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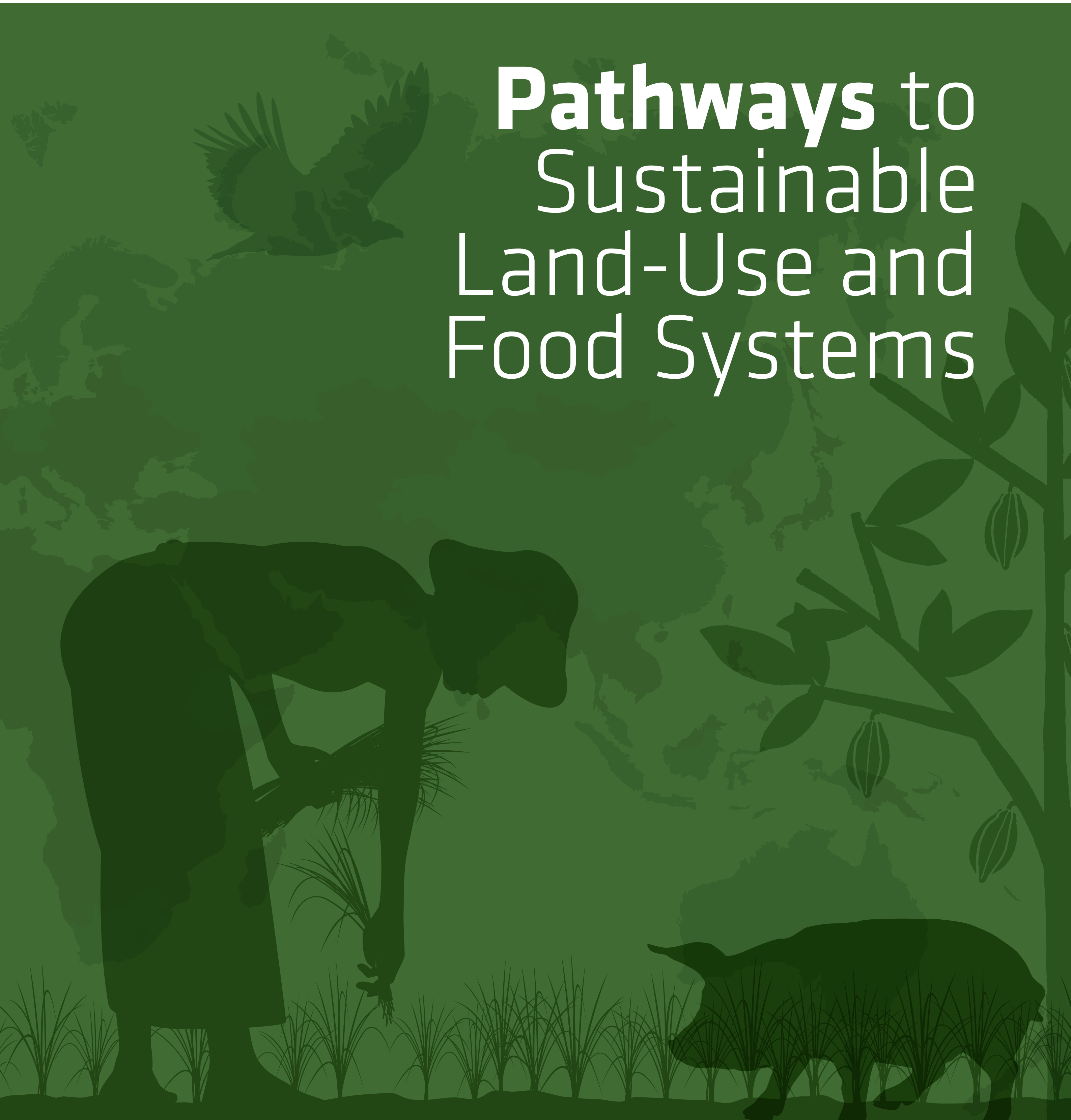
The Food and Land Use Coalition

2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems



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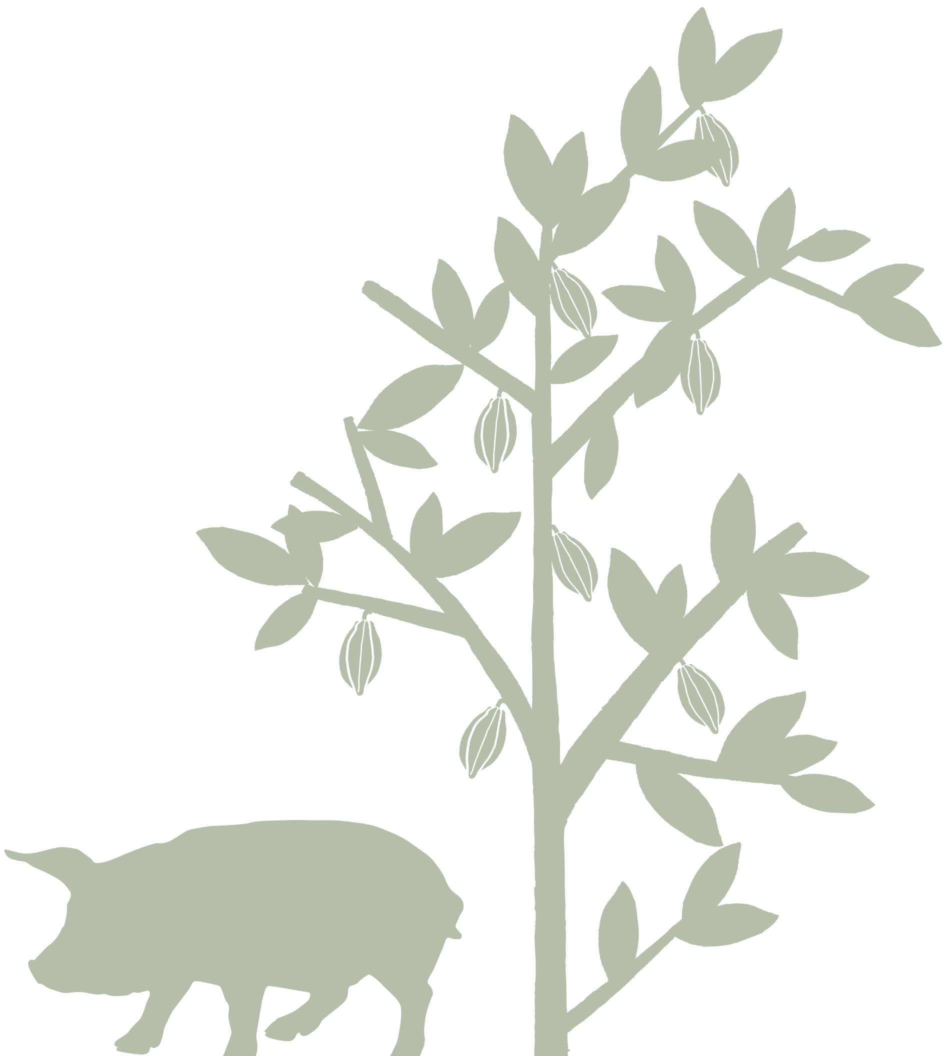
2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems in Brazil by 2050



Brazil

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This chapter of the 2020 Report of the FABLE Consortium *Pathways to Sustainable Land-Use and Food Systems* outlines how sustainable food and land-use systems can contribute to raising climate ambition, aligning climate mitigation and biodiversity protection policies, and achieving other sustainable development priorities in Brazil. It presents three pathways for food and land-use systems for the period 2020–2050: Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition (referred to as “Current Trends”, “Sustainable”, and “Sustainable +” in all figures throughout this chapter). These pathways examine the trade-offs between achieving the FABLE Targets under limited land availability and constraints to balance supply and demand at national and global levels. These pathways were modeled with the FABLE Calculator (Mosnier, Penescu, Thomson, and Perez-Guzman, 2019). See Annex 1 for more details on the adaptation of the model to the national context.

Climate and Biodiversity Strategies and Current Commitments

Countries are expected to renew and revise their climate and biodiversity commitments ahead of the 26th session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 15th COP to the United Nations Convention on Biological Diversity (CBD). Agriculture, land-use, and other dimensions of the FABLE analysis are key drivers of both greenhouse gas (GHG) emissions and biodiversity loss and offer critical adaptation opportunities. Similarly, nature-based solutions, such as reforestation and carbon sequestration, can meet up to a third of the emission reduction needs for the Paris Agreement (Roe et al., 2019). Countries' biodiversity and climate strategies under the two Conventions should therefore develop integrated and coherent policies that cut across these domains, in particular through land-use planning which accounts for spatial heterogeneity.

Table 1 summarizes how Brazil's NDC treat the FABLE domains. According to the NDC, Brazil has committed to reducing its GHG emissions by 37% by 2025 compared to 2005. This includes emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include "strengthening and enforcing the implementation of the Forest Code at federal, state, and municipal levels; strengthening policies and measures with a view to achieve, in the Brazilian Amazon, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030; restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes; enhancing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices; and strengthening the Low Carbon Emission Agriculture Program (ABC)[1] as the main strategy for sustainable agriculture development, including by restoring an additional 15 million hectares of degraded pasturelands by 2030 and enhancing 5 million hectares of integrated cropland-livestock-forestry systems (ICLFS) by 2030" (Government of Brazil, 2018). Biodiversity conservation is included in the current Brazilian commitments to the UNFCCC.

Table 1 | Summary of the mitigation target, sectoral coverage, and references to biodiversity and spatially explicit planning in current NDC

	Total GHG Mitigation					Mitigation Measures Related to AFOLU (Y/N)	Mention of Biodiversity (Y/N)	Inclusion of Actionable Maps for Land-Use Planning[2] (Y/N)	Links to Other FABLE Targets
	Baseline		Mitigation target		Sectors included				
	Year	GHG emissions (Mt CO_2e/yr)	Year	Target					
NDC (2017)	2005	2,735	2025	37% reduction	economy-wide	Y	Y	N	Sustainable water use, deforestation reduction

Note. "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns adapted from IGES NDC Database (Hattori, 2019), except for the GHG emissions baseline, which is extracted from Third National Communication of Brazil to UNFCCC (Ministério da Ciência, Tecnologia e Inovações, 2019).
Source: Brazil (2015)

1 The purpose of the ABC Plan is to encourage and monitor the adoption of practices of sustainable production technologies in order to reduce GHG emissions (Ministério da Agricultura, Pecuária e Abastecimento, 2012).
2 We follow the United Nations Development Programme definition, "maps that provide information that allowed planners to take action" (Cadena et al., 2019).

Table 2 provides an overview of targets listed in the National Biodiversity Strategies and Action Plan (NBSAP) from 2017, as listed on the CBD website (CBD, 2020) which are related to at least one of the FABLE Targets. NBSAP and FABLE Targets are defined for different years (2020 for the NBSAP, and 2030 or 2050 for FABLE). NSBAP Target 5 refers to a reduction of loss of native habitats by at least 50% while the FABLE Target describes a fixed amount of land which supports biodiversity conservation. The NBSAP Target 11 has the goal to conserve at least 30% of the Amazon biome, which matches the FABLE Target. NBSAP Target 15 has no mention of reaching zero GHG emissions from LULUCF and only pledges to restore 15% of degraded ecosystems.

Table 2 | Overview of the latest NBSAP Targets in relation to FABLE Targets

NBSAP Target	FABLE Target
(5) **By 2020, the rate of loss of native habitats is reduced by at least 50% (in comparison with the 2009 rate) and, as much as possible, brought close to zero, and degradation and fragmentation is significantly reduced in all biomes.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(11) **By 2020, at least 30% of the Amazon, 17% of each of the other terrestrial biomes, and 10% of the marine and coastal areas, [...], are conserved through protected areas foreseen under the SNUC Law and other categories of officially protected areas such as Permanent Protection Areas, legal reserves, and indigenous lands with native vegetation [...].**	**BIODIVERSITY:** At least 30% of global terrestrial area protected by 2030
(15) **By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced through conservation and restoration actions, including restoration of at least 15% of degraded ecosystems, prioritizing the most degraded biomes, hydrographic regions and ecoregions, thereby contributing to climate change mitigation and adaptation and to combatting desertification.**	**GHG EMISSIONS:** Zero or negative global GHG emissions from LULUCF by 2050

Brief Description of National Pathways

Among possible futures, we present three alternative pathways for reaching sustainable objectives, in line with the FABLE Targets, for food and land-use systems in Brazil.

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by medium population growth (from 214 million inhabitants in 2020 to 236 million in 2050), no constraints on agricultural expansion, no afforestation target, no deforestation control, an evolution towards a SSP2 diet, and a BAU scenario regarding biofuel feedstock use for ethanol (see Annex 2). This corresponds to a future based on current policies and historical trends that would also see a considerable increase with regards to the volume of exports of the main commodities and moderate agricultural productivity growth. Moreover, as with all FABLE country teams, we embed this Current Trends Pathway in a global GHG concentration trajectory that would lead to a radiative forcing level of 6 W/m^2 (RCP 6.0), or a global mean warming increase likely between 2°C and 3°C above pre-industrial temperatures, by 2100. Our model includes the corresponding climate change impacts on crop yields by 2050 for corn, rice, soybeans, and wheat (see Annex 2).

Our Sustainable Medium Ambition Pathway represents a future in which significant efforts are made to adopt sustainable policies and practices and corresponds to an intermediate boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would lead to higher productivity in the agricultural sector, lower population growth, moderate constraints on agricultural expansion, an evolution towards a SSP1 diet, a renewable-fuel-oriented scenario, and no deforestation beyond 2030. This pathway also considers the restoration of 12 Mha of forest by 2030 (Government of Brazil, 2018; Bonn Challenge, 2014), and food waste and post-harvest loss reductions when compared to the historical period. With the other FABLE country teams, we embed this Sustainable Medium Ambition Pathway in a global GHG concentration trajectory that would lead to a lower radiative forcing level of 2.6 W/m^2 by 2100 (RCP 2.6), in line with limiting warming to 2°C (see Annex 2).

Our Sustainable High Ambition Pathway represents a future in which significant efforts are made to adopt ambitious sustainable policies and corresponds to the highest boundary of feasible action. Assumptions on diets and reforestation targets are different from the Sustainable Medium Ambition Pathway. First, in order to go beyond Brazil's NDC commitment of restoring 12 Mha of forests by 2030, we considered an overall restoration target of approximately 27 Mha by 2050. This restoration goal takes into account the amount of environmental debt from the Rural Environmental Cadastre (CAR) (Guidotti et al., 2017) for all biomes but the Atlantic Forest, where we consider the Atlantic Forest Pact target of restoring 15 Mha. Second, we assume this future would lead to an evolution towards an EAT-Lancet recommended diet (Willett et al., 2019), which defines a universal reference diet healthy for both humans and the planet, minimizing chronic disease risks and maximizing human wellbeing. This diet is rich in fruits and vegetables, with carbohydrates from whole grains, and protein and fats mainly from plant-based foods (see Annex 2).

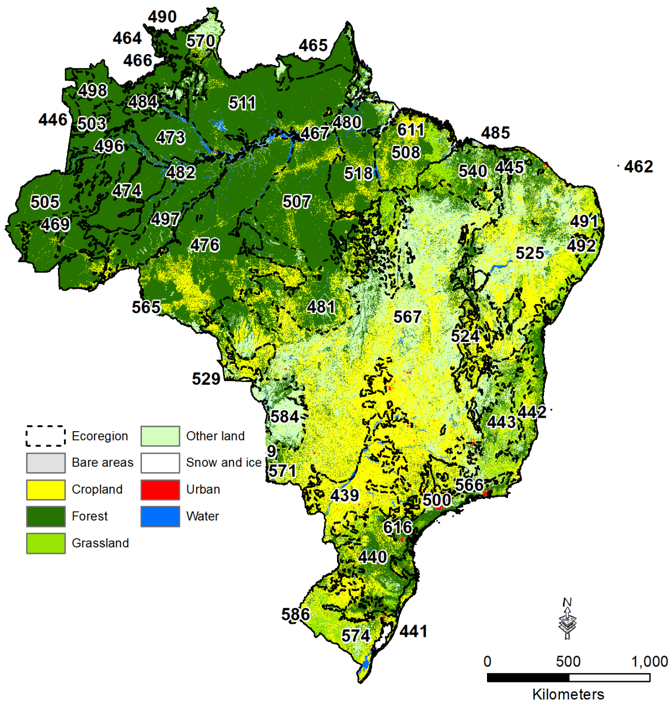
Land and Biodiversity

Current State

In 2010, Brazil was covered by 8% cropland, 21% grassland, 69% forest, 0.3% urban and 2% other natural land (Souza et al., 2020; PAM/IBGE, 2020). Map 1 shows the land cover by aggregated land cover types in 2010 and ecoregions from ESA CCI (ESA, 2017). As can be seen in Map 1, most of the agricultural area is located in the south and center-west while forest and other natural lands can be mostly found in the Amazon biome.

Land where natural processes predominate[3] accounted for 47% of Brazil's terrestrial land area in 2010 (Map 2). The 490-Pantepui forests and shrublands holds the greatest share of land where natural processes predominate, followed by 464-Guianan Highlands moist forests and 498-Rio Negro campinarana (Table 3). Across the country and according to this data, while 250 Mha of land is under formal protection, meeting the 30% zero-draft CBD post-2020 target, only 56% of land where natural processes predominate is formally protected. In order to monitor key biodiversity areas, the Brazilian Ministry of the Environment defined a set of priority areas for biodiversity, last updated in 2018 (Ministério do Meio Ambiente, 2018). The priority areas are spread across all the biomes and the Atlantic coast. Different conservation targets were considered in the identification of these areas, such as the number of endemic and endangered species, remnants of native ecosystems, climatic refuges, important areas for migratory and pollinating species, among others (Ministério do Meio Ambiente, 2005). One of the practices that endangers biodiversity in some of these areas is the illegal occupation of public lands, which leads to deforestation, fires, crime, and corruption, causing damage to ecosystems and biodiversity.

Map 1 | Land cover by aggregated land cover types in 2010 and ecoregions

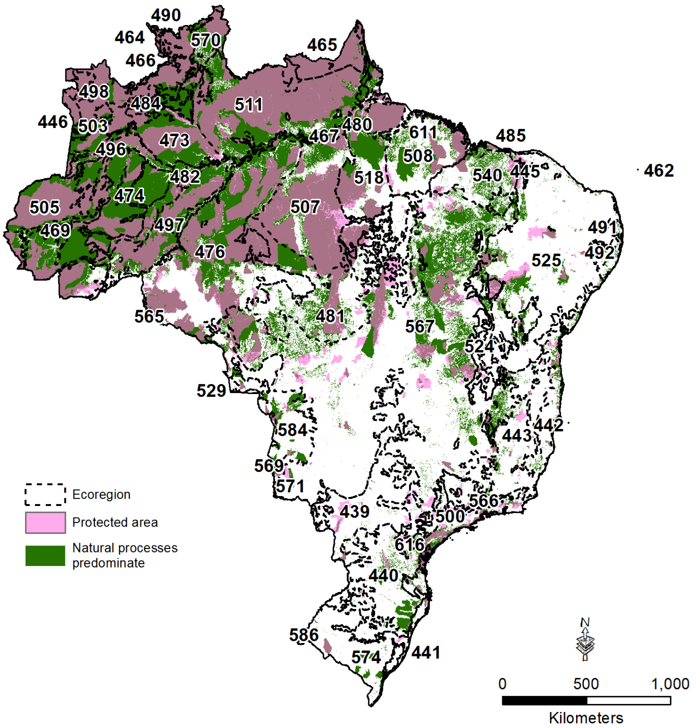


Notes. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3.
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)

3 We follow Jacobson, Riggio, Tait, and Baillie (2019) definition: "Landscapes that currently have low human density and impacts and are not primarily managed for human needs. These are areas where natural processes predominate, but are not necessarily places with intact natural vegetation, ecosystem processes or faunal assemblages".

Approximately 54% of Brazil's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively biodiversity-friendly croplands are most widespread in 490-Pantepui forests and shrublands, followed by 464-Guianan Highlands moist forests and 498-Rio Negro campinarana (Table 3).

Map 2 | Land where natural processes predominated in 2010, protected areas and ecoregions



Notes. Protected areas are set at 50% transparency, so on this map dark purple indicates where areas under protection and where natural processes predominate overlap.
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); protected areas – UNEP-WCMC and IUCN (2020); natural processes predominate comprises key biodiversity areas – BirdLife International (2019), intact forest landscapes in 2016 – Potapov et al. (2016), and low impact areas – Jacobson et al. (2019)

Table 3 | Brazilian ecoregions with the greatest share of land where natural processes predominate and the greatest share of cropland with at least 10% of natural vegetation[4]

Ecoregion		Area (1,000 ha)	Protected Area (%)	Share of Land where Natural Processes Predominate (%)	Share of Land where Natural Processes Predominate that is Protected (%)	Share of Land where Natural Processes Predominate that is Unprotected (%)	Cropland (1,000 ha)	Share of Cropland with >10% Natural Vegetation within 1km² (%)
490	Pantepui forests & shrublands	558	96.9	99.7	96.9	3.1	0.3	100
464	Guianan Highlands moist forests	2770	91.8	99.6	91.9	8.1	2.1	97.9
498	Rio Negro campinarana	8097	63.9	99.4	63.9	36.1	4.7	96.8

Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); cropland, natural and semi-natural vegetation – ESA CCI land cover 2015 (ESA, 2017); protected areas – UNEP-WCMC and IUCN (2020); natural processes predominate comprises key biodiversity areas – BirdLife International 2019, intact forest landscapes in 2016 – Potapov et al. (2016), and low impact areas – Jacobson et al. (2019)

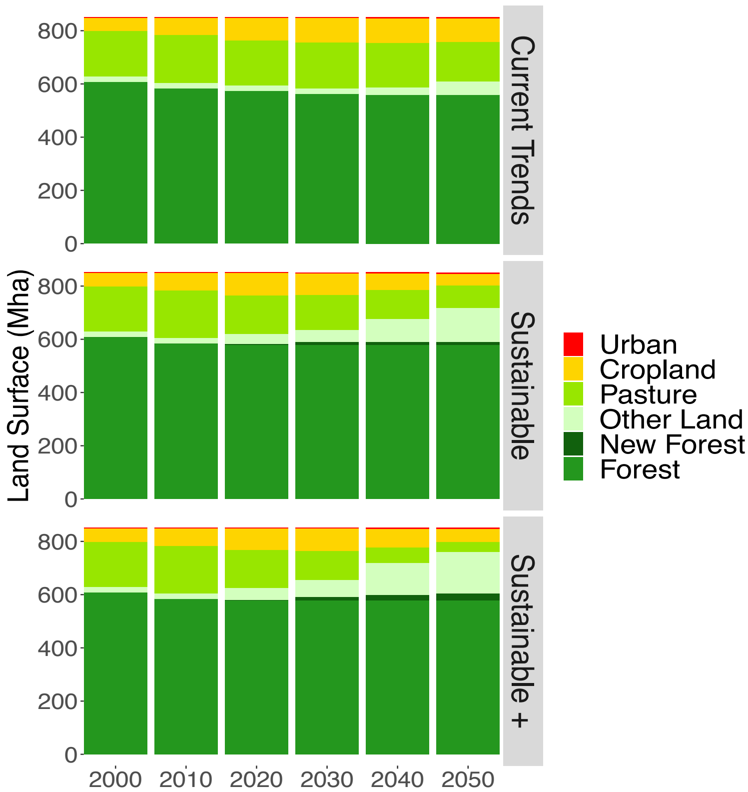
4 The share of land within protected areas and the share of land where natural processes predominate are percentages of the total ecoregion area (counting only the parts of the ecoregion that fall within national boundaries). The shares of land where natural processes predominate that is protected or unprotected are percentages of the total land where natural processes predominate within the ecoregion. The share of cropland with at least 10% natural vegetation is a percentage of total cropland area within the ecoregion.

Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions, including no constraints on land conversion beyond protected areas, no planned afforestation or reforestation (see Annex 2).

From 2010–2030, we estimate that the main changes in land cover in the Current Trends Pathway result from an increase of cropland (from 66 to 93 Mha), a decrease of forest (from 584 to 563 Mha) and grassland (from 180 to 172 Mha), and an increase in the cattle herd (147 to 183 MTLU). The results suggest that cattle ranching intensification is sparing land for cropland expansion. However, since the cropland increase surpasses the reduction of pasture areas, the results also suggest deforestation is mainly driven by cropland expansion through this period (Figure 1). The expansion of the planted area for soybeans, corn, and sugarcane corresponds to 97% of the total cropland increase between 2010 and 2030. For soybeans, the expansion occurs due to an increase in exports, which follows the export trend assumed for the three pathways (see Annex 2). For corn, 69% of expansion is due to an increase in exports and 28% an increase of internal demand for feed. Finally, for sugarcane, 59% results from an increase of internal demand of biofuels and 32% an increase of processed products. On the other hand, our projections for the period 2030–2050 show a slight reduction in the cropland areas (from 93 to 90 Mha), and a decrease in pasture areas (from 172 to 149 Mha) and an increase in the cattle herd (from 183 to 192 MTLU), which is explained by increases in agricultural productivity and ruminant density. There is no deforestation after 2035 and the forest stocks stabilize at 559 Mha. The land abandonment increases over the period 2040–2050 from 27 to 49 Mha while, at the same time, pasture and cropland areas decrease to 19 Mha and 5 Mha, respectively.

Figure 1 | Evolution of area by land cover type and protected areas under each pathway



Source. FABLE Calculator results obtained when using MapBiomas/IBGE as the initial land cover data for the base year 2000.

In the Sustainable Medium Ambition and Sustainable High Ambition Pathways, assumptions on agricultural land expansion, reforestation targets, and the creation of protected areas are different from the Current Trends Pathway. In these sustainable scenarios, there is no deforestation in Brazil after 2030; and the restoration targets reflect Brazil's international commitments. The major differences between the Sustainable Medium Ambition and the Sustainable High Ambition Pathways are that the latter considers an EAT-Lancet diet, instead of a SSP1 diet, and a higher restoration target (see Annex 2).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Brazil in the Sustainable Medium Ambition Pathway: zero deforestation reached by 2020; restoration of 12 Mha by 2030; reduction in cropland areas (from 66 to 46 Mha); a large reduction of pasturelands (from 179 to 83 Mha); and a significant decrease in cattle herd (from 147 to 112 MTLU); an increase in forest areas (from 584 to 591 Mha); and an increase in land abandonment (from 20 to 96 Mha) over the period 2010–2050. In addition, the Sustainable Medium Ambition Pathway also assumes higher crop productivity increases, the inclusion of afforestation/reforestation targets, and a healthier diet compared to the Current Trends Pathway.

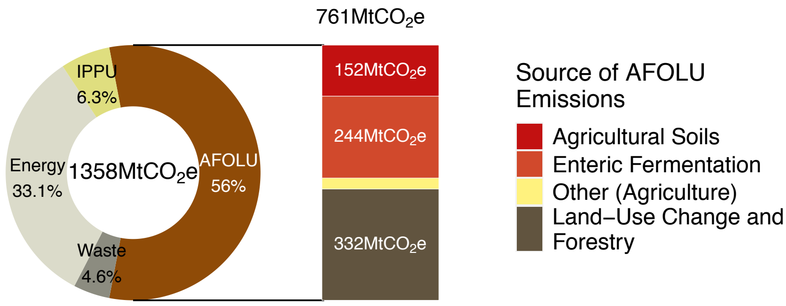
Compared to the Sustainable Medium Ambition Pathway, the Sustainable High Ambition Pathway shows an increase in forest areas (from 584 to 606 Mha) between 2010 and 2050. We also observe a decrease in cropland areas (from 66 to 48 Mha), and a significant reduction of pastures (from 179 to 37 Mha) and cattle herd (from 147 to 50 MTLU), which leads to an increase in land abandonment (from 20 to 154 Mha) over the same period. The increase in the forest areas is explained by the more ambitious afforestation/restoration targets, with approximately 15 Mha more restored forests by 2050. The higher afforestation/restoration targets combined with the EAT-Lancet reference diet explain the huge pasture and cropland reduction between the sustainable pathways. The EAT-Lancet reference diet reduces the consumption of red meat (from 84 to 25 kcal/cap/day) in 2050.

GHG emissions from AFOLU

Current State

Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 56% of total emissions in 2015 (Figure 2). Land use change emissions are the principle source of AFOLU emissions, followed by enteric fermentation, agricultural soils, and manure management. Historically, the deforestation in the Amazon and the Cerrado biomes were the main sources of the land use change emissions in Brazil (SEEG, 2018b; Angelo & Rittl, 2019). Between 1990 and 2014, the increase of emissions in the agricultural sector accompanied the growth in production of Brazil's main commodities: soybeans and beef (SEEG, 2018a). In 2015, Brazil had approximately 215 million cattle heads (PPM/IBGE, 2020) which explains the high emissions from the livestock sector.

Figure 2 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2015



Note. IPPU = Industrial Processes and Product Use
Source. Adapted from GHG National Inventory (UNFCCC, 2020)

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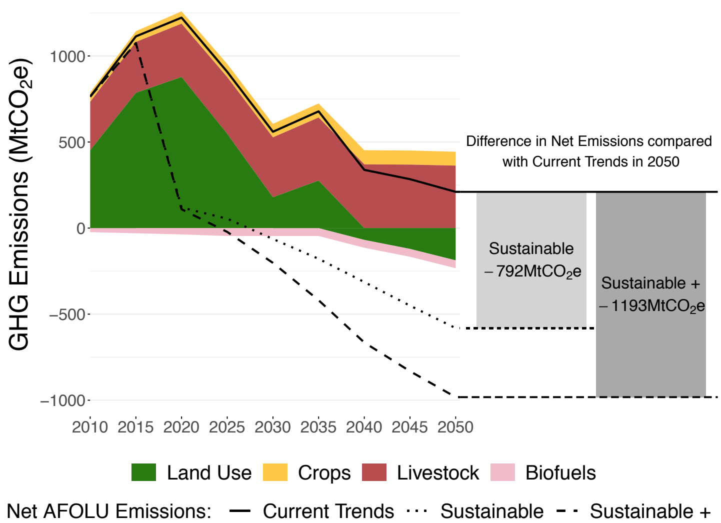
Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU decrease to 560 MtCO$_2$e/yr in 2030, before declining to 211 MtCO$_2$e/yr in 2050 (Figure 3). Over the period 2020–2050, the strongest relative increase in GHG emissions is computed for enteric fermentation (from 211 to 249 MtCO$_2$e/yr) while a reduction is computed for CO_2 sequestration due to regeneration on abandoned agricultural land (from -60 to -220 MtCO$_2$e/yr). The GHG emissions projections from

Figure 3 | Projected AFOLU emissions and removals between 2010 and 2050 by main sources and sinks for the Current Trends Pathway



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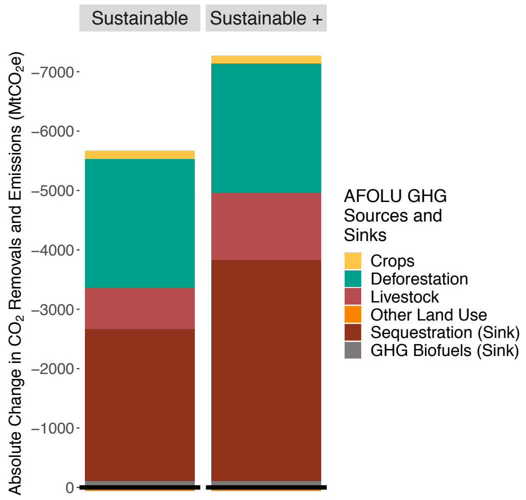
land abandonment are calculated by multiplying the abandoned lands by a factor of 5.23, based on Brazil's CO_2 stock in forest areas. This reduction almost compensates for the GHG emissions for enteric fermentation in this pathway, which will be investigated in the future.

In comparison, the Sustainable Medium Ambition Pathway leads to a reduction of AFOLU GHG emissions from 221 $MtCO_2e$/yr in 2010 to -581 $MtCO_2e$/yr in 2050, and the Sustainable High Ambition Pathway to a reduction from 221 to -981 $MtCO_2e$/yr by 2050 through the same period (Figure 4). The potential emissions reductions under the Sustainable Medium Ambition Pathway is dominated by the CO_2 sequestration from the forestry and land use change sector and a reduction in GHG emissions from enteric fermentation and manure management. The evolution towards healthier diets, which reduces animal protein and fat consumption, the ban on deforestation, and the carbon uptake from natural vegetation regrowth and afforestation are the most important drivers of this reduction. Under the Sustainable High Ambition Pathway, GHG emissions from CO_2 sequestration from the forestry and land use change sector, enteric fermentation, and manure management are further reduced when compared to the Sustainable Medium Ambition Pathway thanks to the ambitious afforestation/reforestation targets and a healthier diet assumption, which decreases the cattle herd.

Figure 4 | Cumulated GHG emissions reduction computed over 2020–2050 by AFOLU GHG emissions and sequestration source compared to the Current Trends Pathway



According to Brazil's commitments under the UNFCCC (Table 1), the country pledged to reduce its GHG emissions by 37% by 2025 compared to 2005 (i.e., a reduction of 1.01 $GtCO_2e$ in 20 years). In the Current Trends Pathway, AFOLU GHG emissions will not fulfill the commitment, reducing only 0.63 $MtCO_2e$ from 2005 to 2025. The commitment is achieved in both sustainable pathways. The AFOLU GHG emissions are reduced by 1.49 and 1.56 $GtCO_2e$ in the Sustainable Medium Ambition and Sustainable High Ambition Pathways, respectively, over the same period. Such reductions could be achieved through the following policy measures: fulfillment of commitments regarding afforestation/reforestation targets, an evolution towards healthy diets, and the increase of use of renewable fuels. These measures could be particularly important when considering options for NDC enhancement.

Food Security

Current State

The "Triple Burden" of Malnutrition

Undernutrition

2.5% of the population were undernourished in 2017. This share has decreased since 2000 (World Bank, 2020a).

7.1% of children under 5 were stunted (World Bank, 2020b) and 1.6% were wasted in 2007 (World Bank, 2020c).

Micronutrient Deficiency

18.9% of women and 8.04% of children under the age of 5 suffered from anemia in 2017, which can lead to maternal death (IHME, 2020).

13.2% of women/the population are deficient in vitamin A, which can notably lead to blindness and child mortality (IHME, 2020), and 0.24% of women/the population are deficient in iodine, which can lead to developmental abnormalities (IHME, 2020).

Overweight/ Obesity

19% of adults and 6% of children were obese in 2015 (EAT, 2017).

49% of adults and 17% of children were overweight in 2015 (EAT, 2017).

Disease Burden due to Dietary Risks

0.53% of deaths are attributable to dietary risk, or 3.4 deaths per year (per 100,000 people) (IHME, 2020).

7.4% of the population suffers from diabetes and 24.5% from arterial hypertension, which can be attributable to dietary risks (Ministério da Saúde, 2019).

Table 4 | Daily average fats, proteins and kilocalorie intake under the Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition Pathways in 2030 and 2050

	2010	2030			2050		
	Historical Diet (FAO)	Current Trends	Sustainable Medium Ambition	Sustainable High Ambition	Current Trends	Sustainable Medium Ambition	Sustainable High Ambition
Kilocalories (MDER)	2,994 (2,084)	3,185 (2,099)	2,836 (2,099)	2,740 (2,099)	3,384 (2,090)	2,726 (2,090)	2,287 (2,090)
Fats (g) (recommended range)	105 (67-100)	103 (71-106)	104 (63-95)	102 (61-91)	101 (75-113)	102 (61-91)	95 (51-76)
Proteins (g) (recommended range)	86 (75-262)	93 (80-279)	84 (71-247)	82 (69-240)	100 (85-296)	83 (68-239)	75 (57-200)

Notes. Minimum Dietary Energy Requirement (MDER) is computed as a weighted average of energy requirement per sex, age class, and activity level (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015) and the population projections by sex and age class (UN DESA, 2017) following the FAO methodology (Wanner et al., 2014). For fats, the dietary reference intake is 20% to 30% of kilocalories consumption. For proteins, the dietary reference intake is 10% to 35% of kilocalories consumption. The recommended range in grams has been computed using 9 kcal/g of fats and 4kcal/g of proteins.

Pathways and Results

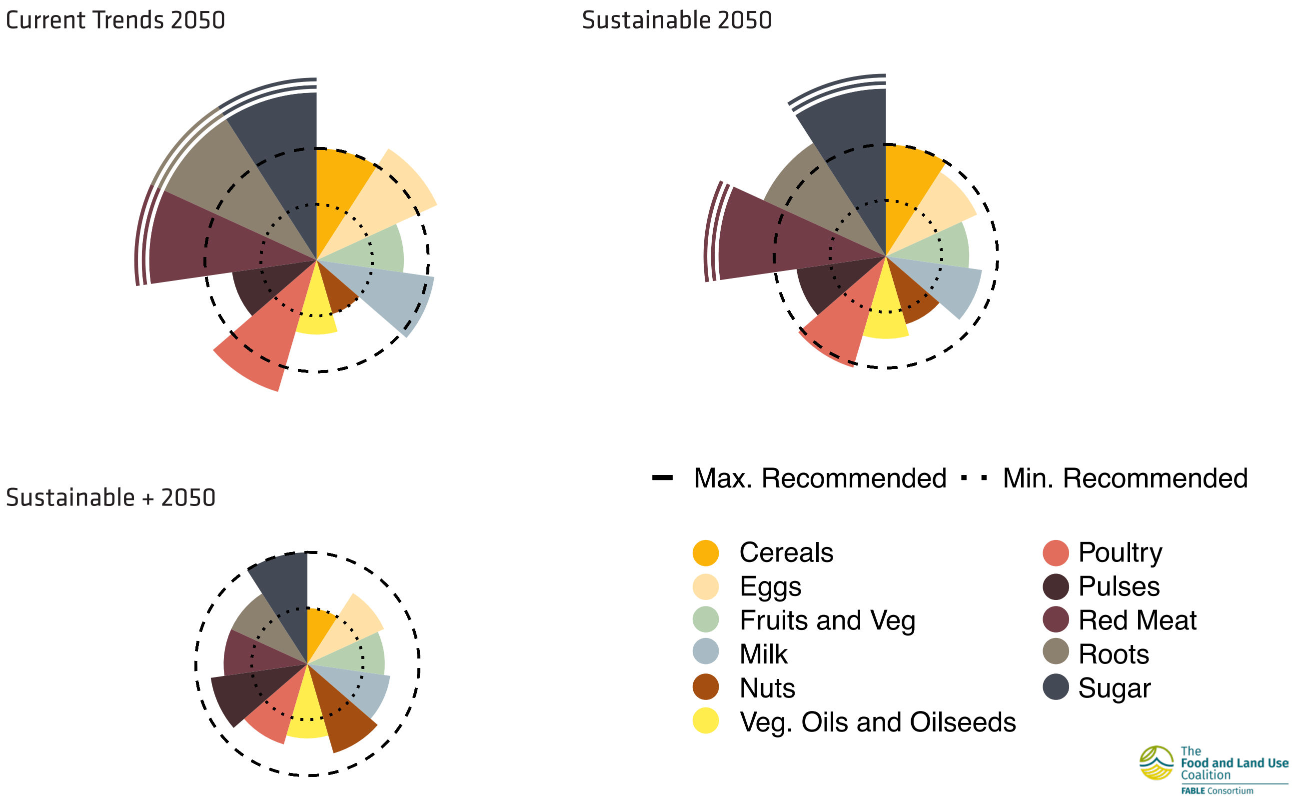
Under the Current Trends Pathway, compared to the average Minimum Dietary Energy Requirement (MDER) at the national level, our computed average calorie intake is 52% higher in 2030 and 62% higher in 2050 (Table 4). The current average intake is mostly satisfied by the following food groups: cereals, oilseed and vegetables oils, sugar, and milk. Animal products represent 26% of the total calorie intake. We project the consumption of animal products and, in particular, red meat, will increase by 16% between 2020 and 2050. The consumption of cereals, pork, milk, eggs, roots, and sugar will also increase while oilseeds and vegetable oils consumption will decrease. Compared to the EAT-Lancet recommendations (Willett et al., 2019), red meat, roots, sugar, eggs, milk, and poultry are over-consumed while nuts are under-consumed (Figure 5). Moreover, fat intake per capita exceed and protein intake per capita is within the range of the dietary reference intake (DRI) in 2030 (Table 4).

Under the Sustainable Medium Ambition Pathway, we assume that diets will transition towards a SSP1 scenario, while we assume an EAT-Lancet recommended scenario in the Sustainable High Ambition Pathway. The ratio of the computed average intake over the MDER decreases to 35% in 2030 and 30% in 2050 under the Sustainable Medium Ambition Pathway, and 31% in 2030 and 9% in 2050 under the Sustainable High Ambition Pathway.

Compared to the EAT-Lancet recommendations, the consumption of eggs and milk are within the recommended range in the Sustainable Medium Ambition Pathway when compared to the Current Trends Pathway (Figure 5). Since we assume an EAT-Lancet diet in the Sustainable High Ambition Pathway, all food products are within the recommended range. Moreover, the fat intake per capita exceeds the dietary reference intake (DRI) in both sustainable pathways by 2030, but the protein intake per capita is reduced when compared to the Current Trends Pathway (Table 4).

Substantial reductions in food loss and waste, major improvements in food practices, and the implementation of policies that provide the public with important health information and encourage healthy behaviors will be particularly important to promote this shift in diets (EAT-Lancet, 2019; Gorski and Roberto, 2015).

Figure 5 | Comparison of the computed daily average kilocalorie intake per capita per food category across pathways in 2050 with the EAT-Lancet recommendations



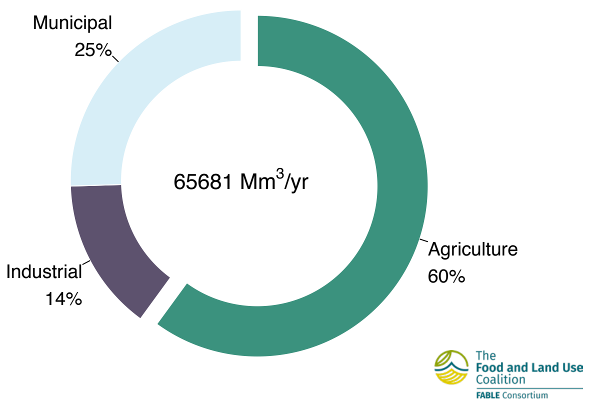
Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings), therefore, different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended values for cereals: when the kcal intake is smaller than the average recommendation it is displayed on the minimum ring and if it is higher it is displayed on the maximum ring. The discontinuous lines in the outer part of the sugar, roots and red meat area indicates that the average kilocalorie consumption of these food categories is significantly higher than the maximum recommended.

Water

Current State

Brazil is characterized by a tropical climate with a dry season in most of the northeast and central areas, and a humid equatorial climate in the Amazon region with 1,761 mm average annual precipitation that mostly occurs over the summer season (FAO, 2020). The agricultural sector represented 60% of total water withdrawals in 2017 (FAO, 2020) (Figure 6). In 2016, 6% of agricultural land was equipped for irrigation, representing 17% of estimated-irrigation potential (FAO, 2020). According to our results, the three most important irrigated crops were sugarcane, rice, and coffee, accounting for 20%, 39%, and 2% of the total harvested irrigated area in 2010. Brazil exported 72% of sugar, 9% of rice (OECD-FAO, 2020), and 61% of coffee (FAO, 2020) in 2017, which indicates that a share of the blue water is indirectly destined to meet export demand.

Figure 6 | Water withdrawals by sector in 2017

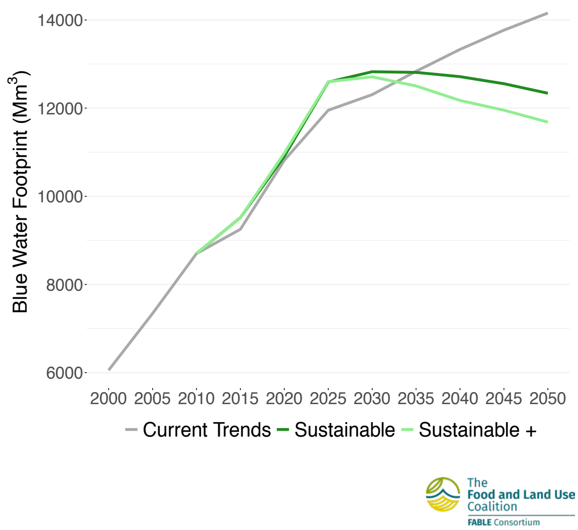


Source. Adapted from AQUASTAT Database (FAO, 2017)

Pathways and Results

Under the Current Trends Pathway, annual blue water use increases between 2000–2015 (6,054 and 9,252 Mm^3/yr), before reaching 12,306 Mm^3/yr and 14,157 Mm^3/yr in 2030 and 2050, respectively (Figure 7), with sugarcane and rice accounting for 47% and 35% of computed blue water use for agriculture by 2050[5]. In contrast, under the Sustainable Medium Ambition Pathway, the blue water footprint in agriculture reaches 12,826 Mm^3/yr in 2030 and 12,338 Mm^3/yr in 2050, respectively, which projects a reduction in blue water use when compared to the Current Trends Pathway. Under the Sustainable High Ambition Pathway, the blue water footprint further decreases when compared to the Sustainable Medium Ambition Pathway and reaches 11,683 Mm^3/yr in 2050. This is explained by the changes in the assumptions with diets with less animal fat and protein consumption (Annex 2) and changes in the production of sugarcane and rice due to a decline in internal food demand.

Figure 7 | Evolution of blue water footprint in the Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition Pathways



5 We compute the blue water footprint as the average blue fraction per tonne of product times the total production of this product. The blue water fraction per tonne comes from Mekonnen and Hoekstra (2010a, 2010b, 2011). In this study, it can only change over time because of climate change. Constraints on water availability are not taken into account.

Resilience of the Food and Land-Use System

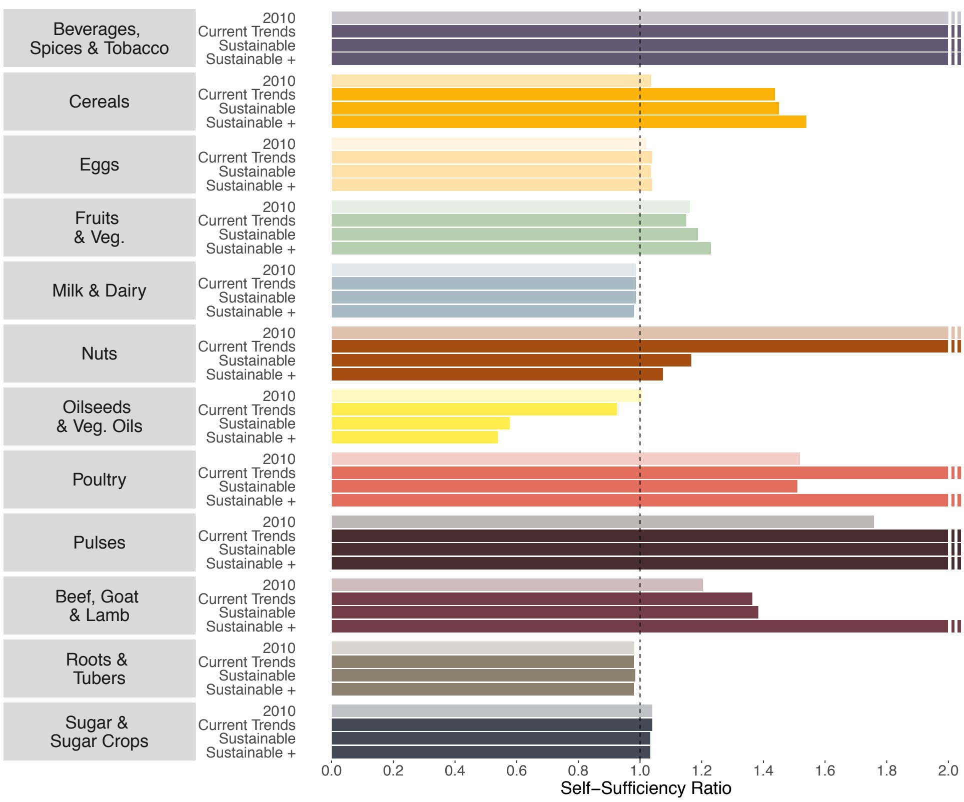
The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Brazil's resilience to agricultural-trade and supply disruptions across pathways: the rate of self-sufficiency and diversity of production and trade. Together they highlight the gaps between national production and demand and the degree to which we rely on a narrow range of goods for our crop production system and trade.

Self-Sufficiency

Defined by FAO (2012), the self-sufficiency ratio (SSR) represents the percentage of food consumed that is produced domestically. Brazil had an SSR between 80%-100% from 2005–2009 (Puma et al., 2015) and was included in the group of countries that met dietary needs while still exporting food over the period 2005–2009 (Clapp, 2015).

Under the Current Trends Pathway, we project that Brazil would be self-sufficient in beverages, spices and tobacco, cereals, eggs, fruits and vegetables, nuts, poultry meat, pulses, beef, goat and lamb, and sugar and sugar crops in

Figure 8 | Self-sufficiency per product group in 2010 and 2050



Note. In this figure, self-sufficiency is expressed as the ratio of total internal production over total internal demand. A country is self-sufficient in a product when the ratio is equal to 1, a net exporter when higher than 1, and a net importer when lower than 1. The discontinuous lines on the righthand side of this figure, which appear for beverages, spices and tobacco, nuts, poultry, pulses, beef, goat and lamb, indicate a high level of self-sufficiency in these categories.

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2050, with self-sufficiency by product group increasing for the majority of products from 2010–2050 (Figure 8). Figure 8 shows Brazil does not need to import most product groups by 2050. The projections indicate that Brazil is close to self-sufficiency for roots and tubers, milk and dairy, and oilseeds and vegetable oil groups. Under the Sustainable Medium Ambition and the Sustainable High Ambition Pathways, Brazil remains self-sufficient in the same list of product groups by 2050, representing stable self-sufficiency, increasing the exports of products from pulses and beef, goat and lamb groups. This is mainly explained by changes to healthier diets, which include more fruits and vegetables, and protein from planted-based foods, and reduces the intake of animal products. There is an increase in the use of renewable fuels in the sustainable pathways and, consequently, the whole production of soy oil is assigned to meet biofuel demand by 2050. While our results show that Brazil is not self-sufficient in oilseeds and vegetable oils, it is important to note that the country is a major producer and exporter of soybeans.

Diversity

The Herfindahl-Hirschman Index (HHI) measures the degree of market competition using the number of firms and the market shares of each firm in a given market. We apply this index to measure the diversity/concentration of:

- **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- **Exports and imports:** where concentration refers to a situation in which a few commodities represent a large share of total exported and imported quantities, and diversity refers to a situation in which many commodities account for significant shares of total exported and imported quantities.

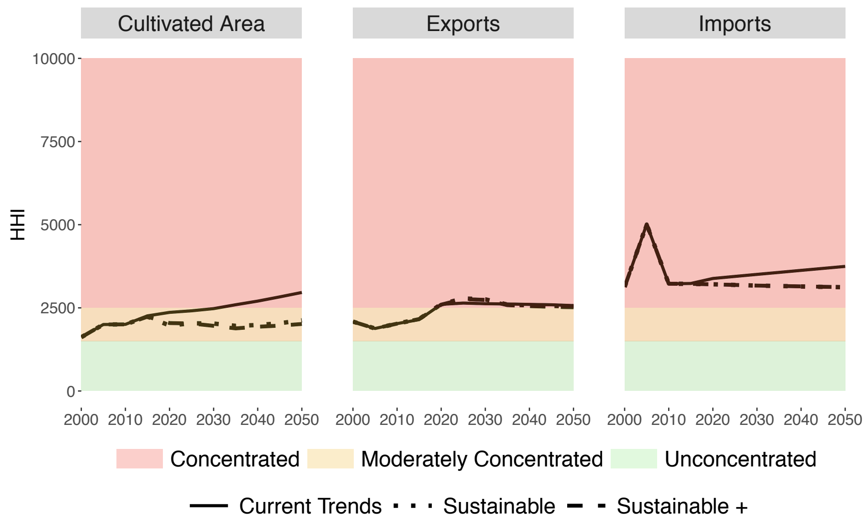
We use the same thresholds as defined by the U.S. Department of Justice and Federal Trade Commission (2010, section 5.3): diverse under 1,500, moderate concentration between 1,500 and 2,500, and high concentration above 2,500.

Figure 9 shows HHI indicates a large share of the imports is represented by a few commodities over the period 2000–2015, while the index indicates a medium concentration of exports in the same period. The cropland area is dominated by a few crops with medium shares of the total cultivated area during the historical period.

Under the Current Trends Pathway, we project high concentration of crop exports and imports (Figure 9). In addition, a high concentration of crops planted is observed in 2050, mostly represented by soybeans and corn fields, a trend which increases over the period 2015–2050. Soybeans and wheat respectively represent the greatest share of total exported and imported quantities of the 92 products considered in the FABLE Calculator. According to our projections, wheat represents 53%, 70%, and 54% of the total share of imports in 2000, 2005, and 2010, respectively. The increase in the share of wheat imports in 2005 compared to 2000 and 2010 leads to a peak in the HHI value in 2005 (Figure 9). However, according to official data provided by FAO (FAOSTAT, 2020), wheat represents 62%, 69%, and 70% of the total share of imports in 2000, 2005, and 2010, respectively. These differences will be investigated in the future following improvements to the FABLE Calculator.

In contrast, under the Sustainable Medium Ambition and Sustainable High Ambition Pathways, we project high concentration of crop exports and imports and moderate concentration in the range of crops planted in 2050, indicating low levels of diversity across the national production system and imports and exports. This is explained by the changes towards healthier diets. The reduction of animal fat and protein intake lowers the soybean and corn production used for animal feed, which changes the crop production proportions when compared to the Current Trends Pathway.

Figure 9 | Evolution of the diversification of the cropland area, crop imports, and crop exports using the Herfindahl-Hirschman Index (HHI)



Discussion and Recommendations

In this study, we presented three pathways for the period 2010-2050 developed using the FABLE Calculator: Current Trends, Sustainable Medium Ambition, and Sustainable High Ambition. The Current Trends Pathway is a business-as-usual scenario that considers the historical trends over the period 2000–2010. It also captures what happens in a food and land-use system in which deforestation is left to continue uncontrolled and where restoration and afforestation policies are not implemented. The Sustainable Medium Ambition and Sustainable High Ambition Pathways assume a series of targets to promote a sustainable food and land-use system, attempting to reach goals such as food waste and post-harvest loss reductions when compared to the historical period. In both sustainable pathways, there is an increase in the use of renewable fuels, improvements in the water use efficiency, and assumptions leading to healthier diets. When compared with the Sustainable Medium Ambition Pathway, the Sustainable High Ambition Pathway has ambitious targets concerning diets and afforestation/reforestation goals, including the restoration of almost 27 Mha instead of 12 Mha, and the implementation of an EAT-Lancet reference diet instead of a SSP1 diet.

First, we would like to highlight that the Current Trends Pathway, as simulated by the FABLE Calculator, generates results that are too optimistic in terms of emissions (for example, carbon uptakes due to land abandonment appear to be overestimated), deforestation reductions, and agricultural productivity gains. A more realistic scenario should be included in future analyses in order to better capture the historical trends of Brazil's AFOLU sector. In the Current Trends Pathway, from 2010 to 2030, deforestation in Brazil amounts to 21 Mha. During the same period, croplands expands by 27 Mha due to the increase in export demand, and the pasture areas decrease by 7 Mha due to cattle ranching intensification. From 2030 to 2050, our results project a slight reduction in cropland areas and a more significant decrease in pastures, which causes land abandonment. The Sustainable Medium Ambition and Sustainable High Ambition Pathways, on the other hand, project an agricultural productivity increase leading to a significant reduction in cropland and pasture areas between 2010–2050. The FABLE Calculator projects forest regrowth and the control of deforestation after 2015 in both sustainable pathways. An increase of crop diversity and a reduction in red meat intake were also observed. The Bonn Challenge and NDC commitments of restoring 12 Mha are reached only in the two sustainable pathways with a slight expansion of protected areas when compared to the Current Trends Pathway (from 30% to 32% in both pathways). The major differences between the sustainable pathways are the higher cropland and pasture reduction due to the different diet assumptions, and the additional 15 Mha of forest restoration in the Sustainable High Ambition Pathway when compared to Sustainable Medium Ambition Pathway.

The average GHG emissions from the AFOLU sector are projected to reach -581 $MtCO_2e$/yr by 2050 in the Sustainable Medium Ambition Pathway, and -981 $MtCO_2e$/yr in the Sustainable High Ambition Pathway. The Current Trends pathway projected 211 $MtCO_2e$/yr by 2050. The negative emissions observed in the sustainable pathways are mainly caused by CO_2 sequestration from restoration/afforestation and an end to deforestation. Brazil's commitment of reducing its GHG emissions by 37% by 2025 compared to 2005 is only fulfilled in the Sustainable Medium Ambition and Sustainable High Ambition Pathways. However, the FABLE Calculator has lower values for the AFOLU GHG emissions in the historical period (39%, 47%, and 19% lower for 2005, 2010, and 2015, respectively) when compared to official data provided by the System for Estimating Greenhouse Gas Emissions (SEEG, 2020b). Improvements to the GHG emissions data used in the FABLE Calculator must be made to address this issue.

In terms of trade, the export assumptions are adjusted for soybeans, corn, and beef to follow the historical trends provided by FAO (FAOSTAT, 2020) and the projections from the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA, 2019), irrespective of the differences in each pathway. Nonetheless, the results of this report have the imports and exports adjusted depending on which products were in excess at the global level. After this international trade adjustment, the soybean exports in 2025 as projected by the Current Trends Pathway are 17% lower (74 Mt) than the expected exports estimated by MAPA (90 Mt). In addition, the Sustainable Medium Ambition and Sustainable High Ambition Pathways lead to a reduction of approximately 35% and 30% in total exports and imports, respectively, by 2050 compared to the Current Trends Pathway. These problems might occur due to the global trade adjustment methodology, which should be improved in the future.

Other refinements are necessary in Brazil's FABLE Calculator beyond GHG emissions and the trade adjustment methodology. A comprehensive validation and calibration against historical data and MAPA projections is necessary before using the FABLE Calculator for estimating future trends of Brazil's AFOLU sector. For the Current Trends Pathway, the tool overestimates the area of dry beans by 65% and underestimates the area of rice by 55%, when compared to MAPA projections in 2025 (MAPA, 2019). Regarding livestock production, livestock productivity (t/head) and stocking rate (head/ha) growth appears to be based on linear extrapolations of historical trends for all three scenarios. Although a higher livestock productivity growth rate was assumed for the sustainable pathways, the FABLE Calculator projects similar growth rates in the three pathways. These assumptions need to be further investigated in the future. Additionally, agroforestry should be included in the next version of the FABLE Calculator, since it represents systems which can mitigate GHG emissions and increase livestock growth and welfare due to thermal comfort (Pereira, 2019). Finally, the FABLE Calculator should generate results per biome or state level, improving deforestation estimates and making it possible to investigate leakages and regional production displacements due to climate change, as captured by other modelling approaches (Soterroni et al, 2018; Zilli et al, 2020).

Annex 1. List of changes made to the FABLE Calculator to adapt it to the Brazilian context

- The historical land cover maps from years 2000, 2005, 2010, and 2015 were replaced based on data provided by MapBiomas (MapBiomas, 2020) and IBGE (PAM/IBGE, 2020).
- The biofuel feedstock use for sugarcane was replaced by the data computed in de Andrade Junior et al. (2019). Three potential scenarios of ethanol demand in Brazil for 2030 were developed in this paper. For the Current Trends Pathway, we used the data related to the BAU (Business as Usual) scenario. For both sustainable pathways (medium and high), the data were replaced by the ones computed for the RFO (Renewable Fuels Oriented).
- Area and production for soybeans, corn, sugarcane, beans, rice, wheat, and cassava were replaced by values provided by IBGE.

Annex 2. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
The population is expected to reach 236 million by 2050. Brazil's population will peak around 233 million by 2050, according to data from IBGE, of which the closest scenario is SSP2 (IBGE, 2020).	The population is expected to reach 221 million by 2050. According to Lampe et al. (2016), a sustainable scenario is found to be close to SSP1, and the population data from SSP1 can be used for the scenario.	Same as Sustainable Medium Ambition Pathway

LAND Constraints on agricultural expansion

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
We assume that there will be no constraint on the expansion of the agricultural land outside beyond existing protected areas and under the total land boundary. The low enforcement of environmental protection laws in the last years provides multiple opportunities for infractions to go undetected or unpunished (Carvalho et al., 2019).	We assume that deforestation will be halted beyond 2030. This is in line with Brazil's NDC (Government of Brazil, 2018) which commits to strengthen its policies and measures with a view to achieve zero illegal deforestation in the Brazilian Amazonia by 2030.	Same as Sustainable Medium Ambition Pathway
LAND Afforestation or reforestation target (1000 ha)		
We do not expect afforestation/reforestation. There is an upward trend in deforestation occurring since 2012 in Brazil. For example, the rate of deforestation in the Amazon in 2019 represents an increase of 29.54% in relation to the deforestation rate in 2018, according to PRODES/INPE (PRODES/INPE, 2020). (No afforestation scenario selected)	We assume total afforested/reforested area reaches 12 Mha by 2030. The Brazilian government pledged to reforest 12 Mha by 2030 under the Bonn Challenge commitment (Bonn Challenge, 2014) and Brazil's NDC pledges (Government of Brazil, 2018). (Bonn Challenge scenario selected)	We assume total afforested/reforested area reaches 26.84 Mha by 2050. In addition to the Bonn Challenge commitment by 2030, we take into account the Atlantic Forest Pact, which aims to restore 15 Mha of degraded/deforest lands in Atlantic Forest by 2050 (Crouzeilles et al., 2019). The assumption also includes to restore by 2050 the environment debts per municipality based on the Rural Environmental Cadastre (CAR) (Guidotti et al., 2017). (Bonn Challenge+ scenario selected)

BIODIVERSITY Protected areas (1000 ha or % of total land)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
Protected areas remain stable: by 2050 they represent 30% of total land. We used the by-default assumption in the FABLE Calculator which is that in the ecoregions where current level of protection is between 5% and 17%, the natural land area under protection increases up to 17% of the ecoregion total natural land area by 2050.	Protected areas increase: by 2050 they represent 32% of total land. We used the by-default assumption in the FABLE Calculator which is that in the ecoregions where current level of protection is between 5% and 17%, the natural land area under protection increases up to 17% of the ecoregion total natural land area by 2050.	Same as Sustainable Medium Ambition Pathway

PRODUCTION Crop productivity for the key crops in the country (in t/ha)		
Current Trends Pathway	**Sustainable Medium Ambition Pathway**	**Sustainable High Ambition Pathway**
By 2050, crop productivity reaches: • 3.2 tonnes per ha for soybeans. • 8.5 tonnes per ha for corn. • 96.6 tonnes per ha for sugarcane. The selected assumption of the same productivity growth as over 2000–2010 is based on projections provided by MAPA (2019) for the main crops for the period 2019–2029.	By 2050, crop productivity reaches: • 5.2 tonnes per ha for soybeans. • 15.9 tonnes per ha for corn. • 127 tonnes per ha for sugarcane. A better analysis of the sustainable pathway could be achieved by implementing national policies, such as the National Plan for Low-Carbon Agriculture (ABC Plan) (Ministério da Agricultura, Pecuária e Abastecimento , 2012). The ABC Plan focuses on the nationwide adoption of technologies such Crop-Livestock-Forestry, No-Till, and Double Cropping. These technologies could be important to develop a sustainable pathway for Brazilian agriculture. Based on these policies, we assume a higher productivity growth than 2000¬–2010.	Same as Sustainable Medium Ambition Pathway
PRODUCTION Livestock productivity for the key livestock products in the country (in kg/head of animal unit)		
By 2050, livestock productivity reaches: • 80 kg per head for cattle beef. • 3044 kg per head for cattle milk. Despite many recent technological advances, it is necessary to create strategies to increase the weight and fertility of the herd, which enable greater animal performance with improved feed efficiency and, consequently, an increase in productivity. Most of the Brazilian pasturelands still maintain an extensive system that depends basically on the nutrient supply of the pastures (Barbosa et al., 2015).	By 2050, livestock productivity reaches: • 84 kg per head for cattle beef. • 3324 kg per head for cattle milk. The use of sustainable technologies, such as the agroforestry systems can contribute to the preservation of soil quality, water conservation, the increase in animal yield and welfare due to thermal comfort, mitigation of the effects of greenhouse gases and the recovery of degraded areas (Pereira, 2019). We assume a higher productivity growth than 2000–2010.	Same as Sustainable Medium Ambition Pathway

PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)

By 2050, the average ruminant livestock stocking density is 0.66 TLU/ha. We keep the low historical density growth as over 2000¬–2010 because, despite recent advances, the productivity of Brazilian pasturelands is still below its potential (Strassburg et al., 2014). According to LAPIG (Image Processing and Geoprocessing Lab) LAPIG (2017), almost 64 Mha of pastures contain signs of degradation in 2017.	By 2050, the average ruminant livestock stocking density is 0.69 TLU/ha. To achieve production and preservation goals in the future, the cattle ranching sector needs higher intensification compared to historical growth. Therefore, cattle ranching intensification will spare land for cropland expansion and decrease the pressure of native vegetation conversion (Soterroni et al., 2018).	Same as Sustainable Medium Ambition Pathway

PRODUCTION Post-harvest losses

By 2050, the share of production and imports lost during storage and transportation remains stable. Post-harvest losses continue to be a persistent problem in Brazil, despite of the modernization of logistics and production systems. One of the greatest challenges in facing the food loss issue is the convergence of interests among public, private, and scientific stakeholders (Henz and Porpino, 2017).	By 2050, the share of production and imports lost during storage and transportation is reduced by 50%. The Brazilian government committed to the United Nations (SDG 12.3.1br) to reduce food loss along production and supply chains by 2030 (IPEA, 2016).	Same as Sustainable Medium Ambition Pathway

TRADE Share of consumption which is imported for key imported products (%)

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
By 2050, the share of total consumption which is imported is: • 51% by 2050 for wheat. Brazilian imports will be almost the same for 2029 over 2019 for wheat (main imported product), according to projections from MAPA (2019). Hence, we choose a stable scenario that reflects that trend.	Same as Current Trends Pathway	By 2050, the share of total consumption which is imported is: • 59% by 2050 for wheat. Brazilian imports will be almost the same for 2029 over 2019 for wheat (main imported product), according to projections from MAPA (2019). Hence, we choose a stable scenario that reflects that trend.

TRADE Evolution of exports for key exported products (Mt)

By 2050, the volume of exports is: • 95.5 Mt by 2050 for soybeans • 4.2 Mt by 2050 for beef • 69.7 Mt by 2050 for corn Exports are multiplied by different values for soybeans, corn and beef, based on projections from the MAPA (2019) report. The exported quantity remains constant at the 2010 level for the other commodities.	By 2050, the volume of exports is: • 58.5 Mt by 2050 for soybeans. • 2.7 Mt by 2050 for beef • 39.2 Mt by 2050 for corn Exports are multiplied by different values for soybeans, corn and beef, based on projections from the MAPA (2019) report. The exported quantity remains constant at the 2010 level for the other commodities.	By 2050, the volume of exports is: • 57.6 Mt by 2050 for soybeans • 2.6 Mt by 2050 for beef • 39 Mt by 2050 for corn Exports are multiplied by different values for soybeans, corn and beef, based on projections from the MAPA (2019) report. The exported quantity remains constant at the 2010 level for the other commodities.

Brazil

FOOD Average dietary composition (daily kcal per commodity group or % of intake per commodity group)

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
By 2030, the average daily calorie consumption per capita is 3,384 kcal and is: • 977 kcal for cereals • 446 kcal for sugar • 151 kcal for red meat The scenario for diets follows FAO projections at the horizon of 2050 for a BAU scenario (FAO, 2018). The SSP2 food demand scenario represents a moderate consumption growth and increasing share of livestock products in the diet (Fricko et al., 2017).	By 2030, the average daily calorie consumption per capita is 2,726 kcal and is: • 803 kcal for cereals • 323 kcal for sugar • 120 kcal for red meat Sustainable pathways explicitly assume a shifter in preferences in favor of balanced and environmentally sustainable diets (FAO, 2018; Lampe et al., 2016). The SSP1 scenario represents a slow consumption growth and more sustainable and healthy diets (Fricko et al., 2017).	By 2030, the average daily calorie consumption per capita is 2,287 kcal and is: • 786 kcal for cereals • 293 kcal for sugar • 95 kcal for red meat Sustainable pathways explicitly assume a shifter in preferences in favor of balanced, healthy, and environmentally sustainable diets (FAO, 2018; Lampe et al., 2016). The selected scenario uses the EAT-Lancet recommendations for a healthy diet for an intake of 2,500/kcal/day (EAT-Lancet, 2019).
FOOD Share of food consumption which is wasted at household level (%)		
By 2030, the share of final household consumption which is wasted at the household level is 10%. Brazil faces the challenge to reduce food waste and ensure sustainability and food security in the face of cyclical social and economic crises in a country with high income inequality (Henz and Porpino, 2017). Also, there is a culture of food waste in all social classes in Brazil (Henz, 2017; Porpino, 2015).	By 2030, the share of final household consumption which is wasted at the household level is 5%. The Brazilian government committed to the United Nations (SDG 12.3.1br) to reduce per capita global food waste at the retail and consumer levels by 2030 (IPEA, 2016).	Same as Sustainable Medium Ambition Pathway

BIOFUELS Targets on biofuel and/or other bioenergy use (kt)

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
By 2050, biofuel production accounts for: • 531,099 kt of sugarcane production. In addition to using the OECD-FAO Agricultural outlook for 2019–2028, the biofuel feedstock use for sugarcane was replaced by the data computed in de Andrade Junior et al. (2019). We used the data related to the BAU scenario, mapped with the macroeconomic elements of the SSP2.	By 2050, biofuel production accounts for: • 742,759 kt of sugarcane production. The data from OECD was also used in this sustainable pathway. However, the data used for the biofuel feedstock use for sugarcane were replaced by the ones computed for the RFO (Renewable Fuels Oriented) scenario in de Andrade Junior et al. (2019).	By 2050, biofuel production accounts for: • 743,443 kt of sugarcane production. The data from OECD was also used in this sustainable pathway. However, the data used for the biofuel feedstock use for sugarcane were replaced by the ones computed for the RFO (Renewable Fuels Oriented) scenario in de Andrade Junior et al. (2019).

CLIMATE CHANGE Crop model and climate change scenario

Current Trends Pathway	Sustainable Medium Ambition Pathway	Sustainable High Ambition Pathway
By 2100, global GHG concentration leads to a radiative forcing level of 6 W/m2 (RCP 6.0). Impacts of climate change on crop yields (corn, rice, soybeans, and wheat) are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilization effect.	By 2100, global GHG concentration leads to a radiative forcing level of 2.6 W/m2 (RCP 2.6). Impacts of climate change on crop yields (corn, rice, soybeans, and wheat) are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilization effect.	By 2100, global GHG concentration leads to a radiative forcing level of 2.6 W/m2 (RCP 2.6). Impacts of climate change on crop yields (corn, rice, soybeans, and wheat) are computed by the crop model GEPIC using climate projections from the climate model HadGEM2-E without CO_2 fertilization effect.

Annex 3. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on Map 1

FABLE classes	ESA classes (codes)
Cropland	Cropland (10,11,12,20), Mosaic cropland>50% - natural vegetation <50% (30), Mosaic cropland><50% - natural vegetation >50% (40)
Forest	Broadleaved tree cover (50,60,61,62), Needleleaved tree cover (70,71,72,80,82,82), Mosaic trees and shrub >50% - herbaceous <50% (100), Tree cover flooded water (160,170)
Grassland	Mosaic herbaceous >50% - trees and shrubs <50% (110), Grassland (130)
Other land	Shrubland (120,121,122), Lichens and mosses (140), Sparse vegetation (150,151,152,153), Shrub or herbaceous flooded (180)
Bare areas	Bare areas (200,201,202)
Snow and ice	Snow and ice (220)
Urban	Urban (190)
Water	Water (210)

Units

°C – degree Celsius

% – percentage

/yr – per year

cap – per capita

CO_2 – carbon dioxide

CO_2e – greenhouse gas expressed in carbon dioxide equivalent in terms of their global warming potentials

g – gram

GHG – greenhouse gas

Gt – gigatons

ha – hectare

kcal – kilocalories

kg – kilogram

km^2 – square kilometer

km^3 – cubic kilometers

m – meter

Mha – million hectares

Mm^3 – million cubic meters

Mt – million tons

t – tonne

TLU – Tropical Livestock Unit is a standard unit of measurement equivalent to 250 kg, the weight of a standard cow

t/ha – tonne per hectare, measured as the production divided by the planted area by crop by year

t/TLU, kg/TLU, t/head, kg/head- tonne per TLU, kilogram per TLU, tonne per head, kilogram per head, measured as the production per year divided by the total herd number per animal type per year, including both productive and non-productive animals

USD – United States Dollar

W/m^2 – watt per square meter

yr – year

References

ANA. (2017). Atlas Irrigação: Uso da água na agricultura Irrigada. Retrieved from http://arquivos.ana.gov.br/imprensa/publicacoes/AtlasIrrigacao-UsodaAguanaAgriculturaIrrigada.pdf

ANA. (2019). Plano Nacional de Segurança Hídrica. Retrieved from http://arquivos.ana.gov.br/pnsh/pnsh.pdf

Angelo, C., & Rittl, C. (2019). SEEG 2019. Relatório Síntese [Report]. Retrieved from SEEG website: https://seeg-br.s3.amazonaws.com/2019-v7.0/documentos-analiticos/SEEG-Relatorio-Analitico-2019.pdf

Barbosa, F. A., Soares Filho, B. S., Merry, F. D., de Oliveira Azevedo, H., Costa, W. L. S., Coe, M. T., … de Oliveira, A. R. (2015). Cenários para a pecuária de corte amazônica (p. 154). Retrieved from Universidade Federal de Minas Gerais website: https://csr.ufmg.br/pecuaria/wp-content/uploads/2015/03/relatorio_cenarios_para_pecuaria_corte_amazonica.pdf

BirdLife International. (2019). Digital boundaries of Important Bird and Biodiversity Areas from the World Database of Key Biodiversity Areas. Retrieved February 8, 2019, from BirdLife International website: http://datazone.birdlife.org/site/requestgis

Bonn Challenge. (2014). Bonn Challenge. Retrieved May 21, 2020, from Bonn Challenge website: https://www.bonnchallenge.org/about-the-goal#commitments

BPBES. (2020). Relatório Temático "Água: Biodiversidade, Serviços Ecossistêmicos e Bem-Estar Humano." Retrieved from https://www.bpbes.net.br/produto/agua/

Brazil. (2015). Intended Nationaly Determined Contribution (INDCs). In: Library of Congress, http://www4.unfccc.int/submissions/INDC/PublishedDocuments/Brazil/1/BRAZILiNDCenglishFINAL.pdf.

Cadena, M., Supples, C., Ervin, J., Marigo, M., Monakhova, M., Raine, P., & Virnig, A. (2019). Nature is counting on us: Mapping progress to achieve the Aichi Biodiversity Targets. United Nations Development Programme.

Carvalho, W. D., Mustin, K., Hilário, R. R., Vasconcelos, I. M., Eilers, V., & Fearnside, P. M. (2019). Deforestation control in the Brazilian Amazon: A conservation struggle being lost as agreements and regulations are subverted and bypassed. Perspectives in Ecology and Conservation, 17(3), 122–130. https://doi.org/10.1016/j.pecon.2019.06.002

CBD. (2020). Brazil—National Targets. Retrieved May 8, 2020, from Convention on Biological Diversity website: https://www.cbd.int/countries/targets/?country=br

Clapp, J. (2015). Food self-sufficiency and international trade: A false dichotomy? [Technical note]. Retrieved from Food and Agriculture Organization website: http://www.fao.org/3/a-i5222e.pdf

Crouzeilles, R., Santiami, E., Rosa, M., Pugliese, L., Brancalion, P. H., Rodrigues, R. R., … Matsumoto, M. H. (2019). There is hope for achieving ambitious Atlantic Forest restoration commitments. Perspectives in Ecology and Conservation, 17(2), 80–83. https://doi.org/10.1016/j.pecon.2019.04.003

de Andrade Junior, M. A. U., Valin, H., Soterroni, A. C., Ramos, F. M., & Halog, A. (2019). Exploring future scenarios of ethanol demand in Brazil and their land-use implications. Energy Policy, 134, 110958. https://doi.org/10.1016/j.enpol.2019.110958

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., … Saleem, M. (2017). An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm. Bioscience, 67(6), 534–545. https://doi.org/10.1093/biosci/bix014

EAT-Lancet. (2019). Healthy Diets from Sustainable Food Systems [Summary report]. Retrieved from https://eatforum.org/content/uploads/2019/01/EAT-Lancet_Commission_Summary_Report.pdf

EAT. (2017). Health Effects of Overweight and Obesity in 195 Countries over 25 Years. New England Journal of Medicine, 377(1), 13–27. https://doi.org/10.1056/NEJMoa1614362

ESA. (2017). Land Cover CCI Product User Guide Version 2. Tech. Rep. Retrieved from

FAO. (2012). FAO Statistical Pocketbook 2012. Retrieved from http://www.fao.org/docrep/016/i2493e/i2493e.pdf

FAO. (2017). AQUASTAT [Database]. Retrieved from http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

FAO. (2018). The future of food and agriculture–Alternative pathways to 2050. Retrieved from http://www.fao.org/3/I8429EN/i8429en.pdf

FAO. (2020). FAOSTAT [Database]. Retrieved from http://www.fao.org/faostat/en/#home

Fricko, O., Havlik, P., Rogelj, J., Klimont, Z., Gusti, M., Johnson, N., … Riahi, K. (2017). The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. Global Environmental Change, 42, 251–267. https://doi.org/10.1016/j.gloenvcha.2016.06.004

GADM. (2020). Global Administrative Areas. Version 3.6. Retrieved from https://gadm.org/data.html

Gorski, M. T., & Roberto, C. A. (2015). Public health policies to encourage healthy eating habits: Recent perspectives. Journal of Healthcare Leadership, 7, 81–90. https://doi.org/10.2147/JHL.S69188

Government of Brazil. (2018). Intended Nationally Determined Contribution: Towards achieving the objective of the United Nations Framework Convention on Climate Change (p. 10). Retrieved from Ministério do Meio Ambiente website: http://www.mma.gov.br/images/arquivo/80108/BRAZIL iNDC english FINAL.pdf

Guidotti, V., Freitas, F. L., Sparovek, G., Pinto, L. F. G., Hamamura, C., Carvalho, T., & Cerignoni, F. (2017). Números detalhados do novo código florestal e suas implicações para os PRAs. Sustentabilidade Em Debate, (5), 1–11. https://doi.org/10.13140/RG.2.2.23229.87526

Hattori, T. (2019). IGES NDC Database v7.1. Retrieved from https://www.iges.or.jp/en/pub/iges-indc-ndc-database/en

Henz, G. P. (2017). Postharvest losses of perishables in Brazil: What do we know so far? Horticultura Brasileira, 35(1), 6–13. https://doi.org/10.1590/s0102-053620170102

Henz, G. P., & Porpino, G. (2017). Food losses and waste: How Brazil is facing this global challenge? Horticultura Brasileira, 35(4), 472–482. https://doi.org/10.1590/s0102-053620170402

IBGE. (2020). IBGE - Projeção da população [Database]. Retrieved from https://www.ibge.gov.br/apps/populacao/projecao/

IHME. (2020). GBD Compare database [Database]. Retrieved from http://vizhub.healthdata.org/gbd-compare

Instituto Trata Brasil. (2018). Perdas de água 2018 (SNIS 2016): Desafios para disponibilidade hídrica e avanço da eficiência do saneamento básico. Retrieved from http://www.tratabrasil.org.br/images/estudos/itb/perdas-2018/estudo-completo.pdf

IPEA, ANA, & PNUD. (2018). Diálogos sobre os Objetivos de Desenvolvimento Sustentável e os Desafios para a Gestão da Água e do Saneamento no Brasil. Retrieved from https://www.ipea.gov.br/portal/images/stories/PDFs/relatorio_institucional/180315_relatorio_agua_e_saneamento.pdf

IPEA. (2016). ODS 12–Consumo e Produção Sustentáveis. Retrieved May 21, 2020, from https://www.ipea.gov.br/ods/ods12.html#coll_12_3

Jacobson, A. P., Riggio, J., M. Tait, A., & E. M. Baillie, J. (2019). Global areas of low human impact ('Low Impact Areas') and fragmentation of the natural world. Scientific Reports, 9(1), 14179. https://doi.org/10.1038/s41598-019-50558-6

Lampe, M. von, Tongeren, F. van, Abderrahmane, M., Giacalone-Belkadi, M., Patterson, M., Thompson-Lipponen, C., & Tabeau, A. A. (2016). Alternative futures for global food and agriculture (No. 9789264247826). Retrieved from OECD website: https://edepot.wur.nl/449948

LAPIG. (2017). Pastagem degradadas (2017) [Database]. Retrieved from https://www.lapig.iesa.ufg.br/lapig/index.php/produtos/atlas-digital-das-pastagens-brasileiras

MAPA. (2019). Projeções do Agronegócio: Brasil 2018/19 a 2028/29 Projeções de longo prazo (p. 126) [Report]. Retrieved from Ministério da Agricultura, Pecuária e Abastecimento website: http://antigo.agricultura.gov.br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio/projecoes-do-agronegocio-2018-2019-2028-2029/@@download/file/PROJEC%CC%A7O%CC%83ES%202019_VERSA%CC%83O_FINAL_3.pdf

ESA. (2017). Land Cover CCI Product User Guide Version 2. Tech. Rep. Retrieved from maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf

Mekonnen, M.M. and Hoekstra, A.Y. (2010a). The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands. Retrieved from http://www.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf

Mekonnen, M.M. and Hoekstra, A.Y. (2010b). The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M.M. and Hoekstra, A.Y. (2011) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No. 50, UNESCO-IHE, Delft, the Netherlands.

Ministério da Agricultura, Pecuária e Abastecimento. (2012). Plano setorial de mitigação e de adaptação às mudanças climáticas para a consolidação de uma economia de baixa emissão de carbono na agricultura: Plano ABC (Agricultura de Baixa Emissão de Carbono) (p. 173). Retrieved from https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/plano-abc/arquivo-publicacoes-plano-abc/download.pdf

Ministério da Saúde. (2019). Vigitel Brasil 2019: Vigilância de fatores de risco e proteção para doenças crônicaspor inquérito telefônico: Estimativas sobre frequência e distribuição sociodemográfica de de fatores de risco e proteção para doenças crônicas nas capitais dos 26 estados brasileiros e no Distrito Federal em 2019 (p. 137) [Report]. Retrieved from Ministério da Saúde website: https://portalarquivos.saude.gov.br/images/pdf/2020/April/27/vigitel-brasil-2019-vigilancia-fatores-risco.pdf

Ministério do Meio Ambiente. (2005). Deliberação CONABIO n. 39, de 14 de dezembro de 2005. Retrieved from Ministério do Meio Ambiente website: http://areasprioritarias.mma.gov.br/images/arquivos/Delib_039.pdf

Ministério do Meio Ambiente. (2018). Áreas Prioritárias. Retrieved May 21, 2020, from Ministério do Meio Ambiente website: http://areasprioritarias.mma.gov.br/2-atualizacao-das-areas-prioritarias

Ministério da Ciência, Tecnologia e Inovações. (2019). Comunicações Nacionais do Brasil à UNFCCC [Report]. Retrieved from Ministério da Ciência, Tecnologia e Inovações website: https://www.mctic.gov.br/mctic/opencms/ciencia/SEPED/clima/Comunicacao_Nacional/Comunicacoes_Nacionais.html

Mosnier, A., Penescu, L., Thomson, M., Perez-Guzman, K. (2019). Documentation of the FABLE Calculator: SDSN/IIASA. Retrieved from https://www.abstract-landscapes.com/fable-calculator

OECD-FAO. (2020). Agricultural Outlook 2019-2028 [Database]. Retrieved from https://stats.oecd.org/Index.aspx?DataSetCode=HIGH_AGLINK_2019#

OECD. (2020). Real GDP long-term forecast (indicator) [Database]. Retrieved from https://doi.org/doi:10.1787/d927bc18-en

PAM/IBGE. (2020). Sistema IBGE de Recuperação Automática—SIDRA. Retrieved from https://sidra.ibge.gov.br/

Pereira, M. de A. (2019). Avaliação econômica de sistemas de Integração Lavoura-Pecuária-Floresta: As experiências da Embrapa. Embrapa Gado de Corte-Documentos (INFOTECA-E). Retrieved from https://ainfo.cnptia.embrapa.br/digital/bitstream/item/209464/1/Avaliacao-economia-de-sistemas.pdf

Porpino, G., Parente, J., & Wansink, B. (2015). Food waste paradox: Antecedents of food disposal in low income households. International Journal of Consumer Studies, 39(6), 619–629. https://doi.org/10.1111/ijcs.12207

Potapov, P., Hansen, M. C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., … Esipova, E. (2017). The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. Science Advances, 3(1). https://doi.org/10.1126/sciadv.1600821

PPM/IBGE. (2020). Sistema IBGE de Recuperação Automática—SIDRA. Retrieved from https://sidra.ibge.gov.br/

PRODES/INPE. (2020). Taxas anuais de desmatamento na Amazônia Legal Brasileira (AMZ) [Data set]. Retrieved from http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates

Puma, M. J., Bose, S., Chon, S. Y., & Cook, B. I. (2015). Assessing the evolving fragility of the global food system. Environmental Research Letters, 10(2), 024007. https://doi.org/10.1088/1748-9326/10/2/024007

Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., … Lawrence, D. (2019). Contribution of the land sector to a 1.5 °C world. Nature Climate Change, 9(11), 817–828. https://doi.org/10.1038/s41558-019-0591-9

SEEG. (2018a). Emissões do setor de agropecuária. SEEG 2018—Documento de Análise. Retrieved from https://www.researchgate.net/profile/Natali_Silveira/publication/327120508_SEEG_-_Relatorio_Analitico_Agropecuaria_-_2018/links/5b7b12e04585151fd123c43e/SEEG-Relatorio-Analitico-Agropecuaria-2018.pdf

SEEG. (2018b). Emissões do setor de mudança da terra. SEEG 2018—Documento de Análise. Retrieved from http://www.observatoriodoclima.eco.br/wp-content/uploads/2018/05/Relato%CC%81rios-SEEG-2018-MUT-Final-v1.pdf

SEEG. (2020a). Impacto da pandemia de Covid-19 nas emissões de gases de efeito estufa no Brasil. Retrieved from http://www.observatoriodoclima.eco.br/wp-content/uploads/2020/05/SEEG-OC_Nota_Tecnica_Covid19_Final.pdf

SEEG. (2020b). Sistema de estimativa de emissões de gases de efeito estufa, Brasil [Data set]. Retrieved from http://seeg.eco.br/

Soterroni, A. C., Mosnier, A., Carvalho, A. X. Y., Câmara, G., Obersteiner, M., Andrade, P. R., … Ramos, F. M. (2018). Future environmental and agricultural impacts of Brazil's Forest Code. Environmental Research Letters, 13(7), 074021. https://doi.org/10.1088/1748-9326/aaccbb

Souza, C. M., Z. Shimbo, J., Rosa, M. R., Parente, L. L., A. Alencar, A., Rudorff, B. F. T., … Azevedo, T. (2020). Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. Remote Sensing, 12(17). https://doi.org/10.3390/rs12172735

Strassburg, B. B. N., Latawiec, A. E., Barioni, L. G., Nobre, C. A., Silva, V. P. da, Valentim, J. F., … Assad, E. D. (2014). When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. Global Environmental Change, 28, 84–97. https://doi.org/10.1016/j.gloenvcha.2014.06.001

The 2017 Revision, Key Findings and Advance Tables [Working Paper No. ESA/P/WP/248]. Retrieved from United Nations website: https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf

U. S. Department of Justice, & Federal Trade Commission. (2010). Horizontal Merger Guidelines. Retrieved from

U.S. Department of Health and Human Services and U.S. Department of Agriculture. (2015). 2015-2020 Dietary Guidelines for Americans, 8th Edition (p. 144). Retrieved from U.S. Department of Health and Human Services website: http://health.gov/dietaryguidelines/2015/guidelines/

UN DESA. (2017). World Population Prospects: The 2017 Revision, Key Findings and Advance Tables [Working Paper]. Retrieved from United Nations website: https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf

UNEP-WCMC, & IUCN. (2020). Protected Planet: The World Database on Protected Areas (WDPA). Retrieved from UNEP-WCMC and IUCN website: www.protectedplanet.net

UNFCCC. (2020). Greenhouse Gas Inventory Data—Flexible Queries Non-Annex I Parties [Database]. Retrieved from https://di.unfccc.int/flex_non_annex1

Wanner, N., Cafiero, C., Troubat, N., & Conforti, P. (2014). Refinements to the FAO Methodology for estimating the Prevalence of Undernourishment Indicator. ESS Working Paper No. 14-05. Retrieved from http://www.fao.org/3/a-i4046e.pdf

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., Vries, W. D., Sibanda, L. M., … Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

World Bank. (2020a). Prevalence of stunting, height for age (% of children under 5) [Database]. Retrieved from https://data.worldbank.org/indicator/SH.STA.STNT.ZS

World Bank. (2020b). Prevalence of stunting, weight for height (% of children under 5) [Database]. Retrieved from https://data.worldbank.org/indicator/SH.STA.WAST.ZS

World Bank. (2020c). Prevalence of undernourishment (% of population) [Database]. Retrieved from https://data.worldbank.org/indicator/SN.ITK.DEFC.ZS

Zilli, M., Scarabello, M., Soterroni, A. C., Valin, H., Mosnier, A., Leclere, D., … Ramos, F. M. (2020). The impact of climate change on Brazil's agriculture. Science of The Total Environment, 139384. https://doi.org/10.1016/j.scitotenv.2020.139384