and waste sectors to limit and reduce emissions by 2030 in order to comply with the NDC target.

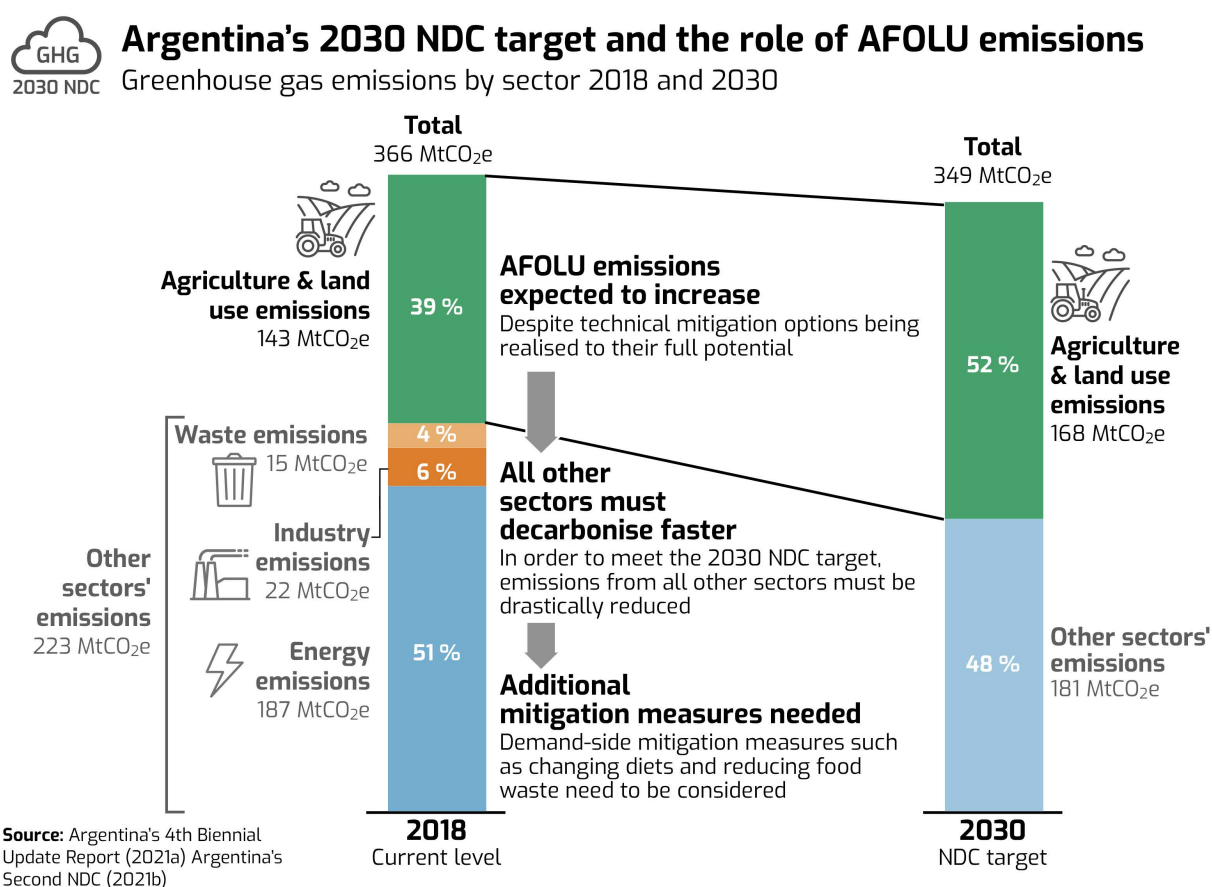


Figure 6: Argentina's 2030 NDC target and the role of AFOLU emissions.

6 CONCLUSION

If Argentina wants to maintain its status as a key global supplier of agricultural commodities and, at the same time, achieve climate commitments under the Paris Agreement, the agricultural sector must implement emissions mitigation measures. This study identified and quantified GHG emissions mitigation actions for both livestock and crop production that additionally improve productivity and provide environmental and economic co-benefits. These included: feed optimisation through the use of deferred forage and improving nitrogen use efficiency, extending grain finishing time for livestock already in intensive systems, improving livestock health and reducing the incidence of reproductive diseases, incorporating cover crops, applying crop rotation practices, improving synthetic fertiliser management, and expanding silvopastoral livestock systems on forest land.

According to our findings, the implementation of the eight selected mitigation measures in the AFOLU sector could reduce emissions by up to 14% in 2030 (~28 MtCO_{2e}) compared to a reference scenario. This results in emissions levels of ~183 MtCO_{2e} by 2030 for the AFOLU sector. This means that, although reducing emissions compared to a baseline, emissions from the AFOLU sector would still continue to grow until 2030, compared to current levels (see Figure 5). AFOLU emissions under the mitigation scenario would represent 52% of the emissions budget planned for NDC commitment for 2030, leaving other sectors (including energy, waste and industry) to make much more significant reductions to the sector emissions, in order to still reach the NDC target (see Figure 6).

When comparing the mitigation and climate neutrality scenario, there is still a substantial gap of about 100 MtCO_{2e} in 2030. This leaves the sector's emissions pathway completely misaligned with where it should be in 2030 to reach climate neutrality by 2050 (see Figure 5). To reach its mid-century target, Argentina would need to increase natural and planted forest areas, stop deforestation, and restore and recover native forests (INTA; Fundacion Bariloche; Fundacion Avina, forthcoming). These findings also underline an important risk, as there is large data uncertainty around emissions and sinks in the land use change and forestry sector.

A significant share of emissions reductions under the mitigation scenario (~80%) are attributable to one measure that limits land use change and deforestation, silvopastoral systems. This both highlights the importance of reducing land use change and deforestation, and makes evident the comparatively limited potential to reduce emissions through other technical measures that increase efficiency in existing livestock and crop production practices. This is in line with findings from Roe et al. (2021) that highlight the protection of forests and other ecosystems as having the highest mitigation efficiency and co-benefits.

By exploring further mitigation measures that go beyond reducing emissions intensity, Argentina could strengthen its position to reach its international climate commitments. According to several studies, demand-side measures such as shifting to more sustainable diets (i.e. with lower meat consumption) and reducing food waste have a particularly high mitigation potential and are likely to provide significant co-benefits at relatively lower costs (Roe et al., 2021). This refers only to emission reductions from diverted agricultural production; if emissions associated with land-use change are also included, demand-side measures have among the highest potentials to mitigate emissions in the AFOLU sector (ibid).

Argentina will likely have to drastically cut the GHG footprint of its AFOLU sector. This is not only imperative for aligning sectoral development with the country's stated climate ambition, but also to safeguard the agriculture industry's economic sustainability and the competitive advantage of export-oriented producers in carbon-constrained markets (Marquardt, Gonzales-Zuñiga, et al., 2022). Pressure on the sector to decarbonise is likely to progressively grow, as exogenous transition risks such as changing consumer preferences come into play. Where mitigation options and efficiency improvements for existing production systems prove inadequate to meet mounting risks, more fundamental transformations in the sector may be required (see Marquardt, Woollands, et al. (2022)).

It is the responsibility of the public sector to support AFOLU stakeholders in identifying and implementing required mitigation options, as well as in enabling more transformative change where required. The public sector can facilitate access to climate-smart agriculture solutions by providing support facilities and technology diffusion programmes where required. The Argentinian government could further improve regulatory frameworks (coverage and enforcement) aimed specifically at land-use change and forest protection, and explicitly reflecting mitigation requirements and potentials in its NDC and LTS.

It is important to note that the mitigation potential calculated in this report relies on the effective implementation of the analysed measures. However, successful implementation of climate policy in the agriculture and -even more- the land-use sectors is notoriously challenging, given its structure and interweaved cultural, socioeconomic, and behavioural elements. More work will be necessary to investigate optimal policy options that create the enabling framework necessary for both agribusiness and small-scale stakeholders to adopt climate-smart practices.

ANNEX: PROSPECTS+ EXTENSION FOR THE AGRICULTURE SECTOR

The PROSPECTS+ Agriculture extension is a bottom-up Excel-based tool that can be used to calculate historical and future agricultural GHG emissions at a national level. Relevant activity and intensity indicators are used to determine total emissions for each sub-sector. Its structure is based on the PROSPECTS+ tool, which covers all emissions intensive sectors (electricity, heat, buildings, transport, industry, waste, and agriculture), but focuses mostly on energy-related emissions and has a low level of detail on agriculture and land use activities, and associated emissions (NewClimate Institute, 2019).

PROSPECTS+ Agriculture divides the agriculture sector into three sub-sectors:

- i. Animal related emissions,
- ii. Land use related emissions,
- iii. Crop related emissions

Animal related emissions include those from enteric fermentation and manure management. Land use related emissions refer to emissions sources and sinks from changes in land use and forestry. Crop related emissions include emissions from fertilizer use, manure applied to soils, manure left on pasture (included as part of “managed soils”, broadly following IPCC guidelines), rice cultivation, crop residues and burning biomass.

The purpose of this tool is to transparently calculate a complete time series of GHG emissions for the agriculture sector, from 1990 to 2050. It also allows the mitigation potential of specific mitigation policies and actions in agriculture to be quantified.

Strengths and limitations of the model

Strengths

This model provides a simplified approach to estimating emissions from the agriculture sector. It provides a complete year-by-year emissions time series. Because it is a bottom-up Excel-based tool, the structure and calculations are easy to follow. Data needs are low and / or requires data usually available in international databases, and compatible with what countries usually report under the IPCC guidelines. This also makes results for different countries easy to compare. The assumptions made during scenario construction are clear and easy to understand and modify.

Current limitations

The goal of the land use change component is to reflect changes between land use types in a simplified manner that also reflects land constraints and possible geographical differences to highlight growth limitations to each land type. However, as the model is not spatially explicit, there are limitations in the extent to which country-specific land-use and biomes can be taken into account.

In its current format, the tool does not estimate the impact on yield changes due to changes in certain activities and intensities, for example, from the implementation of mitigation policies. The tool does not directly reflect changes in demand (food waste, dietary changes). This could be addressed by estimating a change in the number of animals based on external data, or a user-defined demand scenario.

The tool takes emissions intensities at national levels, which make it more difficult to assess the potential of specific options; although still possible to do so on a country-by-country basis, if the relevant data is available. Energy use from agriculture is not integrated into this tool extension but can be easily integrated through the PROSPECTS+ tool.

BASELINE METHODOLOGY AND ASSUMPTIONS

Animal related emissions

Emissions from enteric fermentation and manure management are calculated based on the number of animals (millions) and emissions intensities (tCO₂e/animal).

Main data sources and assumptions – Historical emissions	
Data source(s) used for historical data?	<p>Number of animals (million #):</p> <ul style="list-style-type: none"> 3rd BUR for 2016 numbers, then followed historical development based on FAO (2021), breakdown categories include: <ul style="list-style-type: none"> Dairy cattle Beef cattle and dairy followers Small ruminants (dairy and meat) Pigs Poultry Other <p>Emissions from enteric fermentation (MtCO₂e):</p> <ul style="list-style-type: none"> 3rd BUR for 2016 numbers, then followed historical development based on FAO (2021), same breakdown as above. <p>Emissions intensity of enteric fermentation (tCO₂e/head):</p> <ul style="list-style-type: none"> Calculated based on emissions and number of animals of each category, as described above. <p>Emissions from manure management (MtCO₂e):</p> <ul style="list-style-type: none"> 3rd BUR for 2016 numbers, then followed historical development based on FAO (2021), same breakdown as above. <p>Emissions intensity of manure management (tCO₂e/head):</p> <ul style="list-style-type: none"> Calculated based on emissions and number of animals of each category, as described above.
Until when?	2016
Important assumptions	Emissions converted to CO ₂ equivalent using global warming potential (GWP) of IPCC's Second Assessment Report (SAR)

Main data sources and assumptions – Future projections

Data source(s) used for historical data?	<p>Number of animals (million #):</p> <ul style="list-style-type: none"> Between 0.62% and 0.78% growth rates over time, estimated based on emissions growth for livestock. Taken from INTA; Fundación Bariloche; Fundación Avina (forthcoming publication on inputs to an LTS for the Argentinian AFOLU sector). Same breakdown categories as in historical series <p>Emissions intensity of enteric fermentation (tCO₂e/head):</p> <ul style="list-style-type: none"> Kept constant at 2016 levels. <p>Emissions intensity of manure management (tCO₂e/head):</p> <ul style="list-style-type: none"> Kept constant at 2016 levels.
Until when?	2030 (extended until 2050)
Important assumptions	<ul style="list-style-type: none"> We assumed the same population growth rate for all animals We assumed no new technologies or practices affecting the current emissions intensity of each farm systems would be implemented, therefore keeping intensities constant over time.

Land use related emissions

Emissions related to land use change are calculated based of the number of hectares (ha) of each type of land use type and emissions intensities (tCO₂/ha).

Main data sources and assumptions – Historical emissions

Data source(s) used for historical data?	<p>Land use change (million ha):</p> <ul style="list-style-type: none"> 3rd BUR (Table 39. Land use change matrix for 2014-2016; combined with Annex figures 220-222), breakdown categories include: <ul style="list-style-type: none"> Forest land remaining forest land Land converted to forest land (no data available) Cropland remaining cropland Forest converted to cropland Grassland converted to cropland Grassland remaining grassland Forest converted to grassland Cropland converted to grassland <p>Emissions from land use (MtCO₂e):</p> <ul style="list-style-type: none"> National GHG emissions inventory (2019), with same breakdown as above. <p>Emissions intensity from land (tCO₂e/ha):</p> <ul style="list-style-type: none"> Calculated based on emissions and area of each land use type, as described above.
Until when?	2016
Important assumptions	Emissions converted to CO ₂ equivalent using global warming potential (GWP) of IPCC's Second Assessment Report (SAR)

Main data sources and assumptions – Future projections

Data source(s) used for historical data?	<p>Land use change (million ha):</p> <ul style="list-style-type: none"> • Development trends taken from modelling done by INTA; Fundación Bariloche; Fundación Avina (forthcoming publication on inputs to an LTS for the Argentinian AFOLU sector), applies to the following categories: <ul style="list-style-type: none"> ○ Forest land remaining forest land ○ Cropland remaining cropland ○ Grassland remaining grassland • “Grassland converted to cropland” was estimated based on the annual change in “Grassland remaining grassland” • “Cropland converted to grassland” was estimated based on the annual change in “Cropland remaining cropland” • “Forest converted to cropland” and “Forest converted to grassland” were estimated by taking the forest land lost (annual change in “Forest land remaining forest land”) and splitting it evenly between the two categories • Land converted to forest land was not modelled due to no data available <p>Emissions intensity from land (tCO₂e/ha):</p> <ul style="list-style-type: none"> • Kept constant at 2016 levels for all land categories.
Until when?	2030 (extended until 2050)
Important assumptions	<ul style="list-style-type: none"> • To fix the model to total land area of the country, the category “other land” was estimated as total land minus the area of all the above land uses

Crop related emissions

Rice emissions are based on the area covered by rice paddies (ha) and the emissions intensities of rice production (tCO₂e/ha). Managed soils emissions are based on the amount of nitrogen content applied (kg of N content) and the emissions intensities of their application (tCO₂e/kg of N content). Emissions from burning biomass are based on the area being burnt (ha) and the emissions intensities of burning biomass (tCO₂e/ha).

Main data sources and assumptions – Historical emissions	
Data source(s) used for historical data?	<p>Rice area (ha):</p> <ul style="list-style-type: none"> Area harvested taken from FAO (2021) <p>Emissions from rice (MtCO₂e):</p> <ul style="list-style-type: none"> Taken as reported by FAO (2021) <p>Emissions intensity of rice (tCO₂e/ha):</p> <ul style="list-style-type: none"> Calculated based on emissions and rice area harvested <p>Managed soils (t of nutrients):</p> <ul style="list-style-type: none"> Tonnes of nutrients taken from FAO (2021), breakdown categories include: <ul style="list-style-type: none"> Synthetic fertilizer application Organic fertilizer application (no data available) Crop residue application Manure application Manure left on pasture <p>Emissions from managed soils (MtCO₂e):</p> <ul style="list-style-type: none"> Taken as reported by FAO (2021), with same breakdown as above. <p>Emissions intensity of managed soils (tCO₂e/kg of N content):</p> <ul style="list-style-type: none"> Calculated based on emissions and quantity of Nitrogen of each soil management practice, as described above. <p>Burning biomass (ha):</p> <ul style="list-style-type: none"> Area taken from FAO (2021), breakdown categories include: <ul style="list-style-type: none"> Burning forest land Burning savanna Fires in organic soils Burning crop residues <p>Emissions from burning biomass (MtCO₂e):</p> <ul style="list-style-type: none"> Taken as reported by FAO (2021), with same breakdown as above. <p>Emissions intensity of burning biomass (tCO₂e/ha):</p> <ul style="list-style-type: none"> Calculated based on emissions and area of each burning practice, as described above.
Until when?	2016
Important assumptions	Emissions converted to CO ₂ equivalent using global warming potential (GWP) of IPCC's Second Assessment Report (SAR)

Main data sources and assumptions – Future projections

Data source(s) used for historical data?	<p>Rice area (ha):</p> <ul style="list-style-type: none"> Between 1% and 1.5% growth rates over time, estimated based on emissions growth for cropland. Taken from INTA; Fundación Bariloche; Fundación Avina (forthcoming publication on inputs to an LTS for the Argentinian AFOLU sector). Same breakdown categories as in historical series <p>Emissions intensity of rice (tCO₂e/ha):</p> <ul style="list-style-type: none"> Kept constant at 2016 levels. <p>Managed soils (t of nutrients):</p> <ul style="list-style-type: none"> Between 1% and 1.5% growth rates over time, estimated based on emissions growth for cropland. Taken from INTA; Fundación Bariloche; Fundación Avina (forthcoming publication on inputs to an LTS for the Argentinian AFOLU sector). Same breakdown categories as in historical series <p>Emissions intensity of managed soils (tCO₂e/kg of N content):</p> <ul style="list-style-type: none"> Kept constant at 2016 levels. <p>Burning biomass (ha):</p> <ul style="list-style-type: none"> Between 1% and 1.5% growth rates over time, estimated based on emissions growth for cropland. Taken from INTA; Fundación Bariloche; Fundación Avina (forthcoming publication on inputs to an LTS for the Argentinian AFOLU sector). Same breakdown categories as in historical series <p>Emissions intensity of from burning biomass (tCO₂e/ha):</p> <ul style="list-style-type: none"> Kept constant at 2016 levels.
Until when?	2030 (extended until 2050)
Important assumptions	<ul style="list-style-type: none"> We assumed the same growth rates for activity levels of rice, managed soils and burning practices. We assumed no new technologies or practices affecting the current emissions intensity of each farm systems would be implemented, therefore keeping intensities constant over time.

MITIGATION POTENTIALS METHODOLOGY AND ASSUMPTIONS

The calculations below are based on 2016 as the last available data year and using the third Biennial Update Report for historical emissions. The Forth Biennial Update Report, including data until 2018, was only published in December 2021, when the calculations were already finished.

Feed optimisation – Use of deferred forage

Description: Feed optimisation measures aim to increase productivity and profitability, while reducing methane emissions from enteric fermentation. The use of deferred forage entails the conservation of forage in times of surplus, to then be used to fill feed gaps in periods of deficit. This increase in forage supply and improvement in quality, leads to higher final finishing weights or lower finishing ages and lower enteric fermentation emissions intensity per kilogram of liveweight. Since this measure leads to an increase in liveweight, absolute emissions would increase unless the number of animals is reduced.

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: increase of 2.7 MtCO₂e in 2030

Table 1: Main assumptions to quantify policy impacts – use of deferred forage

	Assumptions	Source / comments
Geographic scope of the measure	Assumed 50% of cattle switch to deferred forage in the temperate and subtropical regions	Assumption. Geographic regions defined as in FAO & NZAGRC (2017)
Share of national beef herd	Temperate zone: 52% Subtropical zone: 37%	Taken from FAO & NZAGRC (2017)
Emissions intensity per live weight (Temperate zone)	19.80 kg CO ₂ e / kg lw	Total emissions intensity recalculated based on FAO & NZAGRC (2017) and the intensities specified for cria, recia and engorde. Estimated weights of each system are: cria = 1.5; recia = 1; engorde=1
Emissions intensity per live weight (Subtropical zone)	30.73 kg CO ₂ e / kg lw	Same as above
Reduction in enteric methane emission intensity / live weight	Temperate zone: -23.4% Subtropical zone: -39.1%	Taken from FAO & NZAGRC (2017) - use of deferred forage (Figure 5.1)
Change in live weight	Temperate zone: 30.5% Subtropical zone: 65.0%	Taken from FAO & NZAGRC (2017) - use of deferred forage (Figure 5.1)
Average finishing weight	Temperate zone: 360 kg Subtropical zone: 420 kg	From FAO & NZAGRC (2017) - average of finishing weights in different systems (calculated from Figure 3.1)

Feed optimisation – Improved nitrogen use efficiency on dairy cattle

Description: A higher nitrogen use efficiency (NUE) represents higher animal productivity and lower nitrogen losses. The protein content of animal diets is the most relevant factor in determining the NUE, and thus, nitrogen emissions from livestock (i.e., direct and indirect N₂O emissions from manure). Diets with lower protein levels can lead to higher NUE levels and lower nitrogen in manure.

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: reduction of 0.4 MtCO₂e in 2030

Table 2: Main assumptions to quantify policy impacts – improved nitrogen use efficiency

	Assumptions	Source / comments
Protein level in dairy cattle diets	Currently at 18% and could be lowered to 13% by 2030	Based on results from Tieri, M.P. (2021)
Changes in direct & indirect N₂O from manure	N concentration currently at around 440 g N/head/day, could go down to 250 g N/head/day. This represents a 43.4% reduction in N emitted in manure	Assumption based on results of field work in Tieri, M.P. (2021)
Changes in methane emissions	Assumed to be non-significant	Assumption based on expert consultation and Tieri, M.P. (2021)

Health monitoring and reproductive disease prevention

Description: Monitoring and improving the health and reproductive status of livestock can decrease the rate of disease and output loss, thus improving productivity and decreasing the emissions intensity per kilogram of liveweight. Reducing the extent of reproductive diseases and its negative impacts on cow fertility can reduce calf losses during gestation, resulting in a greater number of calves produced and weaned. Since this measure leads to an increase in liveweight, absolute emissions would increase unless the number of animals is reduced.

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: increase of 3.3 MtCO_{2e} in 2030

Table 3: Main assumptions to quantify policy impacts – health monitoring and reproductive disease prevention

	Assumptions	Source / comments
Geographic scope of the measure	Assumed 50% of cattle will be subject to health monitoring practices in the temperate and subtropical region	Assumption. Geographic regions defined as in FAO & NZAGRC (2017)
Share of national beef herd	Temperate zone: 52% Subtropical zone: 37%	Taken from FAO & NZAGRC (2017)
Emissions intensity per live weight (Temperate zone)	19.80 kg CO _{2e} / kg lw	Total emissions intensity recalculated based on FAO & NZAGRC (2017) and the intensities specified for cria, recia and angorde. Estimated weights of each system are: cria = 1.5; recia = 1; engorde=1
Emissions intensity per live weight (Subtropical zone)	30.73 kg CO _{2e} / kg lw	Same as above
Reduction in enteric methane emission intensity / live weight	Temperate zone: -14.8% Subtropical zone: -21.7%	From FAO & NZAGRC (2017) – reduced reproductive diseases (Figure 5.1)
Change in live weight	Temperate zone: 20.6% Subtropical zone: 31.4%	From FAO & NZAGRC (2017) – reduced reproductive diseases (Figure 5.1)
Average finishing weight	Temperate zone: 360 kg Subtropical zone: 420 kg	From FAO & NZAGRC (2017) - average of finishing weights in different systems (calculated from Figure 3.1)

Extended grain-finishing times

Description: Extending the grain finishing time of cattle can reduce the extent of enteric methane emissions while also reducing emissions from managed feedlot manure due to improved feed digestibility.

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: reduction of 0.5 MtCO_{2e} in 2030

Table 4: Main assumptions to quantify policy impacts – extended grain-finishing times

	Assumptions	Source / comments
Geographic scope of the measure	Assumed this measure would be applied to cattle in the temperate zone and only to cattle that is currently grain-finished	Assumption. Geographic regions defined as in FAO & NZAGRC (2017)
Share of national beef herd	Temperate zone: 52%	Taken from FAO & NZAGRC (2017)
Share of national beef herd currently grain-finished	75%	Assumptions based on expert consultation.
Additional grain-finish time	40 days	Assumption based on Pierre J. Gerber et al. (2013)
Reduction in enteric methane emission intensity	-2%	Assumption based on Pierre J. Gerber et al. (2013)
Reduction in methane in manure	-11.3%	Assumption based on Pierre J. Gerber et al. (2013)
Share of methane emissions in manure	96%	Calculated based on historical data (2016)

Cover crops

Description: The inclusion of cover crops leads to an average increase in soil organic carbon (SOC) stocks, which increases carbon sequestration rates on cropland. Cover crops also decrease soil Nitrate-N levels, contributing to reduced emissions from managed soils (indirect emissions from synthetic fertilizer and crop residues).

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: reduction of 1.3 MtCO_{2e} in 2030

Table 5: Main assumptions to quantify policy impacts – cover crops

	Assumptions	Source / comments
Share of cropland with cover crop application	Increase from 2% in 2016 to 40% in 2030	Based on Brihet et al. (2021a), assuming the same trend as in the last 3 years (2017-2020)
Cover crop sequestration potential	-0.45 tC/ha/year	Based on FAO & ITPS (2021), see page 312, table 117
Nitrate-N decrease from cover crop application	30%	Based on Alvarez et al. (2017), assumed nitrate-N is linked to indirect emissions from soils. Meta-analysis from Argentinian Pampas
Indirect emissions from synthetic fertilizer (proportion)	32% in 2016	Calculated based on historical data (2016)
Indirect emissions from crop residues (proportion)	23% in 2016	Calculated based on historical data (2016)

Crop rotation

Description: Carrying out crop rotations can potentially increase the rate of soil organic carbon (SOC) storage, thereby increasing cropland carbon sequestration rates, while decreasing the extent of nitrate leaching, reducing N₂O emissions from managed soils.

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: reduction of 0.6 MtCO₂e in 2030

Table 6: Main assumptions to quantify policy impacts – crop rotation

	Assumptions	Source / comments
Share of cropland with crop rotation	Increase from 39% in 2016 to 60% in 2030	Based on historical trend from Brihet et al. (2021b) and expert consultation
Crops included	Corn, wheat and soybean	Assumption based on expert consultation
Current share of cropland used for production	Corn: 16% Wheat: 12% Soybean: 57%	Based on FAO (2021), taking 2016 harvested area in million hectares relative to total cropland
Elasticities of carbon sequestration	Corn: -0.26 tCO ₂ /ha Wheat: -0.27 tCO ₂ /ha Soybean: -0.06 tCO ₂ /ha	Taken from West & Post (2002)
Nitrogen leaching reduction from crop rotation	60%	Taken from De Notaris et al. (2018). Leaching emissions are linked to indirect emissions from soils. Assume kg nutrients is equivalent to kg N
Indirect emissions from synthetic fertilizer (proportion)	32% in 2016	Calculated based on historical data (2016)
Indirect emissions from crop residues (proportion)	23% in 2016	Calculated based on historical data (2016)

Synthetic fertiliser (nutrient) management

Description: Improved nutrient management achieved through a reduction in synthetic fertilizer use via more precise and deliberate application can reduce nitrous oxide emissions.

Period of implementation: 2022-2030 (kept constant afterwards)

Emissions impact: reduction of 0.7 MtCO_{2e} in 2030

Table 7: Main assumptions to quantify policy impacts – synthetic fertiliser (nutrient) management

	Assumptions	Source / comments
Share of cropland with improved nutrient management	Increase from 34% in 2016 to 50% in 2030	Based on historical trend from Brihet et al. (2021b), graph 7
Nitrogen emissions reduction potential	-0.44 tCO _{2e} /ha/year	Taken from Project Drawdown (no date)

Silvopastoral systems

Description: Silvopastoral systems combine tree species with farming activities, allowing the production of both timber and livestock products on the same unit of land. In this way, they reduce pressure on forests and result in avoided emissions from deforestation caused by the expanding livestock frontier.

Period of implementation: 2022-2040 (kept constant afterwards)

Emissions impact: reduction of 24.6 MtCO_{2e} in 2030

Table 8: Main assumptions to quantify policy impacts – silvopastoral systems

	Assumptions	Source / comments
Geographic scope of the measure	Focused only on systems in the subtropical zone	Assumption based on expert consultation. Geographic regions defined as in FAO & NZAGRC (2017)
Share of area under silvopastoral systems	Currently at 29%, assumed it will reach up to 70% in the subtropical zone by 2040	Calculations based on information presented at Embrapa (2021) and expert consultation for 2040
Share of beef cattle in silvopastoral systems	Currently at 31%, assumed it will reach up to 63% in the subtropical zone	Calculations based on own herd growth projections and data presented at Embrapa (2021)
Load factor	0.9 head/ha	Based on Embrapa (2021) and expert consultation. We used this load factor to estimate the number of animals that would move silvopastoral systems and thus, reduce pressure on forest land. We estimated a correlation between number of heads and forest land based on the equation below: $Y = -0.9276x + 91.677$ ($R^2 = 0.9998$)

Agrofy News. (2021). *El consumo de carne vacuna cerró el 2020 entre los más bajos en 100 años*. <https://news.agrofy.com.ar/noticia/191394/consumo-carne-vacuna-cerro-2020-mas-bajos-100-anos>

Agroinforme. (2021). *Plantio de soja na Argentina atinge 46,3% da área prevista; semeadura do milho chegou a 31,1%*. Agroinforme. <http://agroinforme.com.br/2021/12/03/plantio-de-soja-na-argentina-atinge-463-da-area-prevista-semeadura-do-milho-chegou-a-311/>

Alvarez, R., Steinbach, H. S., & De Paepe, J. L. (2017). Cover crop effects on soils and subsequent crops in the pampas: A meta-analysis. *Soil and Tillage Research*, 170, 53–65. <https://doi.org/10.1016/j.still.2017.03.005>

Andersen, M. S., & Bonnis, G. (2021). *Climate mitigation co-benefits from sustainable nutrient management in agriculture: Incentives and opportunities* (Issue 186, p. 46). Organisation for Economic Co-operation and Development (OECD). <https://www.oecd-ilibrary.org/docserver/a2960c54-en.pdf?expires=1646923438&id=id&accname=guest&checksum=8DD2EB97B8E9D014FF4184EF1EF9E7F7>

AWA. (2013). *A Breath of Fresh Air*. Animal Welfare Approved. <https://sites.evergreen.edu/grazing/wp-content/uploads/sites/66/2015/03/A-Breath-of-Fresh-Air-v1.pdf>

Belada, A. P. (2017). *Regulación de los agroquímicos en la Argentina: hacia una ley general de presupuestos mínimos regulatorios* [University of San Andrés]. <https://repositorio.udesa.edu.ar/jspui/bitstream/10908/15623/1/%5BP%5D%5BW%5D%5DT.%5BG.%5BAbo.PazBelada%2CAlejandro.pdf>

Brihet, J., Gayo, S., & Regeiro, D. (2021a). *Cultivos de cobertura - Informe mensual N° 42*. Bolsa de Cereales. <https://www.bolsadecereales.com/images/retaa/2021-03/220-retaamensualn°42-cultivoscobertura.pdf>

Brihet, J., Gayo, S., & Regeiro, D. (2021b). *Prácticas ambientales en la producción agrícola Argentina - Informe mensual N° 41*. Bolsa de Cereales. <https://www.bolsadecereales.com/images/retaa/2021-02/219-retaamensualn°41-practicassambientales.pdf>

Bronstein, H. (2013). *Lack of Crop Rotation Slowly Turns Argentine Pampas into "Sand."* Reuters. <https://www.scientificamerican.com/article/analysis-lack-of-crop-rotation-sl/>

Catacora-Vargas, G., Galeano, P., Agapito-Tenfen, S. Z., Aranda, D., Palau, T., & Nodari, R. O. (2012). *Soybean Production in the Southern Cone of the Americas: Update on Land and Pesticide Use*. 43. <http://genok.no/wp-content/uploads/2013/03/Soybean-Production-in-the-Southern-Cone-of-the-Americas-Update-on-Land-and-Pesticide-Use.pdf>

Climate Action Tracker. (2021). *Argentina country update (15 September 2021)*. <https://climateactiontracker.org/countries/argentina/>

De Notaris, C., Rasmussen, J., Sørensen, P., & Olesen, J. E. (2018). Nitrogen leaching: A crop rotation perspective on the effect of N surplus, field management and use of catch crops. *Agriculture, Ecosystems and Environment*, 255(November 2017), 1–11. <https://doi.org/10.1016/j.agee.2017.12.009>

Embrapa. (2021). *Seminario Internacional: Sistemas agrosilvopastoriles en América Latina y el Caribe - Sesión con enfoque en Argentina*.

European Commission. (2015). *Testing nitrogen-use efficiency in cows*. <https://cordis.europa.eu/article/id/151816-testing-nitrogenuse-efficiency-in-cows>

FAO. (n.d.). *Argentina | World Agriculture Watch*. Food and Agricultural Organization of the United Nations (FAO). Retrieved January 12, 2021, from <http://www.fao.org/world-agriculture-watch/our-program/arg/en/>

FAO. (2006). *Livestock's long shadow: Environmental issues and options*. <https://www.fao.org/3/a0701e/a0701e.pdf>

FAO. (2020). *Fertilizers indicators*. Food and Agricultural Organization of the United Nations (FAO). <http://www.fao.org/faostat/en/#data/EF/metadata>

FAO. (2021). *FAOSTAT Emissions Database*. Food and Agricultural Organization of the United Nations (FAO). <http://www.fao.org/faostat/en/#data>

FAO, & ITPS. (2021). Recarbonizing global soils – A technical manual of recommended management practices. In *Recarbonizing global soils – A technical manual of recommended management practices* (Vol. 4). Food and Agricultural Organization of the United Nations (FAO). <https://doi.org/10.4060/cb6598en>

FAO, & NZAGRC. (2017). *Low emissions development of the beef cattle sector in Argentina* (p. 39). Food and Agricultural Organization of the United Nations (FAO) & New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC). <http://www.fao.org/3/i7671e/i7671e.pdf>

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities*. Food and Agriculture Organization of the United Nations (FAO). <https://doi.org/10.1016/j.anifeeds.2011.04.074>

Gerber, Pierre J., Henderson, B., & Makkar, H. P. S. (2013). *Mitigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO₂ emissions*. Food and Agricultural Organization of the United Nations (FAO). <https://www.fao.org/3/i3288e/i3288e.pdf>

Gonzalez Fischer, C., & Bilencia, D. (2020). Can we produce more beef without increasing its environmental impact? Argentina as a case study. *Perspectives in Ecology and Conservation*, 18(1), 1–11. <https://doi.org/10.1016/J.PECON.2019.12.002>

Government of Argentina. (2020). *Argentina's Second Nationally Determined Contribution [Segunda Contribución Determinada a Nivel Nacional de la República Argentina]*. Ministry of Environment and Sustainable Development (MAYDS). https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Argentina/Second/Argentina_SegundaContribucionNacional.pdf

Government of Argentina. (2021a). *Cuarto Informe Bienal de Actualización de Argentina a la Convención Marco de las Naciones Unidas para el Cambio Climático*. <https://unfccc.int/documents/419772>

Government of Argentina. (2021b). *Segunda actualización de la meta de emisiones netas de Argentina al 2030 - Octubre 2021*. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Argentina/Second/Actualizacion_meta_de_emisiones_2030.pdf

- Government of Argentina. (2022). *¿Qué es la neutralidad de carbono?* <https://www.argentina.gob.ar/ambiente/contenidos/neutralidad-de-carbono>
- Greenpeace. (2019). *Greenpeace: "Durante 2018, se deforestó ilegalmente el equivalente a dos veces Buenos Aires."* <https://www.greenpeace.org/argentina/story/issues/bosques/greenpeace-durante-2018-se-deforesto-illegalmente-el-equivalente-a-dos-veces-buenos-aires/>
- GYGA. (n.d.). *Argentina*. Global Yield Atlas. <https://www.yieldgap.org/argentina>
- Hartmann, A., & Fritz, T. (2018). *Trade at any cost?* foodwatch. https://www.foodwatch.org/fileadmin/foodwatch_international/campaigns/TTIP/2018-02_Trade-at-any-cost_report-foodwatch-powershift_EN.pdf
- Heath, M. (2020). *UPDATE 5-Argentina suspends corn exports to ensure domestic food supplies*. Reuters. <https://www.reuters.com/article/argentina-corn-idINL1N2JA1MN>
- Heath, M., & Bronstein, H. (2019). *Argentina's new government hikes export taxes on disgruntled farmers*. Reuters. <https://www.reuters.com/article/us-argentina-grains-idUSKBN1YI0II>
- Hiba, J. (2021). *Argentina's land laws stifle sustainable agriculture*. China Dialogue. <https://chinadialogue.net/en/food/argentinas-land-laws-stifle-sustainable-agriculture/>
- Ibrahim, M., Guerra, L., Casasola, F., & Neely, C. (2010). Importance of silvopastoral systems for mitigation of climate change and harnessing of environmental benefits. In *Grassland Carbon Sequestration: Management, Policy and Economics*. <http://www.fao.org/docrep/013/i1880e/i1880e09.pdf>
- INDEC. (2019). *Comercio exterior* (Vol. 4). National Institute of Statistics and Censuses (INDEC). https://www.indec.gob.ar/uploads/informesdeprensa/complejos_03_201711CCEF8E.pdf
- INDEC. (2021). *Comercio exterior*. National Institute of Statistics and Censuses (INDEC). https://www.indec.gob.ar/uploads/informesdeprensa/ica_01_223173EDC303.pdf
- INTA; Fundacion Bariloche; Fundacion Avina. (n.d.). *Hacia una Estrategia Nacional de Desarrollo con Bajas Emisiones de Gases de Efecto Invernadero a Largo Plazo en el Sector Agropecuario, Forestal y Otros Usos de la Tierra (AFOLU) de Argentina*.
- Llonch, P., Haskell, M. J., Turner, R. J., & Dewhurst, S. P. (2020). Review: current available strategies to mitigate greenhouse gas emissions in livestock systems: an animal welfare perspective. *Animal*, 11(2), 274–284. <https://doi.org/10.1017/S1751731116001440>
- MacSween, K., & Feliciano, D. (2018). *Co-benefits of mitigation options in the CCAFS- Mitigation Options Tool (CCAFS-MOT)*. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://cgspace.cgiar.org/handle/10568/98430%0Ahttps://cgspace.cgiar.org/bitstream/10568/98430/1/CCAFS_WP_229.pdf%0Ahttps://cgspace.cgiar.org/handle/10568/98430
- MAGyP. (2012). *Plan Estratégico Agroalimentario y Agroindustrial Participativo y Federal 2010-2020*. Ministry of Agriculture, Livestock and Fisheries (MAGyP). https://inta.gob.ar/sites/default/files/inta_000001-libro_pea_argentina_lider_agroalimentario.pdf
- MAGyP. (2019). *Plan de Accion Nacional de Agro y Cambio Climatico*. Ministry of Agriculture, Livestock and Fisheries (MAGyP). https://www.magyp.gob.ar/sitio/_pdf/plan_sectorial_cc.pdf
- Marquardt, M., Gonzales-Zuñiga, S., Röser, F., Cabrini, S. M., Gastaldi, L. B., Amaro, I. B., & Guerrero, I. R. P. (2022). *Transition risks for Argentina's agriculture sector*. NewClimate Insitute, INTA. <https://ambitiontoaction.net/outputs/>
- Marquardt, M., Woollands, S., Gonzales-Zuñiga, S., Pelekh, N., & Röser, F. (2022). *The global protein transition: An opportunity for Argentina*. NewClimate Insitute. <https://ambitiontoaction.net/outputs/>
- MAYDS. (n.d.). *Inventario Nacional de Gases de Efecto Invernadero [National GHG inventory]*. Ministry of Environment and Sustainable Development (MAYDS). Retrieved August 12, 2021, from <https://inventariogei.ambiente.gob.ar/resultados>
- MAYDS. (2020). *Informe Nacional del Estado del Ambiente 2020*. Ministry of Environment and Sustainable Development (MAYDS). https://www.argentina.gob.ar/sites/default/files/iea_2020_digital.pdf
- Modernel, P., Rossing, W. A. H., Corbeels, M., Dogliotti, S., Picasso, V., & Tiftonell, P. (2016). Land use change and ecosystem service provision in Pampas and Campos grasslands of southern South America. *Environmental Research Letters*, 11(11). <https://iopscience.iop.org/article/10.1088/1748-9326/11/11/113002/meta>
- Mónaco, M. H., Peri, P. L., Medina, F. A., Colomb, H. P., Rosales, V. A., Berón, F., Manghi, E., Miño, M. L., Bono, J., Silva, J. R., González Kehler, J. J., Ciuffoli, L., Presta, F., García Collazo, A., Navall, M., Carranza, C., López, D., & Gómez Campero, G. (2020). *Causas e impactos de la deforestación de los bosques nativos de Argentina y propuestas de desarrollo alternativas* (p. 60). Ministry of Environment and Sustainable Development (MAYDS). <https://www.argentina.gob.ar/ambiente/bosques/desmontes-y-alternativas>
- Moreira Muzio, M. (2019). *Inventario Nacional de Gases de Efecto Invernadero*. Secretaria de Ambiente y Desarrollo Sustentable. https://www.argentina.gob.ar/sites/default/files/inventario_de_gei_de_2019_de_la_republica_argentina.pdf
- Munoz, L. A., Gómez, M. C., Jiménez, D., Hasiner, E., Schroder, K., Treguer, D., Juergeniemi, A., Horst, A., Jarvis, A., & Kropff, W. (2021). *Digital Agriculture Profile • Argentina* (pp. 1–15). The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Food and Agriculture Organization of the United Nations (FAO), World Bank.
- OECD. (2019). *Agricultural Policies in Argentina*. Organisation for Economic Co-operation and Development (OECD). [https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA\(2018\)9/FINAL&docLanguage=En](https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA(2018)9/FINAL&docLanguage=En)
- OIE. (2017). *Animal welfare: an asset for livestock production*. World Organisation for Animal Health (OIE). <https://www.oie.int/app/uploads/2021/03/bull-2017-1-eng.pdf>
- OIT. (2021). *Empleo informal en la economía rural de América Latina 2012 - 2019*. International Labour Organization (OIT). https://www.ilo.org/wcmsp5/groups/public/-americas/-ro-lima/documents/publication/wcms_795313.pdf

- Pereira, C. H., Patino, H. O., Hoshide, A. K., Abreu, D. C., Alan Rotz, C., & Nabinger, C. (2018). Grazing supplementation and crop diversification benefits for southern Brazil beef: A case study. *Agricultural Systems*, 162(January), 1–9. <https://doi.org/10.1016/j.agsy.2018.01.009>
- Poeplau, C., & Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops - A meta-analysis. *Agriculture, Ecosystems and Environment*, 200, 33–41. <https://doi.org/10.1016/j.agee.2014.10.024>
- Project Drawdown. (n.d.). *Nutrient Management: Technical Summary*. <https://www.drawdown.org/solutions/nutrient-management/technical-summary>
- Rearte, D. H., & Pordomingob, A. J. (2014). The relevance of methane emissions from beef production and the challenges of the Argentinean beef production platform. *Meat Science*, 98(3), 355–360. <https://doi.org/10.1016/j.meatsci.2014.06.021>
- Ritchie, H., & Roser, M. (2013). *Fertilizers*. Our World in Data.
- Rodale Institute. (n.d.). *Crop rotations*. Retrieved September 12, 2021, from <https://rodaleinstitute.org/why-organic/organic-farming-practices/crop-rotations/>
- Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daiglou, V., Deppermann, A., Doelman, J., Emmet-Booth, J., Engelmann, J., Fricko, O., Frischmann, C., Funk, J., Grassi, G., Griscom, B., Havlik, P., Hanssen, S., Humpenöder, F., Landholm, D., ... Lawrence, D. (2021). Land-based measures to mitigate climate change: Potential and feasibility by country. *Global Change Biology*, 27(23), 6025–6058. <https://doi.org/10.1111/gcb.15873>
- Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified Crop Rotation: An Approach for Sustainable Agriculture Production. *Advances in Agriculture*, 2021. <https://doi.org/10.1155/2021/8924087>
- Silveyra, J. (n.d.). *Argentina & South American Soybean Production*. Ministry of Agroindustry. https://www.magyp.gob.ar/sitio/areas/ss_mercados_agropecuarios/informes/Presentación Soja Global Grain.pdf
- Tan, L. (2018). *Fertilizer: Argentina Might be the Next Big Market*. AgFax. <https://agfax.com/2018/01/26/fertilizer-argentina-might-be-the-next-big-fertilizer-market-dtn/>
- Terré, E., & Treboux, J. (2020). *Récord de consumo de fertilizantes en el 2019, con una participación de importados del 65%*. Bolsa de Comercio de Rosario. <https://www.bcr.com.ar/es/mercados/investigacion-y-desarrollo/informativo-semanal/noticias-informativo-semanal/record-de-2>
- Tieri, (2021). *Eficiencia en el uso del nitrógeno en vacas lecheras y su impacto en la emisión de metano*. <https://inta.gob.ar/eventos/sumando-conciencia-gei-eficiencia-en-el-uso-del-nitrogeno-en-vacas-lecheras-y-su-impacto-en-la-emision-de-metano>
- Volante, J. N., Mosciaro, M. J., Gavier-Pizarro, G. I., & Paruelo, J. M. (2016). Agricultural expansion in the Semiarid Chaco: Poorly selective contagious advance. *Land Use Policy*, 55, 154–165. <https://doi.org/10.1016/j.landusepol.2016.03.025>
- West, T. O., & Post, W. M. (2002). Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis. *Soil Science Society of America Journal*, 66(April), 1930–1946.
- World Bank Group. (2016). *Argentina Country Environmental Analysis*. <https://doi.org/10.1596/25775>
- World Bank Group. (2021). *Climate Risk Country Profile - Argentina*. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15850-WB_Argentina_Country_Profile-WEB%281%29.pdf
- World Bank Group. (2022). *World Bank Open Data: Arable land (hectares) - Argentina*. <https://data.worldbank.org/indicator/AG.LND.ARBL.HA?end=2018&locations=AR&start=1990&view=chart>
- Wyatt, D. (2021). *Argentina's beef export ban*. Agriculture and Horticulture Development Board. <https://ahdb.org.uk/news/argentina-s-beef-export-ban>



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