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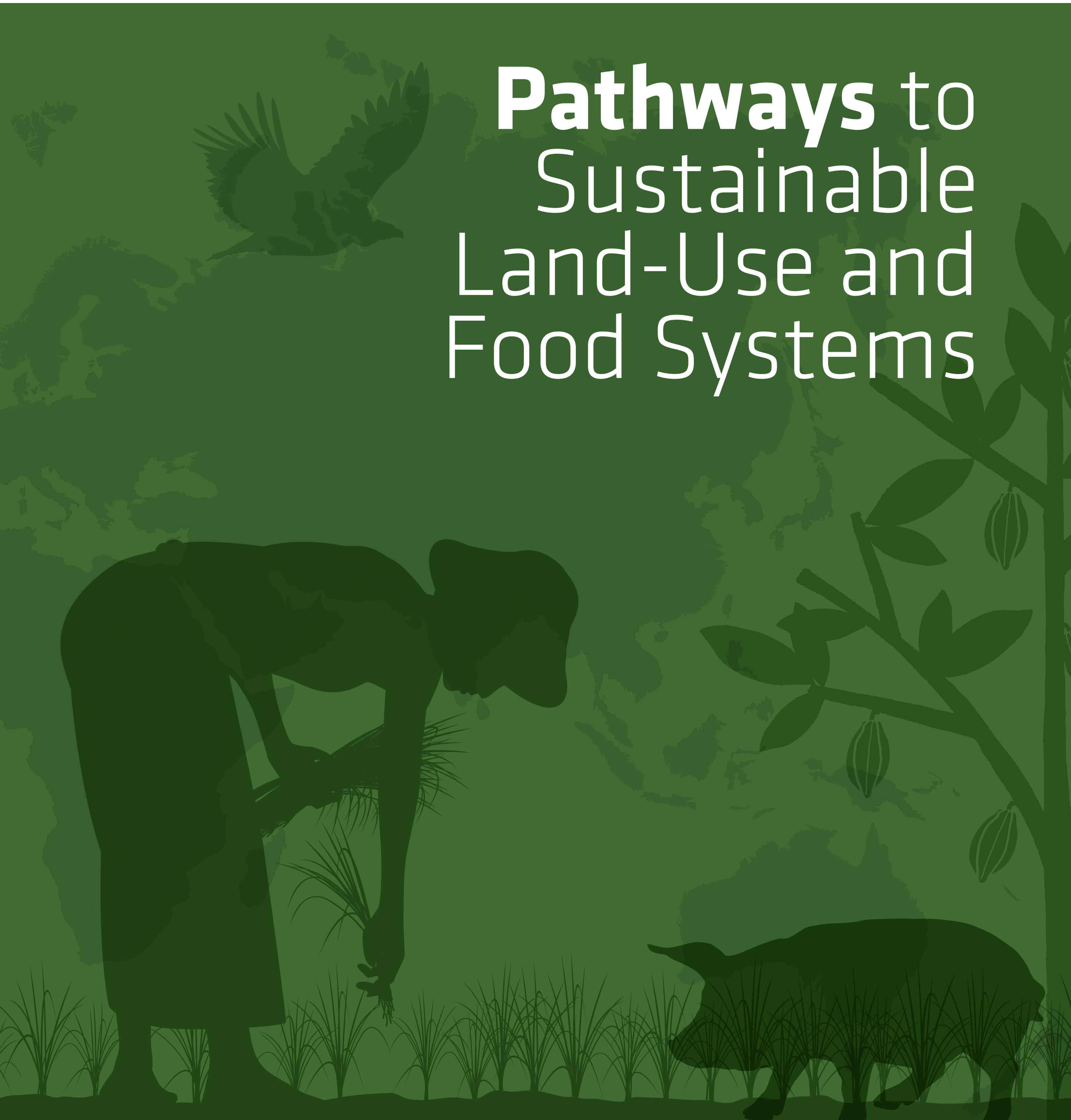
The Food and Land Use Coalition

2020 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems



Published by International Institute for Applied Systems Analysis (IIASA) and the Sustainable Development Solutions Network (SDSN) 2020

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Recommended citation: Molla K.G. and Woldeyes F.B. (2020), "Pathways to Sustainable Land-Use and Food Systems in Ethiopia by 2050" In: FABLE 2020, *Pathways to Sustainable Land-Use and Food Systems,* 2020 Report of the FABLE Consortium. Laxenburg and Paris: International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN), pp. 262-291.
https://doi.org/10.22022/ESM/12-2020.16896

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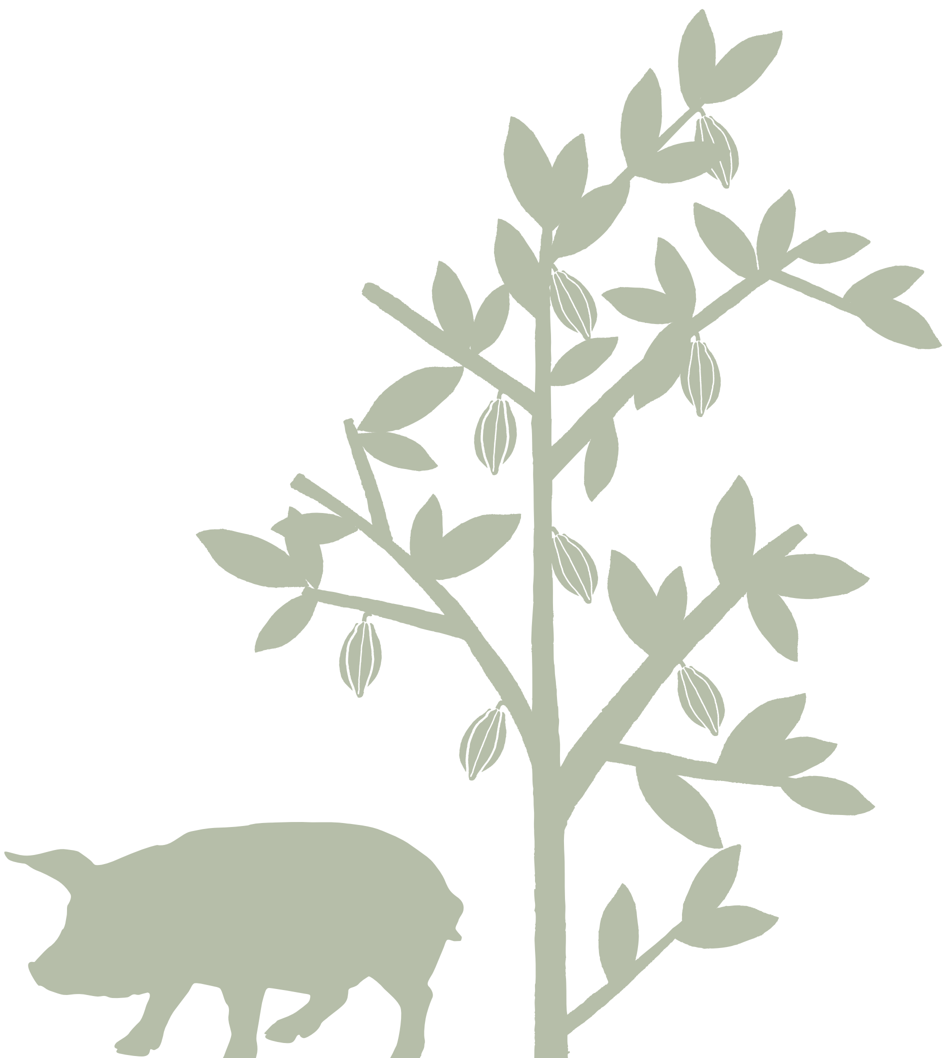
2020 Report of the FABLE Consortium

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



Ethiopia

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This chapter of the 2020 Report of the FABLE Consortium *Pathways to Sustainable Land-Use and Food Systems* outlines how advancing a sustainable food and land-use system can contribute to raising climate ambition, aligning climate mitigation and biodiversity protection policies, and achieving other sustainable development priorities in Ethiopia. It presents two pathways for Ethiopia’s food and land-use system 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 of food at national and global levels. We developed these pathways in consultation with national stakeholders, including experts from the National Integrated Land Use Policy and Plan Project Office and the Ministry of Agriculture, and modeled them with the FABLE Calculator (Mosnier, Penescu, Thomson, & 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 climate change 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 in potential land use.

Table 1 summarizes how Ethiopia's Nationally Determined Contribution (NDC) treats the FABLE domains. According to its NDC, Ethiopia has committed to reducing its GHG emissions by 64% by 2030 compared to a business-as-usual (BAU) scenario. This includes emission reduction efforts from agriculture, forestry, and other land use (AFOLU). Envisaged mitigation measures from agriculture and land-use change include improving crop and livestock production practices and protecting and re-establishing forests for their economic and ecosystem services. Moreover, under its current commitments to the UNFCCC, Ethiopia mentions biodiversity conservation. In particular, it aims to develop biodiversity movement corridors in areas where most land has already been cultivated (Federal Democratic Republic of Ethiopia, 2015).

Table 1 | Summary of the mitigation target, sectoral coverage, and references to biodiversity and spatially-explicit planning in the 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[1] (Y/N)	Links to Other FABLE Targets
	Baseline		Mitigation target		Sectors included				
	Year	GHG emissions (Mt CO_2e/yr)	Year	Target					
NDC (2015)	BAU 2030	145	2030	64% reduction	energy, industrial processes, agriculture, land-use change and forestry, and waste	Y	Y	N	Land-use change and forestry

Note. "Total GHG Mitigation" and "Mitigation Measures Related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019)
Source. Federal Democratic Republic of Ethiopia (2015)

1 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 the targets included in the National Biodiversity Strategies and Action Plan (NBSAP) from 2016, as listed on the CBD website (CBD, 2020) which are related to at least one of the FABLE Targets. This includes five of the eighteen National Biodiversity Targets from 2016-2020 (Ethiopian Biodiversity Institute, 2015). In comparison with the FABLE Target of zero net deforestation by 2030, the NBSAP aims to increase forest cover from 15% to 20%.

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

NBSAP Target	FABLE Target
(Target 10) **By 2020, the contribution of biodiversity and ecosystem services, including climate change adaptation and mitigation, is improved through increasing forest cover from 15% to 20% of the country**	**DEFORESTATION:** Zero net deforestation from 2030 onwards
(Target 4) **By 2020, habitat conversion due to expansion of agricultural land is halved from the existing rate of about 10% per year.** (Target 7) **By 2020, area cover of ecologically representative and effectively managed protected areas are increased from 14% to 20%.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(Target 9) **By 2020, in situ conservation sites for important species and breeds are increased and the standards of the existing in situ conservation are improved.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(Target 10) **By 2020, the contribution of biodiversity and ecosystem services, including climate change adaptation and mitigation, is improved through an increased designated total area of wetlands from 4.5% to 9.0% and doubling the areas of restored degraded lands.**	**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 lines with the FABLE Targets, for the food and land-use system in Ethiopia.

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by medium population growth (from 112 million in 2020 to 170 million in 2050), no constraints on agricultural expansion, a low afforestation target (7 Mha by 2050), medium productivity increases in the agricultural sector, an evolution towards a diet higher in meat, milk, sugar, and fat (in order to meet recommended fat consumption levels), and high GDP growth (see Annex 2). This corresponds to a future based on current policy and historical trends that would also see considerable progress with regards to achieving economic development and meeting Ethiopia's Nationally Determined Contributions. 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/m2 (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 (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 lower population growth, higher afforestation (15 Mha), higher agricultural productivity, an evolution towards a diet higher in meat, milk, sugar, and fat (in order to meet recommended fat consumption levels), and lower agricultural land expansion (see Annex 2). This corresponds to a future whereby policy measures are enacted to meet the Bonn Challenge and that would also see considerable progress with regards to improving forest cover. 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/m2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

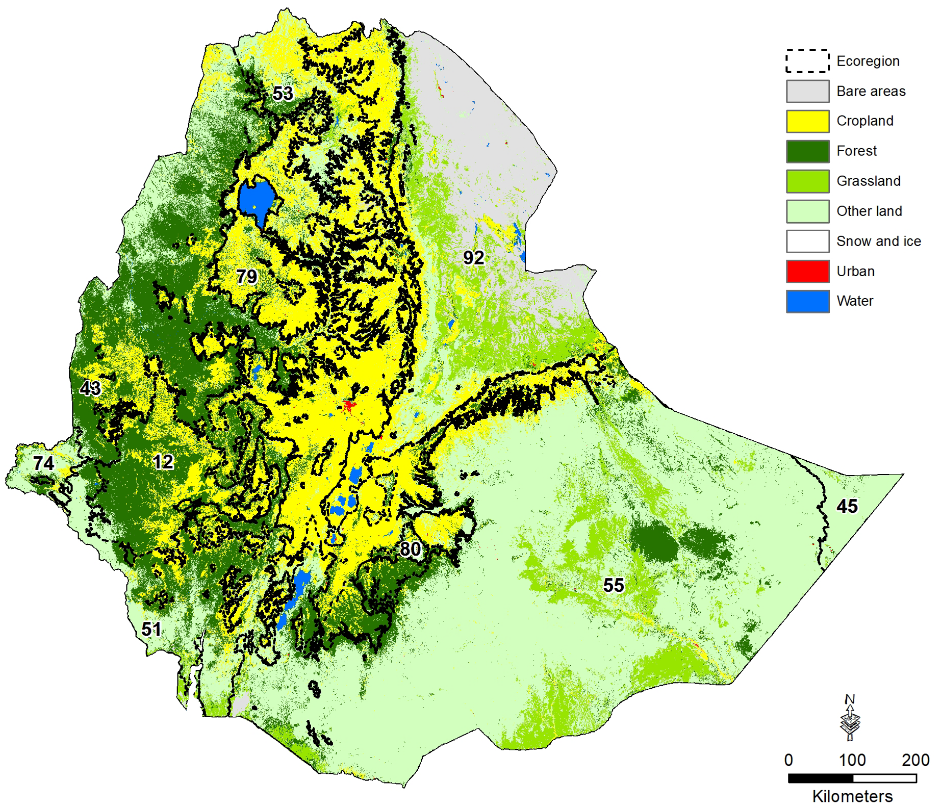
Land and Biodiversity

Current State

In 2010, Ethiopia's land was comprised of 14% cropland, 21% grassland, 13% forest, 0.1% urban, and 52% other natural land FAOSTAT (FAO, 2020). Most of the agricultural land area is concentrated in the central highland part of the country and to some extent spreads to the eastern and western parts of the country, while forest and other natural land are mostly found in the western and, to some extent, the southern, regions (Map 1). While demographic change is an indirect cause of biodiversity loss in Ethiopia, habitat conversion, unsustainable utilization of biodiversity resources, invasive species, replacement of local varieties and breeds, climate change, and pollution are the main direct threats (Ethiopian Biodiversity Institute, 2014).

We estimate that land where natural processes predominate[2] accounted for 23% of Ethiopia's terrestrial land area in 2010 (Map 2 and Table 3). The 80-Ethiopian montane moorlands hold the greatest share of land where natural processes predominate, followed by 74-Sudd flooded grasslands and 12-Ethiopian montane forests (Table

Map 1 | Aggregated land cover types and ecoregions



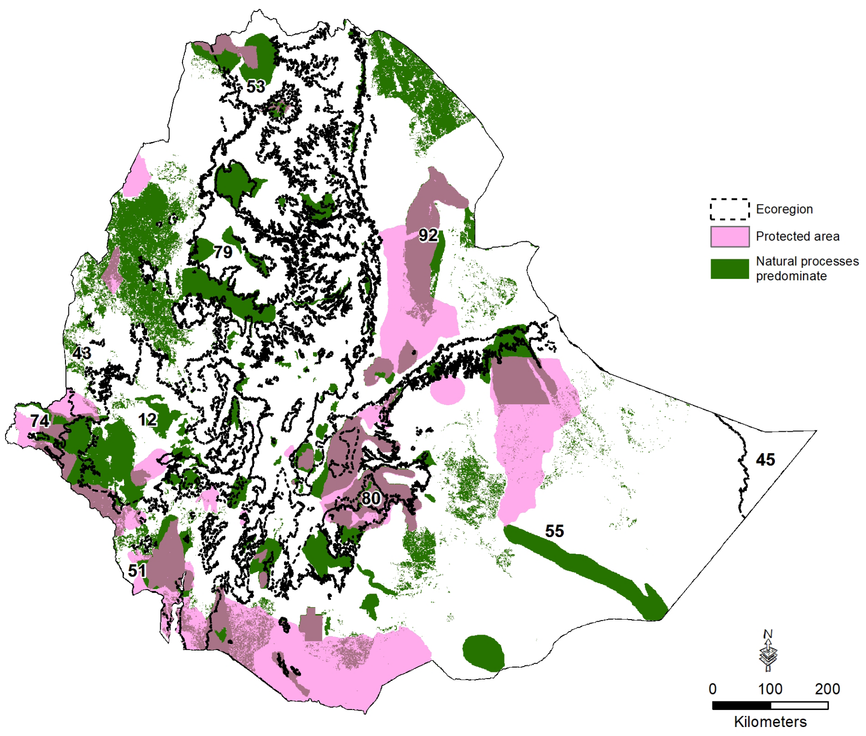
Note. Correspondence between original ESACCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 3. The numbers on the map indicate landcover categories listed in Table 3.
Sources. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)

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".

3). Overall, the 17.5% of protected areas is below the national target of increasing ecologically representative and effectively managed protected areas from 14% to 20% by 2020 (Ethiopian Biodiversity Institute, 2015). While 43-East Sudanian savanna and 51- Northern Acacia-Commiphora bushlands and thickets ecoregions are at or a bit higher than 14%, 11-Ethiopian montane forests, 45-Horn of Africa xeric bushlands, 53- Sahelian Acacia savanna, and 79- Ethiopian montane grasslands and woodlands ecoregions are still below 14%. The remaining ecoregions are well above 20% (Table 3). Across the country, while 20 Mha or 17.5% of land is under formal protection, falling short of the 30% zero draft CBD post 2020 target, only 23.2% of land where natural processes predominate is formally protected. The unprotected areas where natural processes predominate include parts of Ethiopia's highlands, which also form part of the Eastern Afromontane hotspot, as well as forested areas in the south and southwest. These areas are important areas for biodiversity conservation but are under threat due to sustained rates of deforestation, resettlement, and commercial farming (USAID, 2008), and could be prioritized for future protection.

Approximately 56.5% of Ethiopia's cropland was in landscapes with at least 10% natural vegetation in 2017. These relatively biodiversity-friendly croplands are most widespread in 50-Masai xeric grasslands and shrublands, followed by 51-Northern Acacia-Commiphora bushlands and thickets and 74-Sudd flooded grasslands. The regional differences in the extent of biodiversity-friendly cropland can be explained by farming intensity, which is much lower in the aforementioned ecoregions.

Map 2 | Land where natural processes predominate, protected areas and ecoregions



Note. Protected areas are set at 50% transparency, so on this map dark purple indicates areas under protection and where natural processes predominate overlap. The numbers on the map indicate landcover categories listed in Table 3.
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 | Overview of biodiversity indicators for the current state at the ecoregion level[3]

	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)	Cropland as share of eco-region (%)	Share of Cropland with >10% Natural Vegetation within 1km² (%)
12	Ethiopian montane forests	6810.1	11	40.6	15.2	84.8	2206.7	32.4	57.8
43	East Sudanian savanna	21716.2	14.1	34.8	23.4	76.6	3271.5	15.1	68.6
45	Horn of Africa xeric bushlands	1329.2	0	0	0	0	3.8	0.3	29.2
50	Masai xeric grasslands and shrublands	180.7	80.9	37.7	88.1	11.9	3.0	1.7	99.4
51	Northern Acacia-Commiphora bushlands and thickets	8.5	15.8	2	15.1	84.9	0.4	4.7	97.5
53	Sahelian Acacia savanna	3371.3	7.4	24.8	29.6	70.4	1235.2	36.6	62.1
55	Somali Acacia-Commiphora bushlands and thickets	41933.6	21.8	15.5	41.2	58.8	1001.3	2.4	71.7
74	Sudd flooded grasslands	990.4	66.6	42.6	64.2	35.8	119.4	12.1	72.4
79	Ethiopian montane grasslands and woodlands	19660.2	8.5	15.7	43.1	56.9	9889.1	50.3	50.4
80	Ethiopian montane moorlands	1572.9	32.1	46.9	65.4	34.6	540.7	34.4	60.4
92	Djibouti xeric shrublands	15963.3	23.2	27.2	43.3	56.7	1748.6	11.0	51.6

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)

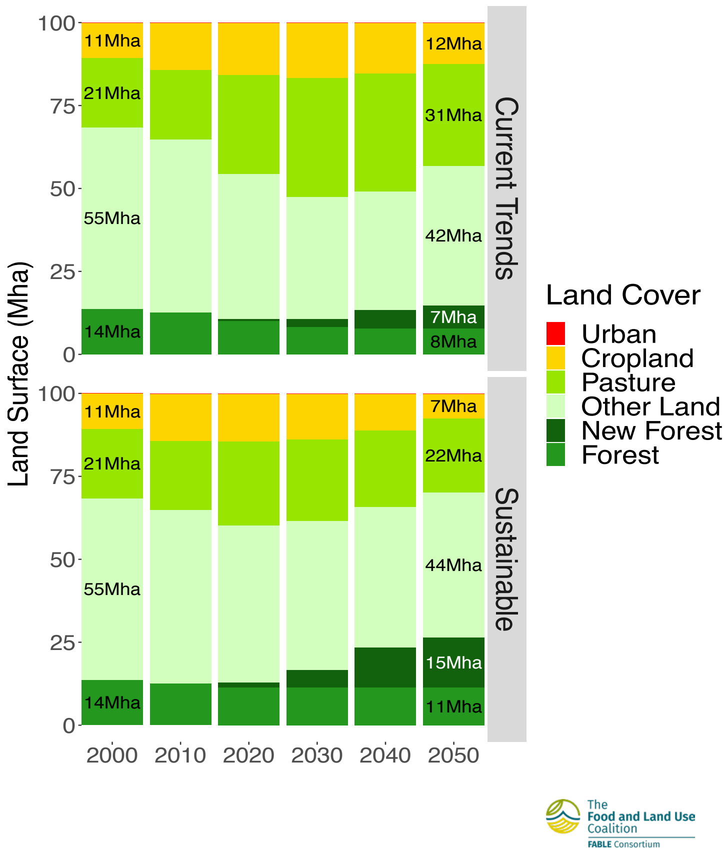
3 The share of land within protected areas and the share of land where natural processes predominate are percentages of the total ecoregion area (counting only the parts of the ecoregion that fall within national boundaries). The shares of land where natural processes predominate that is protected or 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 will result in an additional 7 Mha of reforested or afforested land and an additional 31 Mha of pastureland by 2050.

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result from an increase of pasture and cropland area and a decrease in forest and other land areas; this pathway does not consider important elements of Ethiopia's biodiversity targets and would lead to the loss of another third of its remaining natural, biodiversity-rich native forests. This trend inverts slightly over the period 2030-2050: pasture and cropland area decrease and new forest and other land area increase (Figure 1). The expansion of the planted area for vegetable, sorghum, and corn explains 45% of total cropland expansion between 2010 and 2030. The increase of vegetable production is mainly driven by food demand. For sorghum, 50% of expansion is due to an increase of feed whereas the remaining 30% and 20% of the expansion are due to increases in the share of sorghum (for food and non-food uses). Where the non-food uses of sorghum include use of sorghum for seed and other use (other non-biofuel, non-food uses). Finally, for corn, 59% of the expansion results from an increase in food and 39% an increase of feed, and the remaining 2% is due to increases in non-food use (1%) and food waste (1%). Pasture expansion is mainly driven by the increased demand for milk, beef, and mutton. As a result, even though livestock productivity per head increases, ruminant density per hectare of pasture remains constant over the period 2020-2050. Between 2030-2050, decreases in the area of pastureland could be explained by increases in productivity for the livestock sector and a slowdown in

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

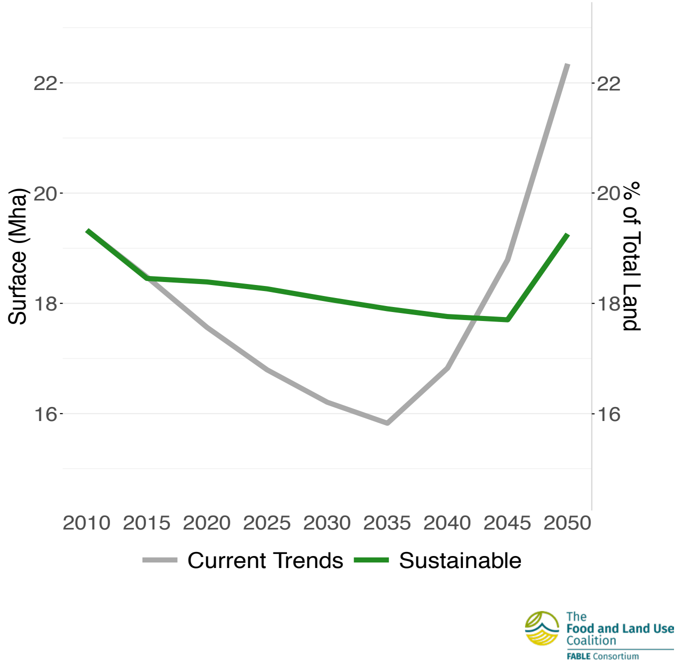


Source: Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000.

population growth. This results in a 16% reduction of land where natural processes predominate by 2030 and an expansion of land where natural processes predominate by 15.6% by 2050 compared to 2010, respectively. The Sustainable Pathway will result in no agricultural land expansion and in an additional 15 Mha reforested or afforested land after 2045.

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Ethiopia in the Sustainable Pathway: (i) deforestation per year is much lower between 2015 and 2050 and the Current Trends Pathway deforestation rate mimics this rate only in the period 2035-2050, (ii) agricultural land expansion is restricted, (iii) new forest increases sharply, and (iv) cropland extent decreases after 2030. In addition to the differences in assumptions regarding land-use planning, these differences compared to the Current Trends Pathway are explained by a lower population growth rate. Among other things, this leads to a relatively low expansion in cropland area. This in turn leads to the stabilization in the area where natural processes predominate, which stops declining by 2045 and increases by 9% between 2045 and 2050. The increases in natural land are greater under the Current Trends Pathway after 2040. This is due to the fact that, under the Sustainable Pathway, reforestation occurs on other natural land, which causes the natural land area to decrease (only increases in natural land are counted as increasing land where natural processes predominate). If the new forest is implemented in a way that supports biodiversity, land where natural processes predominate would, in fact, be greater under the Sustainable Pathway (Figure 2).

Figure 2 | Evolution of the area where natural processes predominate



GHG emissions from AFOLU

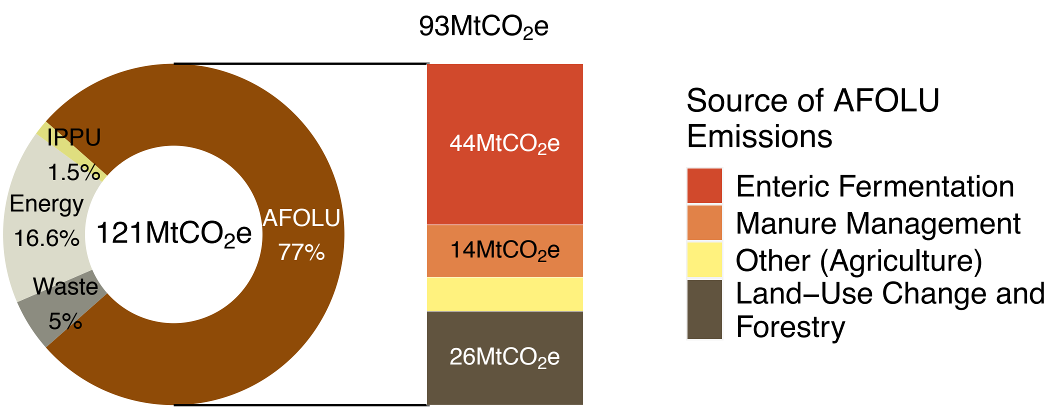
Current State

Direct GHG emissions from Agriculture, Forestry and Other Land Use (AFOLU) accounted for 77% of total emissions in 2013 (Figure 3). Enteric fermentation is the principal source of AFOLU emissions, followed by land-use change and forestry. This can be explained by the large number of cattle in Ethiopia (FAO, 2017b).

Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU increase to 171 Mt CO_2e/yr in 2030, before dropping to 123 Mt CO_2e/yr in 2050 (Figure 4). In 2050, livestock is the largest source of emissions (127 Mt CO_2e/yr) while land converted to forest acts as a sink (-6 MtCO_2e/yr). Over the period 2020-2050, the strongest relative increase in GHG emissions is computed for agriculture (5%), while a reduction is computed for land-use change from reforestation (-900%), deforestation (100%) and loss of other natural land (100%) (Figure 5).

Figure 3 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2013



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

In comparison, the Sustainable Pathway leads to a 31% reduction in GHG emissions from AFOLU by 2050 (Figure 4). The potential emissions reductions under the Sustainable Pathway is dominated by a reduction in GHG emissions from the livestock sector, which is a result of reduced livestock productivity leading to lower pasture demand. The lower population growth and the halting of agricultural land expansion, which has resulted in lower feasible consumption, are the most important driver of this reduction.

Compared to Ethiopia's commitments under UNFCCC (Table 1), our results show that AFOLU could contribute an additional 20% of its total GHG emissions reduction objective by 2030, as outlined in its NDC. Such reductions could be achieved by improving livestock productivity (an area that has not yet received sufficient attention in policy circles), supporting family planning measures, and implementing the Bonn Challenge. These measures could be particularly important when considering options for NDC enhancement.

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

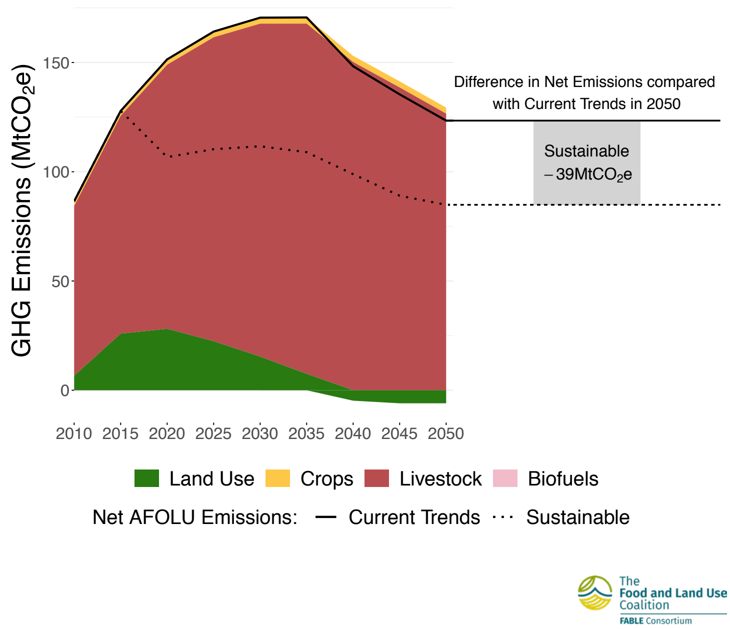
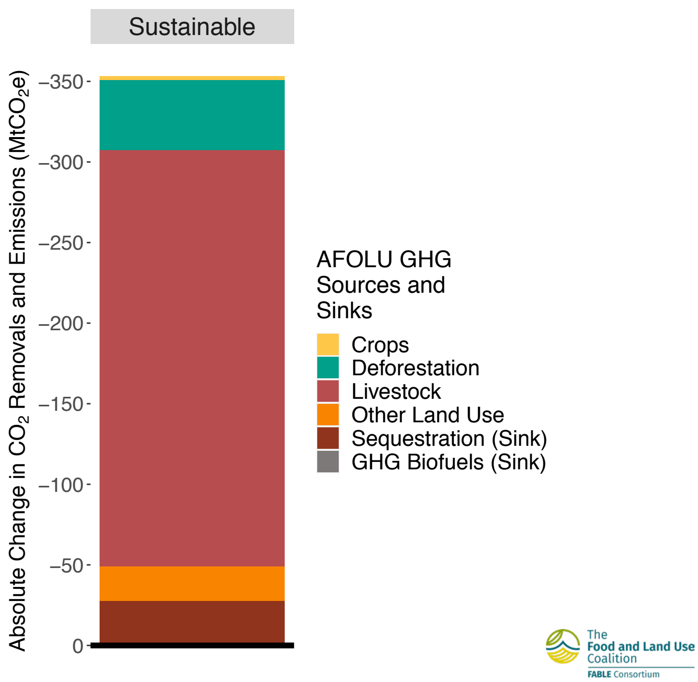


Figure 5 | Cumulated GHG emissions reduction computed over 2020-2050 by AFOLU GHG emissions and sequestration source compared to the Current Trends Pathway



Food Security

Current State

The "Triple Burden" of Malnutrition

Undernutrition

20.6% of the population was undernourished in 2016-2018. This share has decreased since 1999-2001 (Global Nutrition Report, 2020).

38.4% of children under 5 stunted and 9.9% wasted in 2016 (FAO, 2020).

Micronutrient Deficiency

24% of women of reproductive age, between 15-45 years, and 56.9 % of children aged 6-59 months suffer from anemia (<11.0g/dl) in 2016, which can lead to maternal death (CSA & ICF, 2017).

3.4% of women of reproductive age, between 15-45, are deficient in vitamin A (EPHI, 2016), which can notably lead to blindness and child mortality, and 51.8% are deficient in iodine, which can lead to developmental abnormalities (EPHI, 2016).

Overweight/ Obesity

1% of adults were obese in 2016. These shares have increased since 2000 (CSA & ICF, 2017).

4.6% of adults and 1% of children were overweight in 2016. The share of overweight adults has marginally increased

since 2000, while the share of overweight children has remained stable (CSA & ICF, 2017).

Disease Burden due to Dietary Risks

14.5% of deaths are attributable to dietary risks, or 3,856 deaths per year (per 100,000 people) (Melaku et al., 2018).

5.8% of the male and 5% of the female population suffer from diabetes and 31.7% of the female and 28.8% of the male population from cardiovascular diseases (raised blood pressure), which can be attributable to dietary risks (Global Nutrition Report, 2020).

Table 4 | Daily average fats, proteins and kilocalories 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)	2,044 (1938.5)	2,197 (2,020)	2,134 (2,020)	2,232 (2,067)	2,218 (2,067)
Fats (g) (recommended range	25 (45-68)	47 (49-73)	44 (47-71)	52 (50-74)	50 (49-74)
Proteins (g) (recommended range	77 (51-179)	84 (55-192)	80 (53-187)	86 (56-195)	84 (55-194)

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.

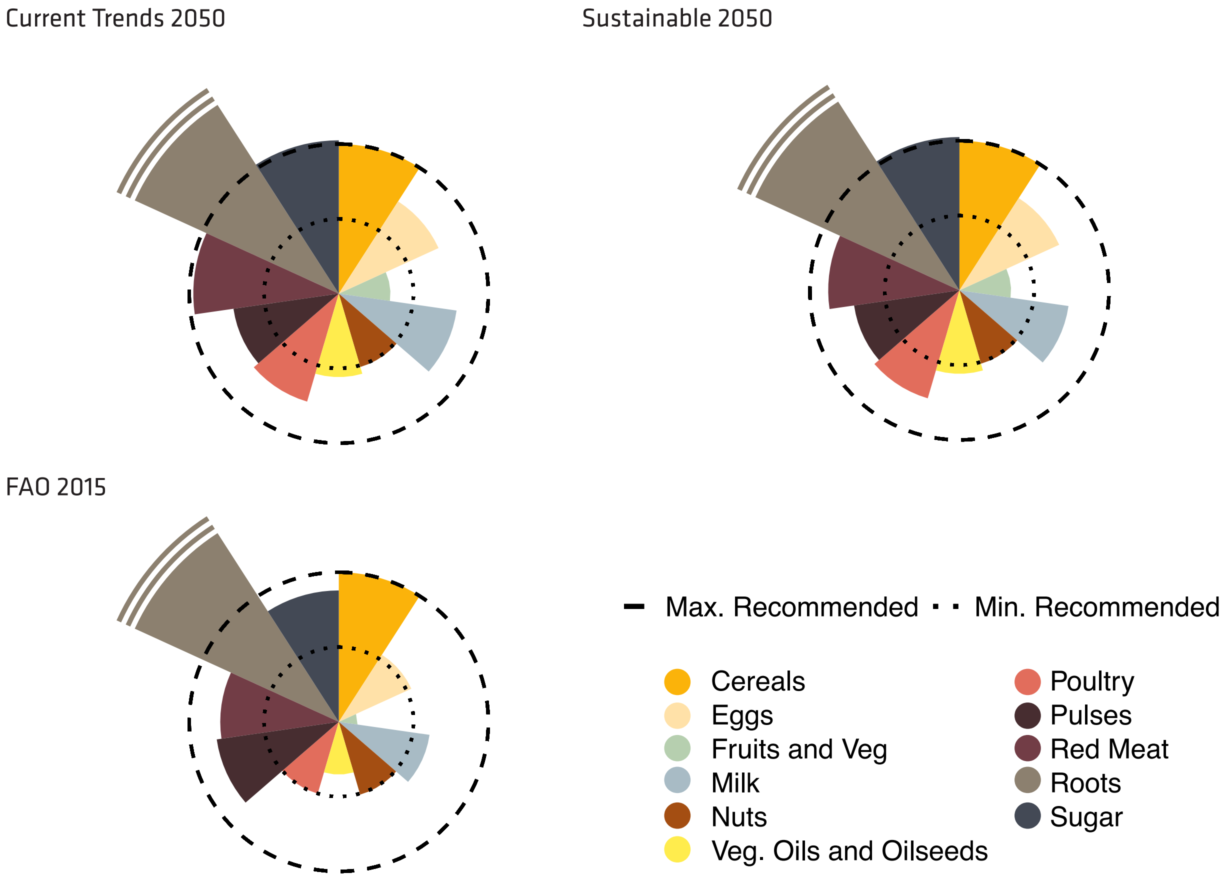
Pathways and Results

Under the Current Trends Pathway, compared to the average Minimum Dietary Energy Requirement (MDER) at the national level, our computed average calorie intake is 9% higher in 2030 and 8% higher in 2050 (Table 4). The current average intake is mostly satisfied by cereals, roots and tubers, and animal products, the latter representing 9% of total calorie intake. We assume that the consumption of animal products, and in particular milk, will increase by 45% between 2020 and 2050. The consumption of fruits and vegetables, meat, eggs, poultry, sugar, and nuts will also increase while cereals, pulses, and root crop consumption will decrease. Compared to the EAT-Lancet recommendations (Willett et al., 2019), roots, cereals, and sugar are over-consumed while animal fat, nuts as well as fruits and vegetables are under-consumed in 2050. Although the consumption of fruits and vegetables show some improvement compared to the baseline, it will remain below the minimum recommended level in 2050 (Figure 6). Moreover, fat intake per capita is inferior to the dietary reference intake (DRI) in 2030 and exceeds the dietary reference intake in 2050. On the other hand, protein intake per capita exceeds the dietary reference intake both in 2030 and 2050. This can be explained by an increase in the consumption of animal products like milk, eggs, and fish (Figure 6).

Under the Sustainable Pathway, we assume that diets will transition towards those higher in meat, milk, sugar, and fat. The ratio of the computed average intake over the MDER increases to 6% in 2030 and 7% in 2050 under the Sustainable Pathway. Compared to the EAT-*Lancet* recommendations, only the consumption of roots remains outside of the recommended range with the consumption of eggs and vegetable oils and oilseeds within the recommended range in 2050 (Figure 6). Moreover, while the fat intake per capita is inferior to the dietary reference intake (DRI) in 2030, the protein intake per capita exceeds the DRI in 2030. However, neither the fat nor protein intake per capita show improvement compared to the Current Trends Pathway.

Transforming the livestock sub-sector towards a higher productivity system and at the same time limiting the adverse environmental impact from intensification will be particularly important to promote this shift in diets (Gebru et al., 2018). In general, government commitments towards improving healthy diets and improving nutrition is reflected in several policy documents, including the Growth and Transformation II (GTP II), the Seqota Declaration, and the National Nutrition Program II (NNP II) (FDRE National Planning Commission, 2016; Federal Democratic Republic of Ethiopia, 2015, 2016). In the Seqota declaration, the government expresses its commitment to end hunger and undernutrition by 2030. Similarly, in the NNP II, it states its objectives of reducing stunting from 40% to 26% by 2020 as well as to reduce chronic undernutrition among women of reproductive age from 27% to 16% by 2020. The Ministry of Agriculture and Natural Resources' "Nutrition Sensitive Agriculture Strategic Plan" document also indicates the government's commitment to the NNP II targets and the need to revise agricultural sector policies and strategies with a nutrition lens (FDRE Ministry of Agricultural and Natural Resource and FDRE Ministry of Livestock and Fishery, 2016).

Figure 6 | Comparison of the computed daily average kilocalories intake per capita per food category across pathways in 2050 with the EAT-Lancet recommendations



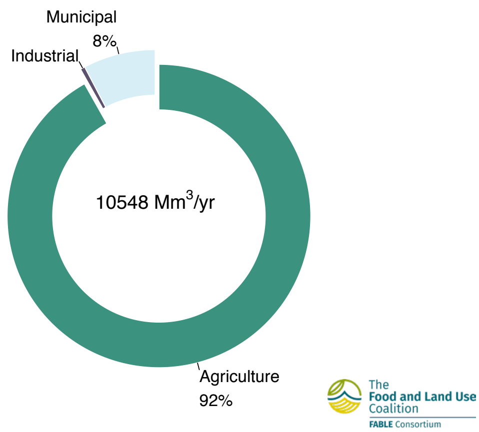
Notes. These figures are computed using the relative distances to the minimum and maximum recommended levels (i.e. the rings) i.e. different kilocalorie consumption levels correspond to each circle depending on the food group. The EAT-Lancet Commission does not provide minimum and maximum recommended 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

Ethiopia is characterized by three climatic zones of tropical rainy, temperate rainy, and dry climate with 848 mm average annual precipitation that mostly occurs between July and September (FAO, 2005; Kidanewold, Seleshi, & Melesse, 2014). The agricultural sector represented 92% of total water withdrawals in 2016 (Figure 7; FAO, 2017a). Moreover, in 2002, 4% of agricultural land was equipped for irrigation, representing 7% of estimated-irrigation potential (FAO, 2005). The three most important irrigated crops, corn, cotton, and sorghum, account for 18%, 14%, and 9% of the total harvested irrigated area. These crops are mostly used for domestic consumption - Ethiopia exported only 1% of corn, 7% of cotton, and 0.1% of sorghum in 2017 (ITC, 2020).

Figure 7 | Water withdrawals by sector in 2005 and 2016

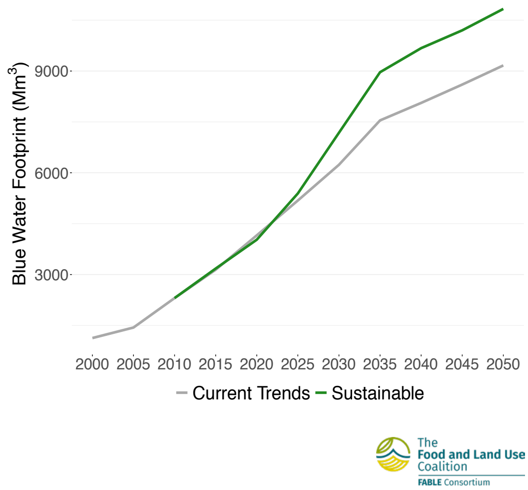


Notes. Agriculture data: 2016, municipal: 2005, industrial: 2005
Source. Adapted from AQUASTAT Database (FAO, 2017a)

Pathways and Results

Under the Current Trends Pathway, annual blue (irrigation) consumptive water use increases between 2000-2015 (1,128 Mm^3/yr and 3,142 Mm^3/yr), before reaching 6,237 Mm^3/yr and 9,165 Mm^3/yr in 2030 and 2050, respectively (Figure 8), with vegetables, soybean, and banana accounting for 49%, 22%, and 7% of computed blue water use for agriculture by 2050[4]. In contrast, under the Sustainable Pathway, the agricultural blue water footprint reaches 7,181 Mm^3/yr in 2030 and 10,832 Mm^3/yr in 2050. This is explained by climate change impacts on water used for irrigation.

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



4 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

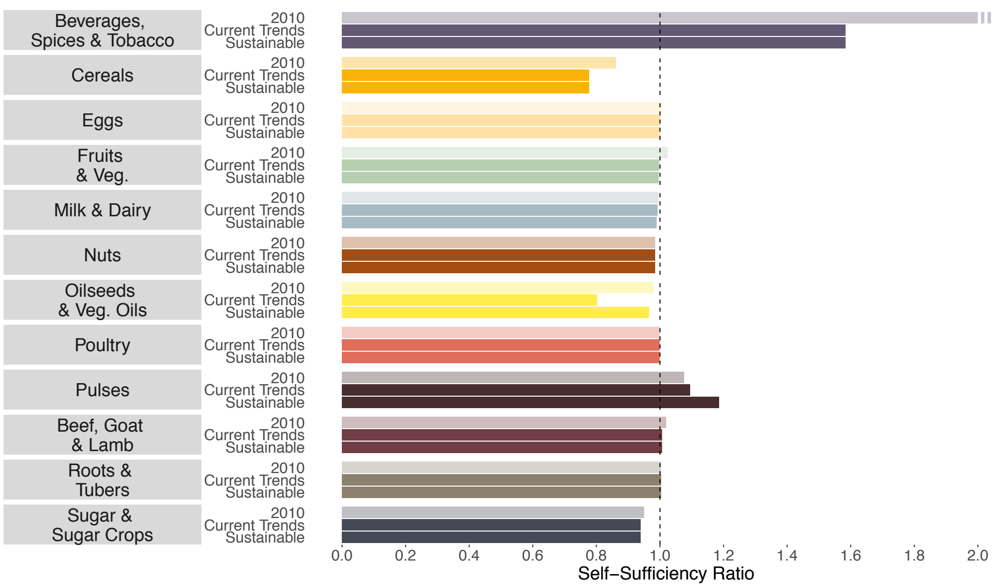
The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Ethiopia's resilience to agricultural-trade and supply disruptions across pathways: the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

Currently, Ethiopia depends on imports of certain food products including wheat, cooking oil, sugar, and sugar products. This is mainly due to the rapidly increasing population size, increasing economic growth and development, which involves dietary changes, and traditional production systems that depend heavily on rain-fed agriculture. Studies (Tesfaye et al., 2018) show that Ethiopia has a self-sufficiency rate of less than one and that the country needs to boost its crop productivity to become more self-sufficient in the future.

Under the Current Trends and Sustainable Pathways, we project that Ethiopia would be self-sufficient in beverages, spices and tobacco, pulses, fruits and vegetables, egg, nuts, and roots and tubers in 2050, with self-sufficiency by product group remaining stable for the majority of products from 2010 – 2050 (Figure 9). It is most dependent on imports of cereals, oilseeds, and vegetable oils as well as sugar and sugar products to satisfy domestic consumption, a trend that will increase until 2050 (Figure 9). This is mainly explained by the growing population and changes in diets.

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:

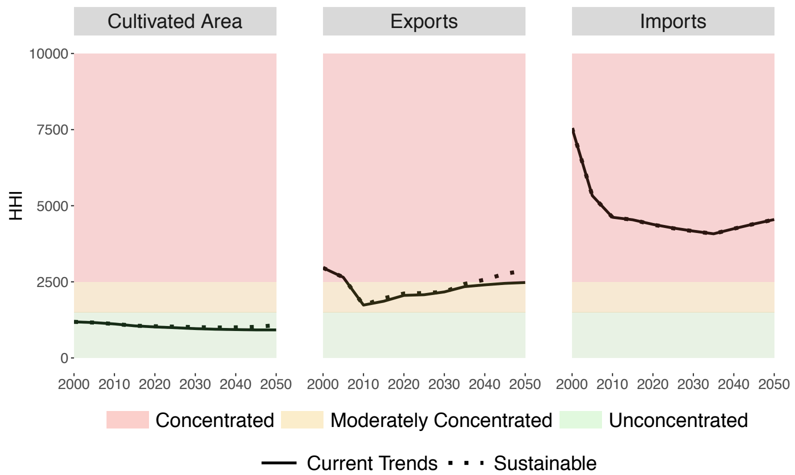
- **Cultivated area:** where concentration refers to cultivated area that is dominated by a few crops covering large shares of the total cultivated area, and diversity refers to cultivated area that is characterized by many crops with equivalent shares of the total cultivated area.
- **Exports and imports:** 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, a moderate concentration between 1,500 and 2,500, and high concentration above 2,500.

Although the five major cereals (teff, wheat, maize, sorghum, and barley) account for about three-quarters of the total area cultivated, Ethiopia's crop production system tends to be relatively unconcentrated thanks to its widely varying agroecological conditions. Cereals account for 74% of the total cultivated area, while pulses and oilseeds account for 12% and 7%, respectively (Taffesse, Dorosh, & Gemessa, 2012). Although Ethiopia's exports are generally concentrated among a few agricultural products, particularly coffee, crop exports are likely to diversify as oilseeds and pulses also happen to be important export items. Ethiopia's crop imports, on the other hand, are likely to be highly concentrated due to its heavy reliance on imports of wheat, which, according to Gebreselassie, Haile, and Kalkuhl (2017), comprises the single most important imported food crop.

Under the Current Trends Pathway, we project a high concentration of crop imports, moderate levels of crop exports, and a low concentration in the range of crops planted in 2050, trends which stabilize over the period 2010 - 2050. This indicates high levels of crop diversity across the national production system, moderate levels of concentration in exports, and low levels of crop diversity in imports. Under the Sustainable Pathway, we project high concentration of crop exports and imports and low concentration in the range of crops planted in 2050, indicating high levels of diversity across the national production system and low levels of diversity across imports and exports (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

Important policy areas in Ethiopia's pathway towards sustainable development are identified in the Climate Resilient Green Economy Strategy (CRGE) and development plans (GTPs). The CRGE, which came into effect in 2011 and remains in force until 2030, is the main document that guides Ethiopia's Nationally Determined Contribution (NDC). It covers both the adaptation and mitigation objectives of the government (Federal Democratic Republic of Ethiopia, 2011).The second GTP, which is the current development plan ending this year (2019/20), will be followed by the Ten-Year Perspective Development Plan (TYPDP) in 2021. The TYPDP, which will be implemented between 2020 and 2030, has an ambitious growth target and a climate-resilient green economy as one of its pillars (*Ethiopian Monitor*, 2020). With its plans and strategies, the government aims to achieve a high economic growth rate while maintaining a low level of emissions. This requires identifying green economy opportunities and needs the support of development partners for its full realization.

Under the Current Trends Pathway, constructed based on Ethiopia's ambitious planned improvement in per capita income and the expected population growth rate, our results show that Ethiopia's per capita consumption of fats, which is below the recommended level, will increase rapidly. This will increase the demand for food and for animal-based production in particular. Assuming the continuation of previously observed growth in crop productivity, our results show that agricultural land will expand at the expense of forest and other natural lands. This result indicates that Ethiopia will struggle to simultaneously achieve the development plan, meet the food demand of its growing population, and, as stipulated in its NDC, keep its GHG emissions at a low level while protecting biodiversity without the concerted technical and financial support of development partners. The feasibility of expanding agricultural land at the expense of other lands is questionable at best. This is due to political, social, cultural, and developmental challenges that will make the free expansion of agricultural land impractical. Moreover, studies indicate that cropland expansion is reaching its limit in the highlands, which has traditionally been an important area for crop production (Schmidt & Thomas, 2018).

Therefore, we developed an alternative Sustainable Pathway with enhanced crop productivity, slower population growth, and restrictions on the expansion of agricultural land. Under this pathway, Ethiopia can better reconcile the demand for land and food. Focusing on increases in productivity and slower population growth will lead to desirable development and GHG emissions outcomes. For example, under such a pathway, it will be possible to increase the forest cover to meet the targets of the ambitious Bonn Challenge by 2050. This underlines the need to have a clear and well-thought-out land use plan and policies, as well as institutions with a land-use mandate at both at the federal and regional levels. However, such a development trajectory will require significant investment to raise productivity and the efficient use of resources. For example, small-scale irrigation with high water use efficiency can be used towards boosting production of vegetables and fruits, diversifying crop production, providing increased access to healthy diets for the growing urban population.

One limitation of the above analysis is that it only applies to the national level despite the well-known regional differences within Ethiopia. Ethiopia is geographically diverse and follows a federal governance arrangement with nine regional states. The challenges in one region may differ from those in others. Therefore, it will be important to introduce an analysis of regional differences within the FABLE framework and have a more granular assessment of the food and land-use system that can inform sectoral plans. Yet another challenge that is disrupting the food and land use system and not covered in the above analysis is the recent outbreak of COVID-19. In particular, supply chain distribution is already impacting fresh vegetable commodities and international trade. The food systems in low-income countries, with limited storage facilities and contact intensive marketing systems, are highly vulnerable and require attention. The implication of adjustments in farming decisions as a result of COVID-19 may also have far-reaching consequences that need to be analyzed using the FABLE framework. Going forward, we will endeavor to fill these gaps and promote the use of FABLE's analytical framework to the relevant stakeholders with the aim of supporting knowledge-based policy making in Ethiopia.

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

- We have separated Teff which is a staple crop in Ethiopia. In FAOSTAT (FAO, 2020), it is considered as other cereals.
- We have included a high economic growth scenario as per governmental plans.

Annex 2. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)

Current Trends Pathway	Sustainable Pathway
UN's low growth scenario was selected, whereby the total population size reaches 170 million by 2050. Based on the UN's population projection database (UNDP, 2015). The primary source of population data is the census, which was conducted in 1994 and 2007. Accordingly, the average population growth rate was close to 2.5% per year between 1994 and 2007 – corresponding to the two census periods (CSA, 2013). However, this rate is expected to decrease.	SSP1 scenario, which influences demographics in the direction that is supposed to improve the sustainability of the food and land use system, was selected. According to this scenario, Ethiopia's population will reach 154 million by 2050

LAND Constraints on agricultural expansion

Current Trends Pathway	Sustainable Pathway
Free expansion of productive land under the total land boundary is selected as the current pathway scenario for land. Although there is little room for further expansion of agricultural land in the highlands of Ethiopia, where the majority of crop production in the country takes place, there is potential to expand cropland activities in the low lands (Schmidt & Thomas, 2018). Concerning pastureland, the grey literature identifies the rise in rangeland enclosures (Fekadu Beyene, 2009; Napier & Desta, 2011). Moreover, since we are not aware of any efforts that aim to limit agricultural land expansion, we assume that free land expansion will be closer to what is likely to happen in the current pathway.	For the sustainable scenario, we assume no productive land expansion beyond the 2010 value. This is assumed to be consistent with limited availability of land for further expansion of agricultural land in the highland areas of the country as indicated in Schmidt & Thomas (2018). Although there is some land in the low lands that can potentially be used for agricultural expansion, that there might be political as well as infrastructural constraints that holds back the country from doing so thus far. Schmidt & Thomas (2018) also indicate the difficulty of expanding agricultural land in the lowlands as these areas are characterized by a relatively higher risk of disease as well as more erratic and limited rainfall.

LAND Afforestation or reforestation target (1000 ha)

Current Trends Pathway	Sustainable Pathway
Ethiopia's NDC Target is 7 Mha by 2030 (FDRE National Planning Commission, 2016). In line with this, we assume that Ethiopia will achieve this target by 2050.	Afforestation/reforestation target in line with the Bonn Challenge commitment. Specifically, considering the commitment towards a Climate Resilient Green Economy that Ethiopia outlined in 2011 and the afforestation pledge it has made, we have taken Ethiopia's Bonn challenge commitment targeting 15 Mha for afforestation by 2020 (Pistorius, Carodenuto, & Wathum, 2017). This is extremely ambitious and we assume that the country will achieve this target by 2050.

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

Current Trends Pathway	Sustainable Pathway
No expansion of protected areas beyond the current extent, which means keeping the share of protected areas at 20% of total land. Given the increasing population pressure and the resulting habitat conversion, unsustainable utilization of biodiversity resources, climate change, pollution, etc. that threaten protected areas, we assume restricted expansion of protected areas (Ethiopian Biodiversity Institute, 2014; USAID, 2008).	Expansion of protected areas in the future, increasing share of protected areas to 21% of total land area from its current level of 20%.

PRODUCTION Crop productivity for the key crops in the country (in t/ha)	
Current Trends Pathway	**Sustainable Pathway**
We assume the same crop yield growth as in 2000-2010.	We assume higher crop yield growth compared to 2000-2010. The reason for assuming high crop productivity growth is based on Ethiopia's currently relatively low cereal productivity base (Taffesse et al., 2012) and significant improvements that took place after 2010 - following the government's focus on agricultural transformation through various programs such the agricultural growth program (World Bank, 2017), which showed a 16% improvement in yield in five years (between 2011 and 2016). In GTP II period (2015/2016-2019/2020) the government aims to sustain the achievements in crop productivity obtained in the GTP I period (2010/2011-2014/2015) (FDRE Ministry of Finance and Economic Development, 2010; FDRE National Planning Commission, 2016).
PRODUCTION Livestock productivity for the key livestock products in the country (in t/head of animal unit)	
We assume higher yield growth for livestock than what is observed for 2000-2010. Specifically, we assume an increase in productivity rate of 200%, 100%, and 70% if the annual growth rate in the period 2000-2010 is negative, between 0% and 1%, and greater than 1%, respectively. This is because of the renewed interest among policymakers and development partners towards the livestock sector, as well as the low level of current productivity. Ethiopia's cattle meat production of 14 kg per standing head is lower than neighboring countries like Kenya (21 kg per standing head) and milk production is even less productive 72.5 kg per standing head compared to Kenya's 194.74 kg per standing head (Shapiro et al., 2015).	Same as Current Trends
PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)	
We assume no change in the management of permanent pasture area, leading to pasture degradation in some cases. The baseline (2010) livestock density value used in our scenario is 1.58 TLU/ha. Tilahun & Schmidt (2012) report a livestock density value of 0.3 TLU/ha, excluding camel and donkey.	Same as Current Trends
PRODUCTION Post-harvest losses	
We assume a reduction in the proportion of food that is wasted. We have assumed a reduced (50%) share of food waste compared to 2010 as many development partners are looking at food waste as a possible area of intervention (Federal Democratic Republic of Ethiopia, 2011).	Same as Current Trends

TRADE Share of consumption which is imported for key imported products (%)	
Current Trends Pathway	**Sustainable Pathway**
We assume increased import shares for wheat following the pattern of imports in the country (Olana et al., 2018). As is also indicated in Olana et al. (2018), Ethiopia's wheat imports have been growing rapidly and are expected to increase in the future given the high population growth and improvements in living standards in the country, which in turn is likely to lead to higher demand for wheat products.	Same as Current Trends
TRADE Evolution of exports for key exported products (1000 tons)	
We assume increases in exports in the future. Specifically, we assume that exports will be multiplied by 1.5 by 2050. This assumption is consistent with the GTP II's target of increasing agricultural export revenue as a share of GDP by 2.9 percentage points (FDRE National Planning Commission, 2016)	Same as Current Trends

FOOD Average dietary composition (daily kcal per commodity group or % of intake per commodity group)	
Current Trends Pathway	**Sustainable Pathway**
Here we selected the fat diet scenario which implies a higher share of meat products, oil, and sugar in the total food intake. This is assumed to be consistent with the assumption of high yield growth for livestock than what is observed for 2000-2010 as well as government's target of increasing the production and consumption of animal source foods in the five year period between 2016-2020 (FDRE Ministry of Agricultural and Natural Resource and FDRE Ministry of Livestock and Fishery, 2016).	Same as Current Trends
FOOD Share of food consumption which is wasted at household level (%)	
We have assumed a reduced share of food loss compared to 2010. This assumption is made as many development partners are looking at food waste as a possible area of intervention (Federal Democratic Republic of Ethiopia, 2011).	Same as Current Trends

BIOFUELS Targets on biofuel and/or other bioenergy use	
Current Trends Pathway	**Sustainable Pathway**
We assume no change, which implies stable biofuel demand as in 2010.	Based on OECD_AGLINK scenario which makes projections until 2028 that remain stable afterward. Accordingly, biofuel use is assumed to increase for wheat, corn, sugarcane, and soy oil, by a factor of about 3.34 - 7.91 over the period 2015-2050. This is consistent with studies that report increased use of biofuel in Ethiopia (Ferede, Gebreegziabher, Mekonnen, Guta, & Levin, 2015; Teka, 2007).

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)

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

ha – hectare

kcal – kilocalories

kg – kilogram

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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