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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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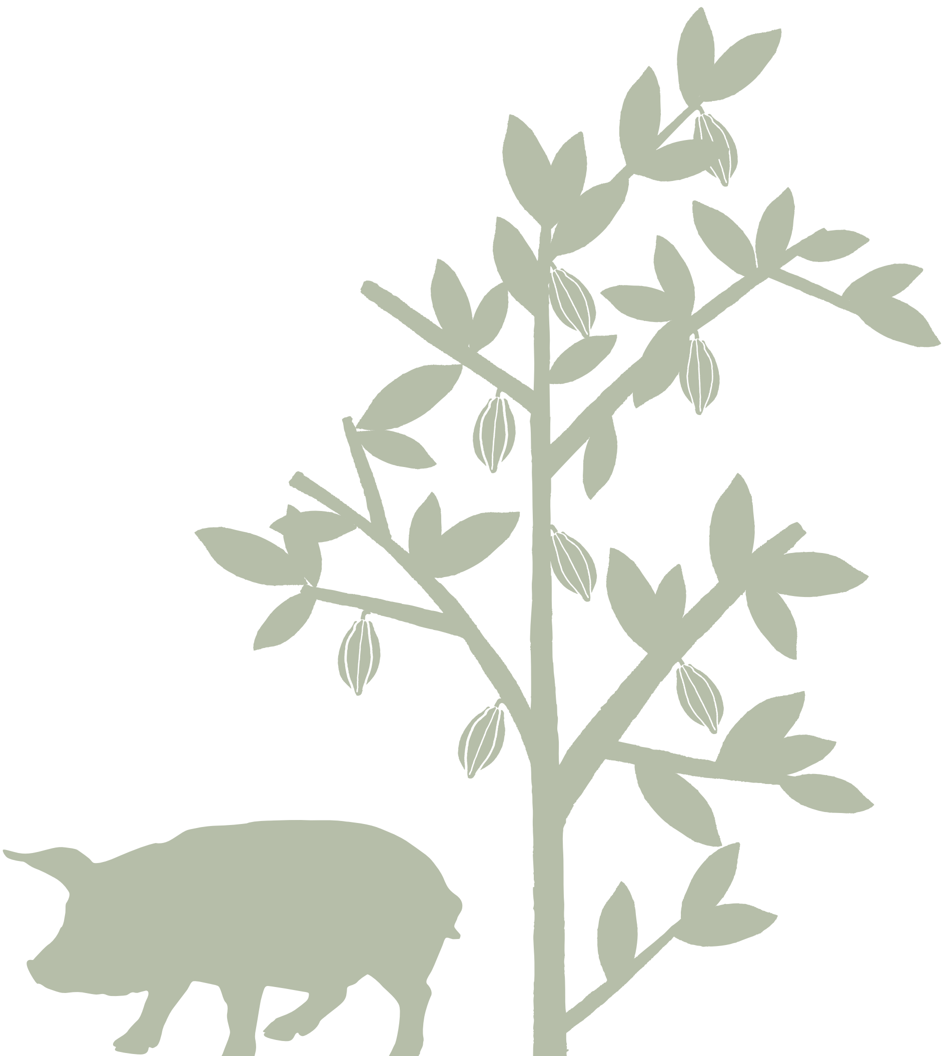
2020 Report of the FABLE Consortium

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



Colombia

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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 Colombia. It presents two pathways for food and land-use systems for the period 2020-2050: Current Trends and Sustainable. 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. We developed these pathways in consultation with national stakeholders and experts, including the Ministry of Environment and Sustainable Development (MADS), the Ministry of Agriculture and Rural Development (MADR), the National Planning Department (DNP) and the Food and Land Use Coalition for Colombia (FOLU-Colombia), and modeled them 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 Colombia's Nationally Determined Contribution (NDC) and Forest Reference Emission Level (FREL) treat the FABLE domains. According to the Government of Colombia, the country has committed to reducing its GHG emissions by 20% by 2030 compared to the projected business-as-usual (BAU) scenario for 2030 (Gobierno de Colombia, 2017). This includes emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include reducing deforestation by 39% with

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

	Total GHG Mitigation					Mitigation Measures Related to AFOLU (Y/N)	Mention of Biodiversity (Y/N)	Inclusion of Actionable Maps for Land-Use Planning[1] (Y/N)	Links to Other FABLE Targets
	Baseline		Mitigation target		Sectors included				
	Year	GHG emissions (Mt CO_2e/yr)	Year	Target					
NDC (2018)	2010 2030	224 335	2030	20% reduction compared to projected BAU scenario by 2030	Agriculture, land use and forestry, energy, industrial processes, and waste	Y	N	N	Water, deforestation
FREL (2016)	-	51.6 (UNFCCC, 2020)	-	-	Agriculture, land use and forestry	Y	N	Y Forest and No Forest map for 2020 Y Deforestation risk map for 2022 at subnational level	Deforestation

Note. "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)

1 We follow the United Nations Development Programme definition, "maps that provide information that allowed planners to take action" (Cadena et al., 2019).

respect to NDC baseline, implementing the Nationally Appropriate Mitigation Action -NAMA- (MADS, 2017), including intervention on 3.2 Mha for the implementation of sustainable actions for livestock production, restoring 17,000 hectares per year of disturbed areas, establishing commercial forest plantations, and implementing cocoa plantations in areas previously occupied by grasslands. Under its current commitments to the UNFCCC, Colombia does not mention biodiversity conservation.

Table 2 provides an overview of the targets included in the latest National Biodiversity Strategies and Action Plan (NBSAP) from 2017 (MINAMBIENTE, 2017), as listed on the CBD website (CBD, 2020), which are related to at least one of the FABLE Targets. By gradually reducing deforestation and increasing carbon stocks via restoration, the NBSAP contributes to both biodiversity and climate objectives.

Table 2 | Overview of the NBSAP targets in relation to FABLE targets

NBSAP Target	FABLE Target
(I.5) **By 2020, 2025 and 2030, Colombia will have 0.2Mha, 0.5Mha and 1Mha respectively, under restoration in areas defined as susceptible by the National Restoration Plan: Ecological Restoration, Rehabilitation and Reclamation of Disturbed Areas.**	**GHG EMISSIONS:** Zero or negative global GHG emissions from LULUCF by 2050 **BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(I.6) **Deforestation rates will be progressively reduced from 120,000ha/yr to 50,000ha/yr by 2020, from 50,000ha/yr to 25,000ha/yr by 2025 and from 25,000/yr to 10,000ha/yr by 2030. The reduction will be focused on deforestation *hotspots* identified by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM).**	**DEFORESTATION:** Zero net deforestation from 2030 onwards
(III.4) **By 2020, Colombia will apply eco-efficiency principles based on the integrated management of biodiversity and its ecosystem services to 0.3Mha intended for agricultural production. By 2025, an additional 0.6Mha will be incorporated.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(III.5) **By 2020, sustainable production systems that combine production and conservation actions to generate local development will be identified. Sustainable production systems will be rolled out in municipalities that are highly biodiverse and affected by the armed conflict.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate

Brief Description of National Pathways

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

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by medium population growth (from 51.1 million in 2020 to 62.8 million in 2050), constraints on agricultural expansion, limiting deforestation by 2030, a medium afforestation target of 1 Mha by 2035, an 18% increase in the extent of protected areas by 2050, low productivity increases in the agricultural sector, a constant share of internal consumption being imported, and an increase in exports of banana, coffee, and raw sugar (see Annex 2). This corresponds to a future based on current policy and historical trends that would also see considerable progress with regards to slowing population growth, gradually curbing deforestation to less than 10,000 hectares per year by 2030 (CBD, 2020), implementing Colombia's defined National Agricultural Frontier (40.1 Mha) to limit further agricultural expansion (MADR-UPRA, 2018), increasing afforestation efforts via implementation of the National Restoration Plan (MINAMBIENTE, 2015), and increasing terrestrial protected areas in compliance with Aichi Target 11. 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 rice and corn, (see Annex 2).

Our Sustainable Pathway represents a future in which significant efforts are made to adopt sustainable policies and practices and corresponds to a high boundary of feasible action. Compared to the Current Trends Pathway, we assume that this future would lead to higher economic growth, a transition to more sustainable diets, higher livestock and crop productivity, higher exports, and lower food waste (see Annex 2). This corresponds to a future based on the implementation of ambitious policies that would also see considerable progress with regards to: (i) Colombia's increased productivity and competitiveness through the sustainable use of natural capital and the promotion of social inclusion, compatible with climate policies such as the Green Growth Policy (DNP, 2019b); (ii) increasing productivity for prioritized crops (i.e. rice, corn, potato, sugar cane for panela[2], and avocado) as a result of national production management plans (POPs) (UPRA, 2015); (iii) increasing livestock productivity in line with mitigation measures (e.g. sustainable livestock) (Pinto-Brun, 2016); (iv) diversifying exports and destinations for crops and livestock, and; (v) reducing food waste in line with Colombia's Policy for Preventing Food Waste and Loss -Law 1990, 2019- (Congreso de Colombia, 2019). With the other FABLE country teams, we embed this Sustainable 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.

2 The word "panela" in Spanish-speaking Latin American countries refers to unrefined whole cane sugar. It is a solid product obtained by boiling and evaporating sugarcane juice.

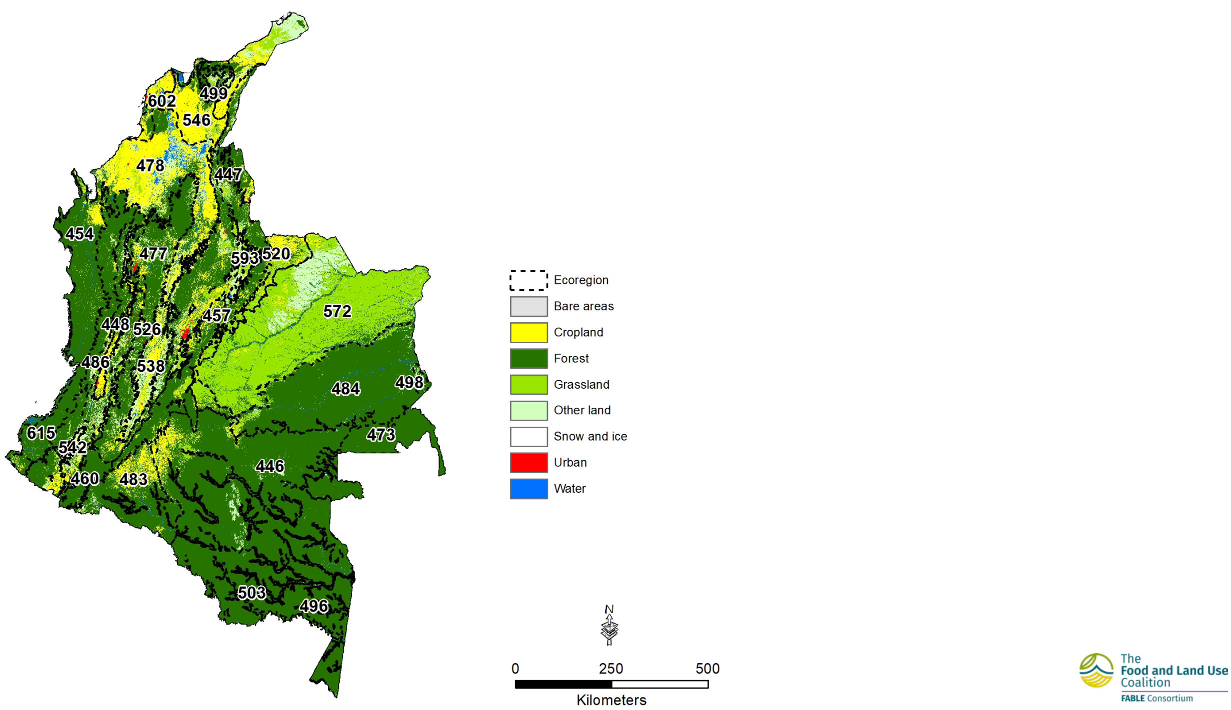
Land and Biodiversity

Current State

In 2010, Colombia was covered by 4% cropland, 35% grassland, 55% forest, 0.2% urban and 6% other natural land (FAO, 2020). Most of the agricultural area is located in the north (Caribbean region), northeast (The Plains or *Los Llanos* region), and in the inter-Andean valleys of the Magdalena and Cauca rivers. Forest can be mostly found in the south, as part of the Amazon region, and in the west towards the Pacific Ocean (Map 1). Finally, other natural lands, in particular grasslands, are located in the east as part of *Los Llanos* region. Land-use change related to agricultural expansion mainly for livestock production has historically been the main factor contributing to ecosystem fragmentation and biodiversity loss in Colombia (Etter, McAlpine, & Possingham, 2008). In 2012, the Ministry of Environment designed the National Policy for the Integral Management of Biodiversity and its Ecosystem Services. The policy aims to integrate conservation and production, especially for land-use activities.

We estimate that land where natural processes predominate[3] accounted for 57% of Colombia's terrestrial land area in 2010 (Map 2). The 503-Solimões-Japurá[4] moist forests hold the greatest share of land where natural processes predominate, followed by 484-Negro Branco moist forests and 446-Caquetá moist forests (Annex 4). Across the country, while 12 Mha of land is under formal protection, falling short of the 30% zero-draft CBD post-2020 target, only

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



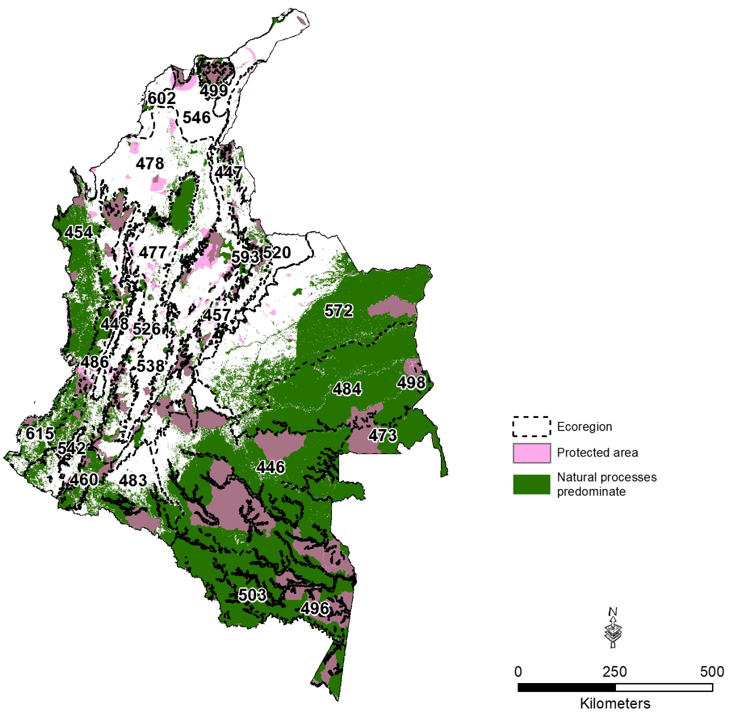
Notes: Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3.
Sources: countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)

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".
4 Solimões-Japurá moist forests, Negro Branco moist forest, and Caqueta moist forest are ecoregions with land in more than one country (e.g. Colombia, Brazil, and Venezuela). For this reason, their names do not necessarily correspond to geographical referents in Colombia, except for Caqueta. Within Colombia, these three ecoregions are spatially contiguous and belong to the Amazon region in the southern half of the country.

22% of land where natural processes predominate is formally protected. This indicates that *paramo* areas in northern Colombia (Santa Marta and Andean), dry forests in the Sinu Valley and Apure-Villavicencio, and montane forests in Santa Marta and the Cordillera Oriental are likely to remain important in the future. *Paramo* areas are important not only for biodiversity, but due to their role in regulating water supply for human activities in urban centers and in the countryside. Dry forests are one of the most endangered ecosystems in Colombia (Pizano & García, 2014). In this sense, forests such as those located in the Cauca Valley and Patia Valley are at high risk due to increased pressure from human activity. This tension also affects moist forests in Choco-Darien and natural grasslands in *Los Llanos*. It is worth noting that Choco-Darien is one of the most biodiverse regions in the world (WWF-Colombia, 2014).

Approximately 60% of Colombia's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively biodiversity-friendly croplands are most widespread in the 484-Negro-Branco moist forests, followed by 503-Solimões-Japurá moist forests, and 572-Llanos. They are all located in the east and southeast. The regional differences in the extent of biodiversity-friendly cropland can be explained by regional production practices and prevailing landscape conditions. For instance, remnants of natural vegetation in the Andes mountains are scattered and usually located in areas where agricultural activities are not always possible (e.g. steep slopes). Additionally, land plots tend to be small, numerous, and used for different activities, generating landscapes that are heavily transformed and heterogeneous. In contrast, in low-lying areas like the Llanos, crop fields tend to be large and surrounded by heterogeneous natural landscapes (e.g. natural grasslands mixed with riparian forests). Such conditions tend to increase the natural vegetation associated with croplands.

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



Note: 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)

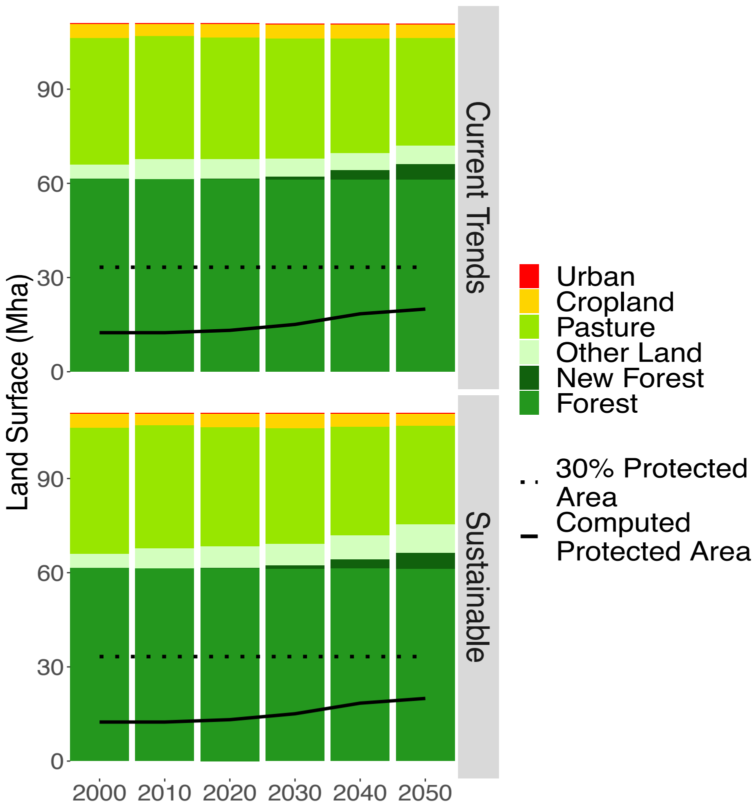
2 We follow Jacobson, Riggio, Tait, and Baillie (2019) definition: "Landscapes that currently have low human density and impacts and are not primarily managed for human needs. These are areas where natural processes predominate, but are not necessarily places with intact natural vegetation, ecosystem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

Pathways and Results

Projected land use in the Current Trends Pathway is based on several assumptions, including the prevention of deforestation by 2030 (in line with the agricultural frontier), afforestation or reforestation of 1 Mha by 2035 (in line with the National Restoration Plan), and an increase in protected areas from 11% of the total land in 2000 to 18% in 2050 (see Annex 2). For the Sustainable Pathway, assumptions on agricultural land expansion, reforestation, protected areas were not changed. These assumptions were based on existing policies that were designed within the last five to ten years and are set to be implemented in the medium to long-term with ambitious sustainable targets. Their implementation is still in early stages, therefore it is too soon to assess their performance and consider any additional increase in their targets, particularly for policies addressing agricultural land expansion and afforestation.

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result from an increase in cropland and new forest area and a decrease in other natural land and pasture areas. This trend continues over the period 2030-2050: pasture area further decreases and new forest area increases (Figure 1). The expansion of the planted area for sugar cane, coffee, and rice explains 71% of total cropland expansion between 2010 and 2030. For sugar cane, 51% of expansion is explained by an increase in the export of raw sugar and 48% by an increase in domestic consumption. For coffee, 73% of expansion is due to an increase in exports and 27% by an increase in domestic consumption. Finally, for rice, 65% results from an increase in domestic consumption and 24% from an increase in demand for animal feed. Pasture decline is mainly driven by the increase in ruminant

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

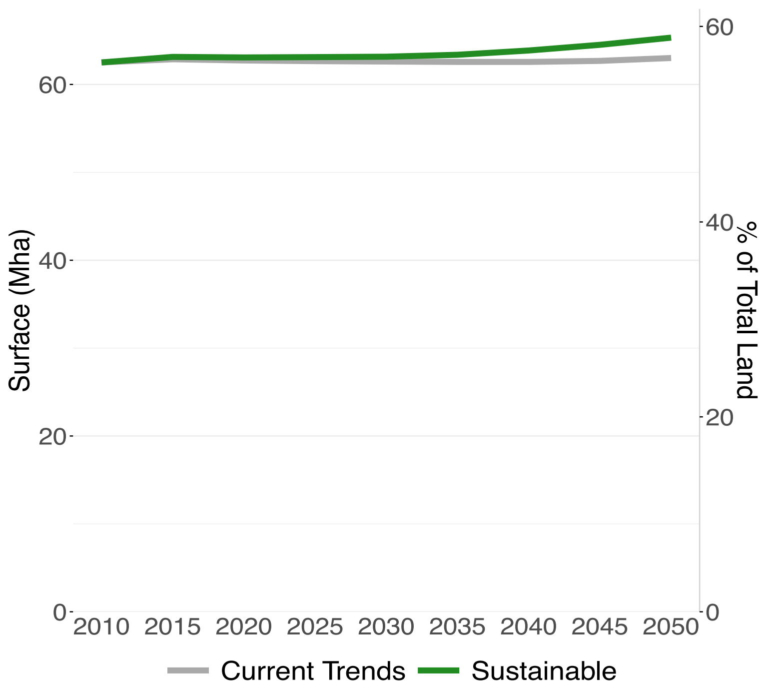


Source. Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000, and IDEAM (2010) for protected areas for years 2000, 2005 and 2010.

density per hectare and livestock productivity per head over the period 2020-2030. Between 2030-2050, pasture areas continue to decrease. This is explained by a decline in the consumption of red meat, leading to a reduction in the average food intake per capita, and an increase in livestock productivity. This results in an expansion of land where natural processes predominate by 0.2% by 2030 and by 0.8% by 2050 compared to 2010, respectively.

Compared to the Current Trends Pathway, the overall evolution of land cover in Colombia is similar in the Sustainable Pathway. However, we observe two main differences. First, the pasture area is 2.8 Mha lower in 2050. Increases in productivity per head and ruminant density, as well as changes in diets (i.e. reduction in red meat consumption) are the main contributing factors to this change. Second, and similarly, the cropland area is slightly lower (0.6 Mha) in 2050. This result is due to the assumptions of increased crop productivity to respond to growing demand and the prevention of further agricultural expansion. Additional contributing factors to these two changes include reductions in food waste and the shift towards a more healthy and sustainable diet. This leads to a 4.5% increase in the area where natural processes predominate between 2010 and 2050 (Figure 2).

Figure 2 | Evolution of the area where natural processes predominate



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GHG emissions from AFOLU

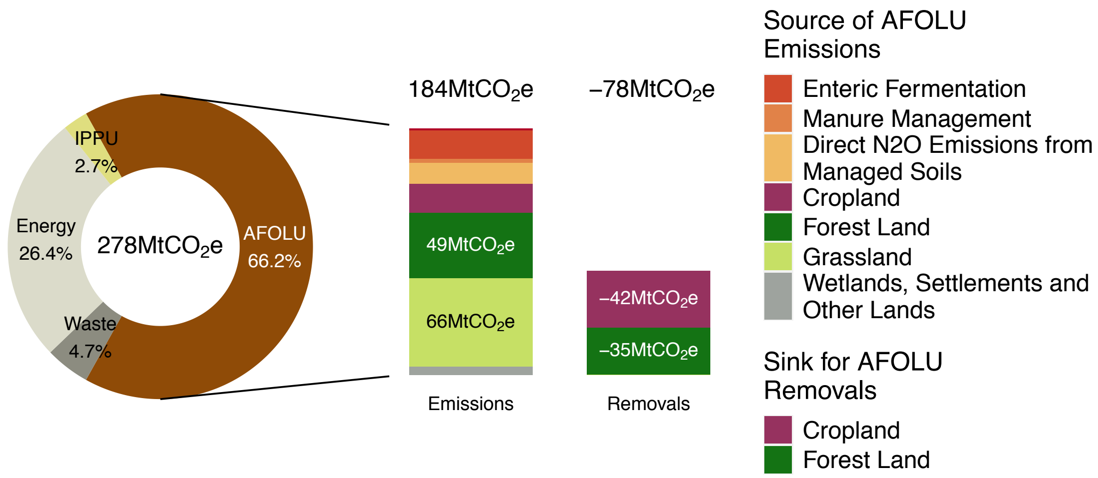
Current State

Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 66% of Colombia's total emissions in 2010 (Figure 3). Grassland is the main source of AFOLU emissions, followed by forest land, and enteric fermentation. This can be explained by the following factors: (i) conversion of natural forests into grasslands (*deforestation*) due to land grabbing, illicit crops and extensive cattle ranching (MINAMBIENTE & IDEAM, 2017); (ii) conversion of natural forests into secondary vegetation (*degradation*) caused by selective and illegal logging, among other factors (Meyer et al., 2019); and (iii) beef and milk production from bovine cattle. As for removals, the main contributing factor between 2000 and 2010 was the increase in the area used for commercial plantations and permanent crops like oil palm (Gobierno de Colombia, 2017).

Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU decrease to 48 Mt CO_2e/yr in 2030, before reaching 1 Mt CO_2e/yr in 2050 (Figure 4). In 2050, livestock is the largest source of emissions (53 Mt CO_2e/yr) while land-use change acts as a sink (-60 Mt CO_2e/yr). Over the period 2020-2050, the strongest relative increase in GHG emissions is computed for crops (6%) while land-use change consolidates its role as a sink (from -16 Mt CO_2e/yr to -60 Mt CO_2e/yr). In comparison, the Sustainable Pathway leads to a reduction in GHG emissions from AFOLU GHG by 25.2 Mt CO_2e/yr

Figure 3 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2010



Note. IPPU = Industrial Processes and Product Use
Source. Tercera comunicación nacional de Colombia a la Convención Marco de las Naciones Unidas sobre Cambio Climático [Third National Communication of Colombia to the United Nations Framework Convention on Climate Change] (Gobierno de Colombia, 2017)

compared to the Current Trends Pathway by 2050 (Figure 4). The potential for emissions reduction under the Sustainable Pathway is dominated by a reduction in GHG emissions from land-use change (39%), biofuels (39%) and livestock (20%) (Figure 5). The most important drivers of this reduction are the increases in livestock productivity and ruminant density which result in a decrease in the expansion of pasture areas; and the increase in biofuel production to include more ethanol (from sugar cane) and biodiesel (from oil palm) in the national fuel mix.

Compared to Colombia's commitments under UNFCCC (Table 1), our results show that AFOLU could contribute to as much as 35% of its total GHG emissions reduction objective by 2030. Such reductions could be achieved through policy measures that increase livestock productivity, promote the transition to a more healthy and sustainable diet, and increase biofuel production. An increase in livestock productivity coupled with a shift in diets (i.e. reducing the consumption of red meat) should reduce pressure on existing natural areas for agricultural expansion. By reducing the expansion of agricultural land, new forest land should increase, enhancing the latter's role as a sink for sequestering carbon. These measures are of particular relevance when considering options for NDC enhancement and for other transversal policies including Colombia's Green Growth Policy, the National Development Plan, among others.

Figure 4 | Projected AFOLU emissions and removals between 2010 and 2050 by main sources and sinks for the Current Trends Pathway

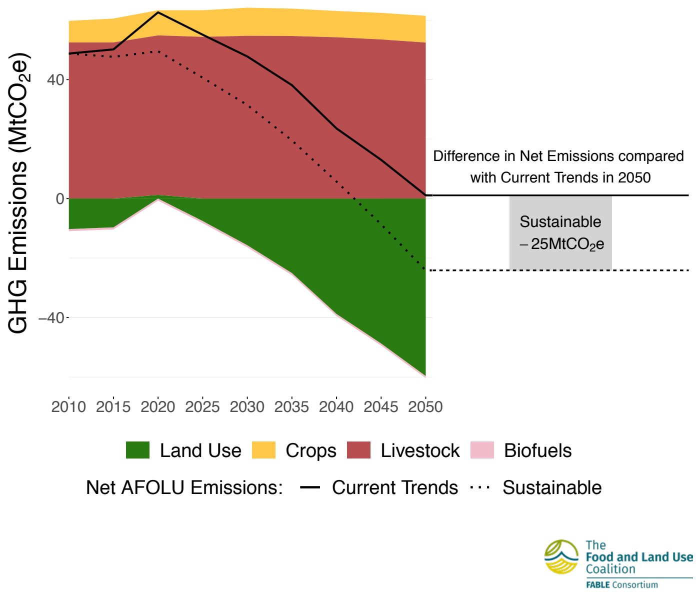
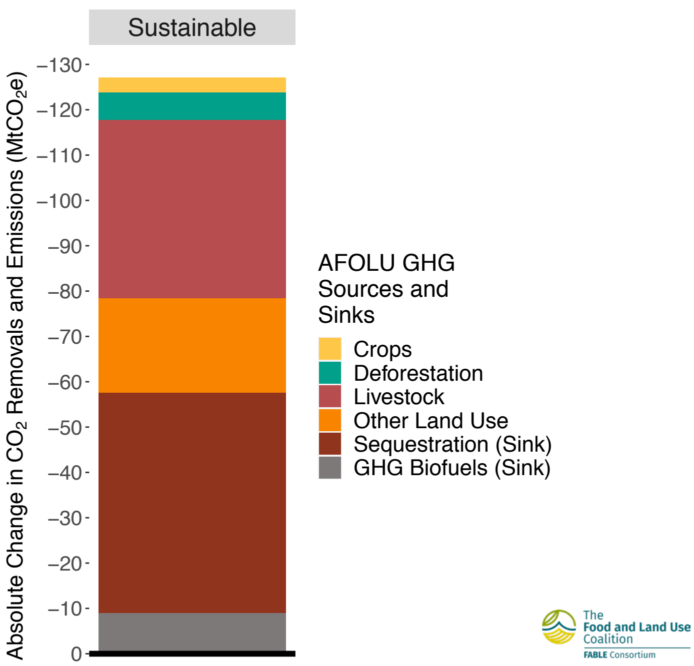
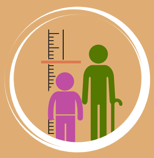


Figure 5 | Cumulated GHG emissions reduction computed over 2020-2050 by AFOLU GHG emissions and sequestration source compared to the Current Trends Pathway



Food Security

Current State



Undernutrition

11% of the population was undernourished in 2010. This share decreased to 5% in 2017 (FAO, 2019).

13% of children under 5 stunted and 1% were wasted in 2010 (FAO, 2019).

Micronutrient Deficiency

8% of women and 8% of children (5-12 years) suffered from anemia in 2010, which can lead to maternal death (Instituto Colombiano de Bienestar Familiar [ICBF], 2010).

Overweight/ Obesity

56% of the population is overweight and 21% obese (WHO, 2016), 57% of adults and 24% of children (5-12 years), were overweight or obese in 2015. These shares have increased since 2010 (ICBF, 2015).

Disease Burden due to Dietary Risks

15% of deaths are attributable to dietary risks (Institute of Health Metrics and Evaluation, 2019).

8% of the population suffers from diabetes (WHO, 2016) and 30% from cardiovascular diseases (WHO, 2018), which can be attributable to dietary risks.

Table 3 | Daily average fats, proteins and kilocalorie intake under the Current Trends and Sustainable Pathways in 2030 and 2050

	2010	2030		2050	
	Historical Diet (FAO)	Current Trends	Sustainable	Current Trends	Sustainable
Kilocalories (MDER)	2,621 (2,072)	2,777 (2,092)	2,530 (2,092)	2,934 (2,084)	2,437 (2,084)
Fats (g) (recommended range)	82 (58-87)	80 (62-93)	81 (56-84)	79 (65-98)	80 (54-81)
Proteins (g) (recommended range)	59 (66-229)	61 (69-243)	58 (63-221)	64 (73-257)	58 (61-213)

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

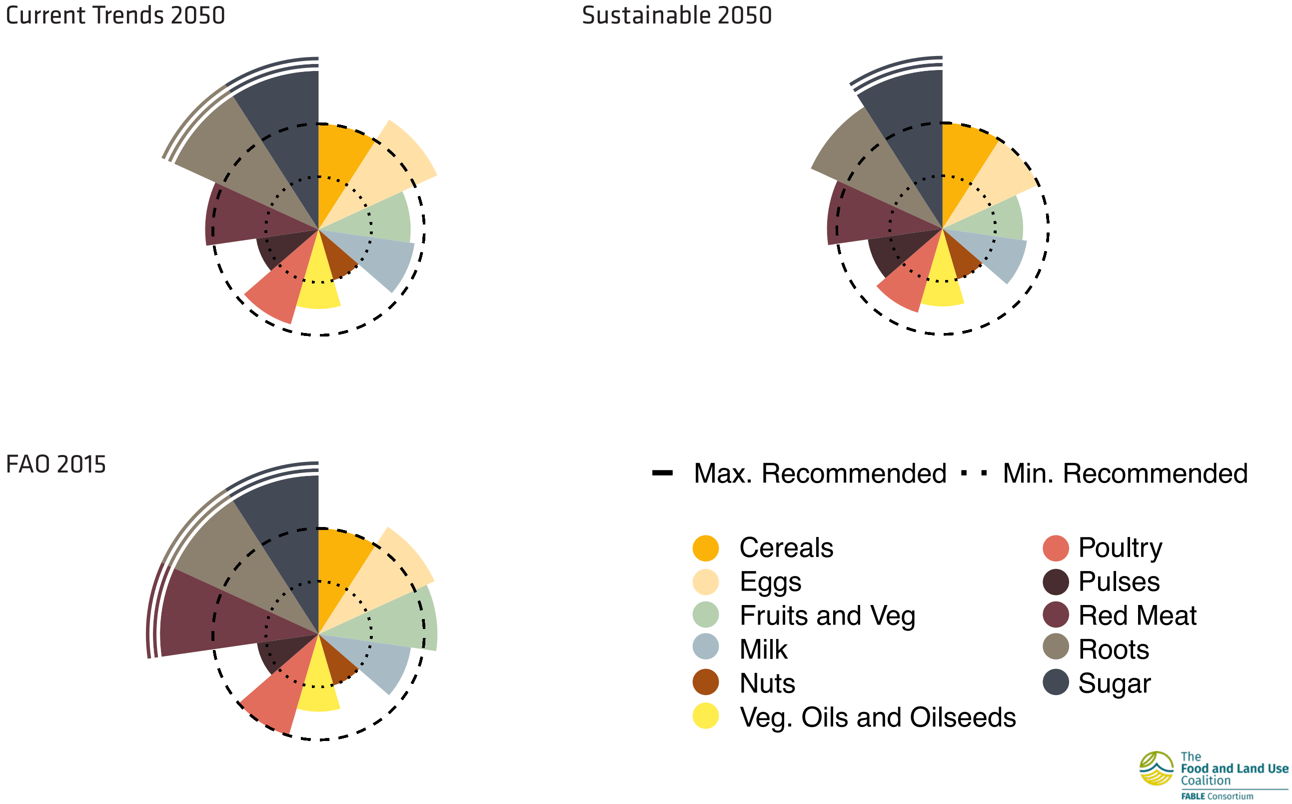
Under the Current Trends Pathway, compared to the average Minimum Dietary Energy Requirement (MDER) at the national level, our computed average calorie intake is 33% higher in 2030 and 41% higher in 2050 (Table 3). The current average intake is mostly satisfied by cereals, sugar, vegetable oils, fruits and vegetables, and roots (80%). In turn, animal products (i.e. milk, red meat, poultry, eggs, and pork) represent 16% of the total calorie intake. We assume that the consumption of animal products, and in particular milk, will increase by 15% between 2020 and 2050. The consumption of beverages and spices, roots, sugar, eggs, and poultry will also increase while red meat and pork consumption will decrease. Compared to the EAT-Lancet recommendations (Willett et al., 2019), roots, sugar, red meat, and eggs are currently over-consumed while nuts are at the minimum recommended level. By 2050, this overconsumption of roots and sugar continue to increase while, in contrast, the consumption of red meat will decrease (Figure 6). Moreover, fat and protein intake per capita exceeds the dietary reference intake (DRI) in 2030, before falling below in 2050. This can be explained by an increase in the consumption of vegetable oils (i.e. oil palm and soy oil) and a decrease in the consumption of red meat, pork, and pulses (Figure 6).

Under the Sustainable Pathway, we assume that diets will transition towards a more healthy and sustainable diet. The ratio of the computed average intake over the MDER increases to 21% in 2030 and then decreases to 17% in 2050 under the Sustainable Pathway. Compared to the EAT-Lancet recommendations, the consumption of sugar, roots, and red meat remain outside the recommended range with the consumption of eggs within the recommended range in 2050 (Figure 6). Moreover, the fat and protein intake per capita exceeds the DRI in 2030 before falling below in 2050. Compared to the Current Trends Pathway, there is also a moderate improvement in the fat intake per capita but the protein intake still remains higher than the recommended level.

The following measures will be particularly important to promote a shift to more healthy and sustainable diets: updating the current national nutritional guidelines, providing information on the nutritional contents of food, promoting alternatives to animal-based foods, and applying economic incentives to deter the consumption of unhealthy foods.

The current national guidelines state that up to one-third of healthy diets should incorporate the consumption of animal-based food products (ICBF & FAO, 2015). These guidelines have been considered unsustainable as they only focus on health and disregard the sustainable dimension of food consumption (Blanco-Murcia & Ramos-Mejia, 2019). In addition, enhanced information on nutritional content via improved labels could help consumers make better-informed choices, including identifying unhealthy foods with high-sugar content (Cabezas-Zabala, Hernandez-Torres, & Vargas-Zarate, 2016). Additional measures include the promotion of plant-based food alternatives to partially substitute meat consumption. For instance, a higher consumption of pulses such as red beans and lentils, could be an alternative since they already form part of the Colombian diet (Blanco-Murcia & Ramos-Mejia, 2019). Finally, implementing economic incentives such as taxes on the consumption of unhealthy food could also help consumers choose healthier options (Cecchini, Sassi, Lauer, Guajardo-Barron, & Chisholm, 2010; Lake & Townshend, 2006).

Figure 6 | Comparison of the computed daily average kilocalories 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 that appear at the outer edge of roots indicate that the average kilocalorie consumption of this food category is significantly higher than the maximum recommended.

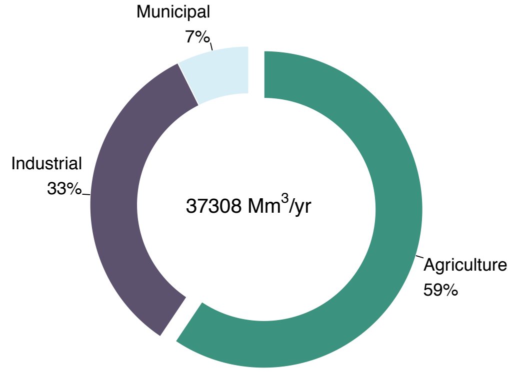
Water

Current State

Colombia is under the influence of the El Niño Southern-Oscillation (ENSO) and the latitudinal migration of the Intertropical Convergence Zone (ITCZ) (Poveda, 2004) m with an average annual precipitation of 2,888 mm (IDEAM , 2019). The rainy seasons are from March to May and October to November for regions with two rainy periods; and from May to September for regions with only one rainy season. The agricultural sector accounted for 59% of total water withdrawals in 2016 (Figure 7; IDEAM, 2019). Moreover, in 2014, 11% of the agricultural land was equipped for irrigation, representing 21% of estimated-irrigation potential (Perfetti et al., 2019). The three most important irrigated crops, rice, sugar cane, and oil palm accounted for 30%, 20%, and 19% of the total harvested irrigated area. Rice is mostly used for domestic consumption, while a sizeable portion of raw sugar is exported (27% in 2015).

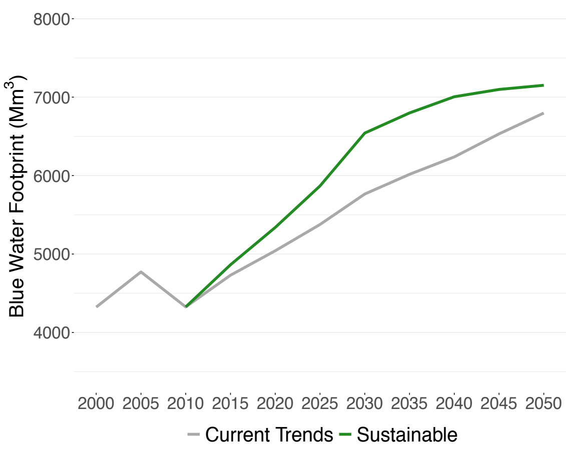
Despite the high-water availability at the country level, water use pressure indicators have reached critical levels, especially for the Magdalena and the Caribbean basins. According to the National Water Study (IDEAM, 2019), the blue water footprint increased by 11% between 2012 and 2016. For its part, the index of water pressure on ecosystems (IWPE) reflects that close to 37% of the units called hydrographic subzones (HSZ) present a highly critical situation (IDEAM et. al., 2019). At the same time, extreme climate variability is a factor that can potentially exacerbate the pressure on water resources.

Figure 7 | Water withdrawals by sector in 2016



Source. Adapted from AQUASTAT Database (FAO, 2017)

Figure 8 | Evolution of blue water footprint in the Current Trends and Sustainable Pathways



Pathways and Results

Under the Current Trends Pathway, annual blue water use increases between 2000–2015 (4,323 and 4,730 Mm^3/yr), before reaching 5,765 Mm^3/yr and 6,798 Mm^3/yr in 2030 and 2050, respectively (Figure 8), with sugarcane, plantain, and rice accounting for 41%, 23%, and 15% of computed blue water use for agriculture by 2050[5]. In contrast, under the Sustainable Pathway, the blue water footprint in agriculture reaches 6,542 Mm^3/yr in 2030 and 7,151 Mm^3/yr in 2050. This is explained by an increase in the provision of infrastructure for irrigation. This allows a reduction of the blue water use in agriculture even though the production of sugarcane and plantain increases compared to the Current Trends Pathway to satisfy higher exports.

5 We compute the blue water footprint as the average blue fraction per ton of product times the total production of this product. The blue water fraction per ton comes from Varón-Cardenas & Garcia-Nuñez (2019). 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

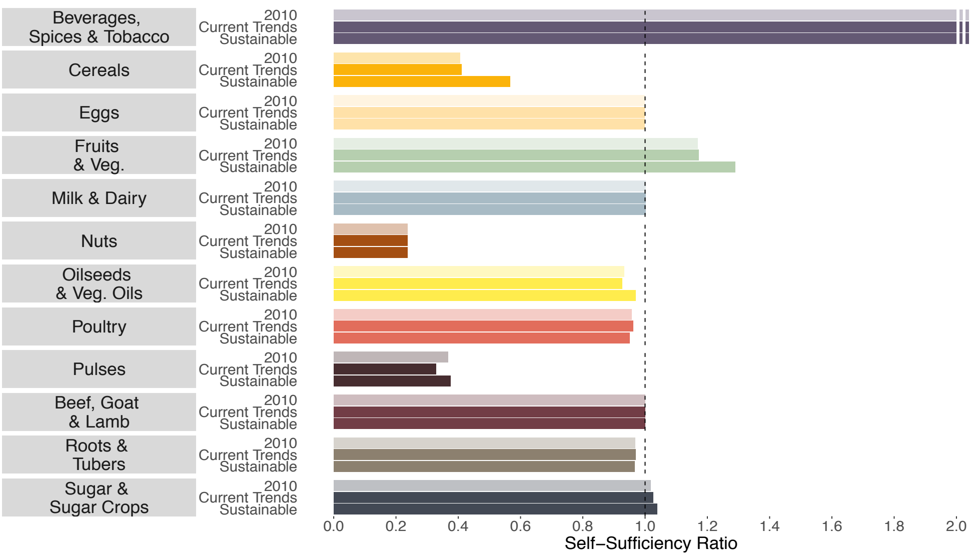
The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Colombia's resilience to agricultural-trade and supply disruptions across pathways: the 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

Self-sufficiency levels in Colombia have decreased from 94% in 2002 to 88% in 2010 (MINSALUD, 2015). This decline is due to the economic policies implemented in the early 90s, free trade agreements, and changes in dietary patterns, triggering increased demand for animal products like pork and chicken, and therefore, increasing demand for animal feed products.

Under the Current Trends Pathway, we project that Colombia will remain self-sufficient in beverages, spices and tobacco, eggs, fruits and vegetables, milk and dairy, vegetable oils, poultry meat, beef, roots and tubers, and sugar in 2050 (Figure 9). Colombia is highly dependent on imports of cereals, nuts, and pulses to satisfy domestic consumption, a dependency that will remain stable until 2050. Similarly, under the Sustainable Pathway, Colombia remains self-sufficient for most products except cereals, nuts, and pulses in 2050.

Figure 9 | 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 right side of this figure, as appear for beverages, spices and tobacco, indicate a high level of self-sufficiency in these categories.

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:

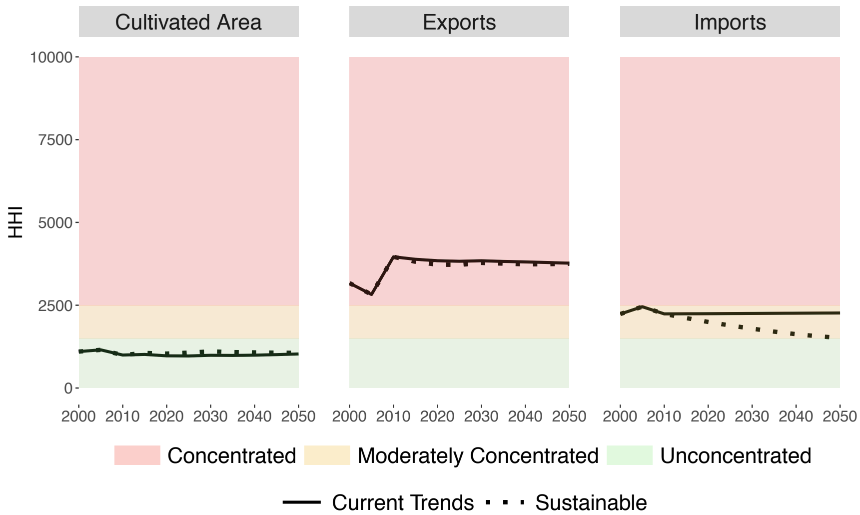
- **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- **Exports and imports:** 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.

In 2010, the HHI indicates a low concentration in Colombia's cropland area, a moderate concentration in crop imports and a high concentration in crop exports (Figure 10). Six crops represent 65% of the cultivated area with shares of total cropland area varying between 10 and 17%: by order of importance these are corn, coffee, sugarcane, plantain, and rice. For imports, two crops, corn and wheat, represent 63% of the total volume of imported crops. Finally, Colombia exports few crops of which banana, coffee, and sugar represent 95% of the total volume of exported.

Under the Current Trends Pathway, we project high and medium concentration of crop exports and imports, respectively, and a low concentration in the range of crops planted in 2050, trends which stabilize over the period 2010–2050. This indicates a low level of diversity for exports, a moderate level for imports, and a high diversity across the national production system. These trends remain relatively similar under the Sustainable Pathway, with the exception of imports which have lower levels of concentration, indicating higher levels of diversity (Figure 10).

Figure 10 | Evolution of the diversification of the cropland area, crop imports and crop exports of the country using the Herfindahl-Hirschman Index (HHI)



Discussion and Recommendations

The Colombian government recognizes the need for using a multi-sectoral and science-based approach for decision-making on food and land use systems. This approach has been central in the process to formulate national policies (NP), including the ***NP on climate change*** (in charge of the NDC), the ***NP on the integral management of biodiversity and its ecosystem services*** (in charge of the NBSAP targets) among others[6]. With this multisectoral approach, the government aims at promoting policy actions that allow for the simultaneous fulfillment of the objectives and targets of various policies (synergies), reducing potential conflicts between them. These medium- to long-term policies have been formulated within the last 5-10 years and seek, among others, to achieve balances between agricultural production and environmental protection. In this sense, they are largely consistent with the holistic approach proposed by the FABLE Consortium and have been incorporated into our modeling tools.

In general, our results are consistent with the multi-sectoral and comprehensive spirit of these existing policies on climate change and biodiversity (see *Climate and Biodiversity Strategies and Current Commitments*). On the one hand, these results are coherent with the objectives under which these policies have been formulated. Both the NDC and NBSAP have, respectively, converging policy actions and targets for reducing deforestation to reduce emissions and to protect biodiversity and ecosystem services. On the other hand, our results point out possible intervention points for additional or complementary measures that could be included within existing or prospective policies. This is the case of sustainable production systems that aim at increasing or maintaining productivity while fostering conservation since sustainable production systems are also part of the NDC (e.g. sustainable livestock) and NBSAP targets for Colombia.

Assumptions on agricultural expansion, including *no deforestation by 2030, afforestation and increase in protected areas* - both consistent with the NDC and NBSAP - determine to a large extent the following patterns in the Current Trends and Sustainable Pathways by 2050: a relatively constant proportion of forests and cropland areas, an increase in new forest areas, and a reduction in pasture areas. Increases in new forest areas and reductions in pasture areas in the Sustainable Pathway can also be traced to a dietary changes and increases in productivity that contribute to preventing agricultural expansion. Both deforestation prevention and forests expansion have synergistic positive effects on reducing emissions and conserving biodiversity. First, by avoiding emissions from deforestation and, second, by contributing to maintaining areas where natural processes predominate through preserving forests. In this sense, the FABLE Calculator captures aspects that are at the core of climate change and biodiversity policies in Colombia.

However, we note that for the Current Trends Pathway, the category *other land* may potentially be negatively affected, particularly by 2030. This category includes areas that may not be under protection and are not well represented in the system of protected areas (e.g parts of Los Llanos ecoregion). This indicates a possible point to consider as part of the NP on biodiversity in anticipation of the post-2020 CBD target. An additional aspect to consider when revising or preparing NPs are the main drivers of deforestation in Colombia, including land grabbing, illicit crops, infrastructure, mining, extensive livestock, and others (MINAMBIENTE & IDEAM, 2017). Most of these factors reflect the social, economic, and environmental complexities of Colombia over the past twenty years, including the periods of internal conflict and the post-conflict. These factors are not explicitly represented in the FABLE Calculator, the modeling tool used for this analysis. In consequence, part of the emissions related to land-use change may not be well represented.

Regarding potential intervention points, we have identified that changes in agricultural yields in the Sustainable Pathway, in particular for livestock, have important effects on reducing expansion (i.e. decreases in the pasture areas). This is a very relevant aspect for

6 Other multisectoral NPs include the agricultural frontier, the Green Growth policy, the policy on Water Resources Management.

Colombia's 2018 policy on the agricultural frontier of (MADS, 2018). Currently, there is a mismatch between areas suitable for agriculture and livestock production and the actual areas used for those purposes within the frontier. For instance, Colombia has around 13.9 Mha of land suitable for agriculture but only 28.6% of agriculture is located on this land. In contrast, livestock production occupies more than 30 Mha, far above the area suitable for that purpose, or 17.6% of the agricultural frontier. This situation negatively impacts Colombia's agricultural productivity (Perfetti et al., 2019). In this sense, sustainable land use that takes into account the lands most suitable for certain production types, and considers technological development, GHG emissions, water use, and biodiversity should result in increasing productivity and reducing the need for agricultural expansion in natural areas. Sustainable livestock, one of the country's NAMAs, is an example. It aims at simultaneously targeting increases in livestock productivity, carbon capture, and biodiversity conservation, among others. This mitigation measure was not included in the assumptions for this analysis, but harbors the potential for future improvements in the FABLE Calculator for Colombia.

Another potential intervention point identified from our results is diets. Like other emerging economies with a growing middle class, Colombia is experiencing an increasing trend in the consumption of products of animal origin and sugar. Results from the Current Trends Pathway are consistent with this pattern, in particular for products such as eggs, poultry, and milk. In contrast, for the Sustainable Pathway, in which we analyze a transition to a healthier and more sustainable diet, our results show that it is possible to maintain the energy requirements of the population and indirectly achieve positive effects on land use (i.e. contribute to limiting agricultural expansion). However, a dietary transition faces a series of barriers in Colombia and would require several policy interventions to address: i) the official national nutritional guides, which encourage the consumption of products of animal origin as part of a healthy diet but do not take into account questions of sustainability, ii) limited information on meat substitutes and on the nutritional quality of food, iii) the absence of economic instruments to disincentivize the consumption of unhealthy foods (e.g. foods with high sugar content). These barriers represent an opportunity to foster interaction with stakeholders, providing a holistic view of the relationships between food systems and land-use. Such a holistic view must underscore that in addition to being healthy, food must be sustainable as well.

The topics described above constitute a reference for continuing the process of improving our modeling tool and for interacting with stakeholders. In the first case, the model currently assumes total water availability will meet crop demand. However, in addition to climate change effects, climatic variability phenomena, including El Niño Southern Oscillation (ENSO), can affect crop yields in the short term (5-7 years) (IDEAM et al., 2019). These impacts are most evident for those rainfed dependent crops and, to a lesser extent, on irrigated crops. Additionally, competition for water use is critical in areas that have the greatest impact on agricultural GDP, such as the Magdalena river basin (IDEAM et al., 2019). Therefore, including the cumulative effects of climate change, climate variability, and pressure on water resources as restrictions for production in the model should produce a greater impact on the productivity of the agricultural sector.

In terms of stakeholder interaction, our results highlight the opportunity of establishing contact with institutions involved in developing the nutritional guidelines for the country, including the Ministry of Health and supporting bodies. This, in addition to the already established interactions with other stakeholders (i.e. the Ministry of Environment, Ministry of Agriculture, and other supporting bodies). Also, there is an opportunity to participate in the upcoming process for updating the National Policy on Water Resources Management and its associated planning instruments (e.g. Watershed Strategic Plans).

Finally, the current COVID-19 crisis and the trend in self-sufficiency indicators present a potential risk for Colombia's food security. This is particularly the case for the production of animal-based protein (i.e. pork, chicken, and eggs), which relies heavily imports of cereals such as corn. Historically, production costs at the national level for cereals have not been competitive enough to be supplied domestically. However, it could be expected that local food production will be promoted to reduce dependence on imports over the medium term, at least for those products whose domestic production is economically feasible.

Annex 1. List of changes made to the model to adapt it to the national context

- Some FAO values have been replaced with official data from Statistical Yearbooks of the Ministry of Agriculture (MADR, 2019), National Water Study (IDEAM et al., 2019), and other sources such as Fedepalma, Fenalce, Asocaña, and Cenicafé.
- Protected Areas data for 2010 were replaced by data from the Colombian Environmental Information System (SIAC).
- Oil Palm was selected as the commodity for biofuel production and national projections by 2050 were added, in accordance with Colombia National Energy Plan: Energetic vision 2050 by Energy-Mining Planning Unit (UPME, 2015).
- A table with the productivity ranges to 2050 was added: three (low, average, and high) ranges were considered according to the Statistical Yearbooks of the Ministry of Agriculture (MADR-UPRA, 2018), and other sources such as Fedepalma, Fenalce, Asocaña, and Cenicafé. These minimum and maximum values are used if the initial projected productivities were below or above these bounds.
- Soybean-cake and rice were added to imported products that can be modified through alternative scenario selection (for the other commodities, independently of the selected scenario, imports are computed with the 2010 share of the internal consumption which was imported times the internal demand). On the other hand, coffee, fruit_other [avocado], and cocoa were added to the export products that can be modified through scenarios.
- The water fraction value was updated for corn, oil palm, banana, rice, and sugar cane crop products using official statistics instead of Hoekstra and Mekonnen values.

Annex 2. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)

Current Trends Pathway	Sustainable Pathway
The population is expected to reach 62.8 million by 2050. Based on expected declining rates in population change, fertility, and international migration, as well as expected increases in access to education and urbanization (UN DESA, 2019). (SSP2 scenario selected)	Same as Current Trends.

LAND Constraints on agricultural expansion

Current Trends Pathway	Sustainable Pathway
We assume that deforestation will be halted beyond 2030. Based on full implementation of the Integral strategy for controlling deforestation and managing forests. This is this REDD+ strategy for Colombia that includes measures to reduce deforestation and forest degradation and contributes to compliance of Colombia's binding commitments to the Paris Agreement by 2030 (MINAMBIENTE, 2017; MINAMBIENTE & IDEAM, 2017).	Same as Current Trends/

LAND Afforestation or reforestation target (1000 ha)

Current Trends Pathway	Sustainable Pathway
We assume total afforested/reforested area to reach 1 Mha by 2035. Based on the target of existing National Restoration Plan formulated in 2015 (MINAMBIENTE, 2015). The plan is one of the implementing instruments for the National Policy on Biodiversity and the integral management of its ecosystem services (MINAMBIENTE, 2017). The policy is aligned with several international agreements under the CBD and UNFCCC (UNFCCC; MADS, 2012) and complementary initiatives such as the Bonn Challenge.	Same as Current Trends.

BIODIVERSITY Protected areas (1000 ha or % of total land)

Current Trends Pathway	Sustainable Pathway
Protected areas increase. By 2050 they represent 18% of total land. Based on Colombia's commitment to comply with Aichi Target 11 by 2020: 17% of total land (terrestrial) protected (REDPARQUES, Proyecto IAPA, & Pronatura, 2018).	Protected areas increase. By 2050 they represent 18% of total land. Based on Colombia's commitment to comply with Aichi Target 11 by 2020: 17% of total land (terrestrial) protected (REDPARQUES et al., 2018). An update of the policy for the National System of Protected Areas SINAP is expected. One of the goals is to increase ecosystem representativity in the system of protected areas (WWF-Colombia, 2019). Such increases would imply further increases in protected areas. However, no official targets have been set yet.

Colombia

PRODUCTION Crop productivity for the key crops in the country (in %)

Current Trends Pathway

The relative changes (%) in productivity between the base year and 2050 for key crops are as follows:

- 35% for cocoa
- 28% for plantain
- 17% oil palm fruit

We assume that the productivity growth rate remains stable, as observed between 2000-2010, based on statistics from the Ministry of Agriculture (MADR-UPRA, 2018). By 2050, the agricultural sector achieves moderate technology adoption and low to medium investment in science, technology, and innovation.

For oil palm, we assume it will regain the productivity level that existed before the arrival of the so-called bud rot (pudrición de cogollo) and lethal wilt (marchitez letal). These phytosanitary issues have led to serious productivity declines in several oil palm areas in Colombia. We assume that by 2030, phytosanitary problems are finally overcome. Therefore, a return to higher yields is anticipated.

Considering the above, the BAUGrowth scenario was selected.

Sustainable Pathway

The relative changes (%) in productivity between the base year and 2050 for key crops are as follows:

- 319% for corn
- 35% for rice
- 71% for oil palm fruit

Based on expected improvements in productivity for corn, included as part of the Corn for Colombia: 2030 Vision (Maíz para Colombia: vision 2030) (CIAT & CIMMYT, 2019). For rice, based on (UPRA, 2019), we assume that adoption of the Productive Management Plan for this sector is high, closing the productive gaps in Colombia. Finally, for oil palm, Colombia expects to achieve the initially projected productivity levels included in the document Vision of Palm Growing for the year 2020 (FEDEPALMA, 2000). The formulation of the plan occurred before the emergence of phytosanitary problems (i.e bud rot and lethal wilt) in Colombia.

Considering the above, the HighGrowth scenario was selected.

PRODUCTION Livestock productivity for the key livestock products in the country (in t/head of animal unit)

Current Trends Pathway

The relative changes (%) in productivity between the base year and 2050 for key livestock products are as follows:

- 18.8% per head for beef
- 0.0% per head for pork
- 96.7% per head for chicken

Based on the same productivity growth achieved during the last two decades. Overall, this productivity growth was due to the implementation of livestock systems with higher technological packages (e.g. with irrigation systems and genetic improvement) coupled with better management practices (FEDEGAN, 2019). Also, the country is aiming to increase sustainable livestock production practices that are consistent with improvements in productivity (Pinto-Brun, 2016). The latter is part of the Nationally Appropriate Mitigation Actions (NAMAs) and contribution to Colombia's commitments under the Paris Agreement.

For pork, the yield values indicate a negative trend between 2000 and 2010. We assume that the yield stabilizes in 2015 and remains constant until 2050.

Sustainable Pathway

The relative changes (%) in productivity between the base year and 2050 for key livestock products reach:

- 18.8% per head for beef
- 227% per head for pork
- 164% per head for chicken

Based on a more ambitious implementation of livestock systems with higher technological and better management practices. In the case of pork and chicken, the increases in productivity are also encouraged by an increasing demand for this type of protein.

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

Current Trends Pathway

By 2050, the average ruminant livestock stocking density is 0.5 TLU/ha. Based on the same trend in productivity growth achieved during the last two decades for the livestock sector in Colombia. Overall, growth in productivity occurred by implementing livestock systems with higher technological packages (e.g. irrigated systems and genetic improvement), coupled with better management practices (FEDEGAN, 2019).

Sustainable Pathway

By 2050, the average ruminant livestock stocking density is 0.5 TLU/ha. Based on the increased ambition of implementing higher technological packages for livestock production, including irrigated systems and genetic improvement coupled with better management practices (FEDEGAN, 2019).

PRODUCTION Post-harvest losses

Current Trends Pathway

By 2050, the share of production and imports lost during storage and transportation is 40%. Based on the study of the National Planning Department (DNP, 2016). The study focuses on waste and loss of food in Colombia.

Sustainable Pathway

By 2050, the share of production and imports lost during storage and transportation is reduced compared to 2010. Based on the expected effects of implementing the recently enacted *policy for preventing food waste and loss*. The policy covers not only consumption and household level but other components in the system (e.g. production, storage, processing, distribution).

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

Current Trends Pathway

The share of total consumption which is imported is:
- 88 % by 2050 for soybean
- 97 % by 2050 for barley
- 65 % by 2050 for sorghum

According to official statistics, Colombia imports a high volume of cereals to satisfy internal feed demand. Wheat, barley, and approximately 70% of corn have been imported during the last decades (DANE, 2019). Except for corn, it is highly probable that this trend continues in the future. Colombia is unable to produce most cereals at a competitive cost compared to production costs in other latitudes where soil and climatic conditions allow for a more efficient crop production.

Sustainable Pathway

The share of total consumption which is imported is:
- 88% by 2050 for soybean
- 97% by 2050 for barley
- 65% by 2050 for sorghum

In both the Current Trends and Sustainable Pathways, we selected the same stable import scenario.

TRADE Evolution of exports for key exported products (tonnes)

Current Trends Pathway

The volume of exports is:
- 2,092.8 tonnes by 2050 for sugar raw
- 1,699 tonnes by 2050 for banana
- 685 tonnes by 2050 for coffee

Banana. According to FAO, world production for banana has been increasing at a rate of 3.5% per year over the last 30 years. In Colombia, production for the same period has been increasing at a rate of 4.3% per year. Most of the production in Colombia is intended for export. In 2018, Colombia sent bananas to 31 countries around the world.

Coffee. Over the past ten years, coffee exports have been increasing significantly. Between 2000 and 2019, Colombian coffee exports increased by 84% (DANE, 2019). In the long term, the coffee sector will have to face the impacts of the effects of climate change. According to the results of some studies carried out by the Coffee Research Center, CENICAFE, a redistribution of the coffee production areas is likely. At the same time, it concludes that the adaptation of genotypes, spatial arrangements of shade and cultivation, nutrient dynamics, and water must be included into the research agenda. The sustainability of the coffee sector in Colombia will largely depend on the success of these research efforts.

Sugar raw. Raw sugar exports have been decreasing since 2005. Between 2005 and 2019, the volume of exported raw sugar has decreased by 37% due to biofuel production (DIAN, 2020). Historically, the production of sugar cane (raw material for sugar production) is concentrated in southwest Colombia (70% of the country's total area; MADR, 2018). We assume that the production of sugar cane expands to other territories due to the increase in demand. Currently, the Colombian Orinoquía registered around 26.6 kha in 2019 (13% of the total area of the country; MADR-UPRA, 2018).

Sustainable Pathway

The volume of exports is:
- 2,791.3 tonnes by 2050 for banana
- 2,340.4 tonnes by 2050 for sugar raw
- 822.5 tonnes by 2050 for coffee

Based on the same assumptions as on the Current Trends Pathway with a higher export goal.

Colombia

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

Current Trends Pathway	Sustainable Pathway
By 2050, the main changes in average dietary composition per capita regarding 2020 are an 87% increase in beverages and spices, growth in the consumption of roots and sugar by 32% and 16%, respectively, and a decrease in the consumption of red meat by 30% and 23% for pork. Based on the National Plan on Food and Nutritional Security (PNSAN) 2012-2019 (Gobierno de Colombia, 2013). The PSAN is the implementation instrument for the National Policy on Food and Nutritional Security -CONPES 113/2008 (DNP, 2008a). Additionally, the current National Development Plan 2018/2022 aims at improving the nutritional state of the Colombian population (DNP, 2019a).	By 2050, the key changes in average dietary composition per capita regarding 2020 are a significant increase in the consumption of nuts (288%), a rise in the consumption of pulses and fish rise by 60% and 50%, respectively, and a reduction in the consumption of red meat (28%), sugar (27%), and roots (26%). Based on the partial implementation of the recommendations of the EAT-*Lancet* Commission Report on Food, Planet, and Health, (Willett et al., 2019) which encourages the change towards healthy eating that is compatible with the environment.

FOOD Share of food consumption which is wasted at household level (%)

Current Trends Pathway	Sustainable Pathway
By 2030, the share of food wasted at consumption level (including household) is 16 %. Based on the study of the National Planning Department on waste and loss of food in Colombia (DNP, 2016). Policies targeting food waste at the household level remain scarce and the extent of the problem is not well known. Therefore, we assume the same share as in 2010.	By 2030, the share of final household consumption which is wasted at the household level is reduced compared to 2010. Based on the expected effects of implementing the *policy for preventing food waste and loss* of 2019. The policy is still in the formulation process but is expected to define specific targets, policy instruments, and monitoring processes. Its implementation during the medium to long-term should lead to a significant reduction in the share of food wasted. It is worth mentioning that the policy targets not only food waste at the household level but waste and loss for other sectors in the country. Therefore, we assume a reduced share compared to 2010.

BIOFUELS Targets on biofuel and/or other bioenergy use

Current Trends Pathway	Sustainable Pathway
By 2050, biofuel production accounts for: • 233.4kt of sugar cane production • 298.2kt of oil palm production Based on the stability in the fuel mix percentages for both ethanol (from sugarcane) and biodiesel (from palm oil). These percentages have remained relatively stable over the last several years (around 10%; DNP, 2019a; UPME, 2019).	By 2050, biofuel production accounts for: • 261.9kt of sugar cane production • 969.5kt of oil palm production Based on the full implementation of CONPES 3510/2008 on Policy Guidelines for promoting Sustainable Production of Biofuels in Colombia (DNP, 2008b). These guidelines constitute the basis for achieving 20% biofuels in the fuel mix.

CLIMATE CHANGE Crop model and climate change scenario

Current Trends Pathway	Sustainable 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 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 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)

Annex 4. Overview of biodiversity indicators for the current state at the ecoregion level[7]

	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 at > 10% natural vegetation within 1km²(%)
611	Amazon-Orinoco-Southern Caribbean mangroves	273.3	49.9	62.3	70.6	29.4	31.6	61
520	Apure-Villavicencio dry forests	2464.6	4.3	6.5	62	38	501.0	61.2
446	Caqueta moist forests	17195.0	28.9	90.2	31.9	68.1	436.0	74.2
447	Catatumbo moist forests	674.4	10.1	26.9	36.9	63.1	103.2	68.9
526	Cauca Valley dry forests	736.1	1.8	1.4	7.8	92.2	337.2	53.2
448	Cauca Valley montane forests	3212.7	12.5	19.3	31.4	68.6	296.8	87.6
449	Cayos Miskitos-San Andrés and Providencia moist forests	3.4	4.7	100	4.7	95.3	0.2	100
527	Central American dry forests	0.5	21.8	22.2	50.9	49.1	0.0	
454	Chocó-Darién moist forests	6003.3	7	73.2	7.6	92.4	211.1	70.8
457	Cordillera Oriental montane forests	5919.8	20.8	28.6	61.2	38.8	428.6	84.8
460	Eastern Cordillera Real montane forests	1092.9	22.7	84.3	25.9	74.1	20.9	89.3
461	Eastern Panamanian montane forests	87.6	40.3	94.9	38.5	61.5	1.1	96
602	Guajira-Barranquilla xeric scrub	2766.9	5.6	8.3	25.3	74.7	932.4	48.8
466	Guianan piedmont moist forests	1.9	0	78.7	0	0	0.0	
469	Iquitos várzea	30.3	45.3	55.7	56.4	43.6	0.0	100
473	Japurá-Solimões-Negro moist forests	3397.4	24.1	99.1	24.3	75.7	1.9	96.4
572	Llanos	15374.2	4.5	53.1	7	93	169.4	90.7

7 TThe 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.

	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 at > 10% natural vegetation within 1km²(%)
538	Magdalena Valley dry forests	1968.0	2.4	3.9	42.7	57.3	528.3	66.7
477	Magdalena Valley montane forests	10528.9	14.6	25	31.9	68.1	868.5	88.9
478	Magdalena-Urabá moist forests	7690.8	7.5	7.9	30.1	69.9	2995.6	45
483	Napo moist forests	4033.1	10.4	54.8	19	81	512.3	74.3
484	Negro-Branco moist forests	9769.9	4.8	95.4	4.7	95.3	36.4	98.1
593	Northern Andean páramo	1431.1	47.6	53.2	75.4	24.6	13.0	94.6
486	Northwest Andean montane forests	4920.7	15.7	54.6	26.2	73.8	267.9	91
542	Patía valley dry forests	227.6	0.1	23.2	0.3	99.7	29.8	94.3
496	Purus várzea	3025.4	25.4	95.3	26	74	4.9	79.1
498	Rio Negro campinarana	313.7	16.2	99.1	16.3	83.7	0.0	100
499	Santa Marta montane forests	479.6	45.5	70.9	63.7	36.3	5.8	99.7
594	Santa Marta páramo	124.6	97.5	100	97.5	2.5	0.0	100
546	Sinú Valley dry forests	2501.3	10.8	7.8	69.2	30.8	1372.2	41.9
503	Solimões-Japurá moist forests	7265.7	21.3	99	21.4	78.6	2.0	96.6
615	South American Pacific mangroves	557.7	26.3	75.4	29.1	70.9	2.2	86.7
505	Southwest Amazon moist forests	0.4	0	0			0.0	100
513	Venezuelan Andes montane forests	3.8	0	0			1.1	61.2
516	Western Ecuador moist forests	237.3	1.1	28.1	1.5	98.5	24.8	96.7

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)

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

kha – thousand hectares

km^2 – square kilometer

km^3 – cubic kilometers

kt – thousand tonnes

m – meter

Mha – million hectares

mm – millimeters

Mm^3 – million cubic meters

Mt – million tonnes

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

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