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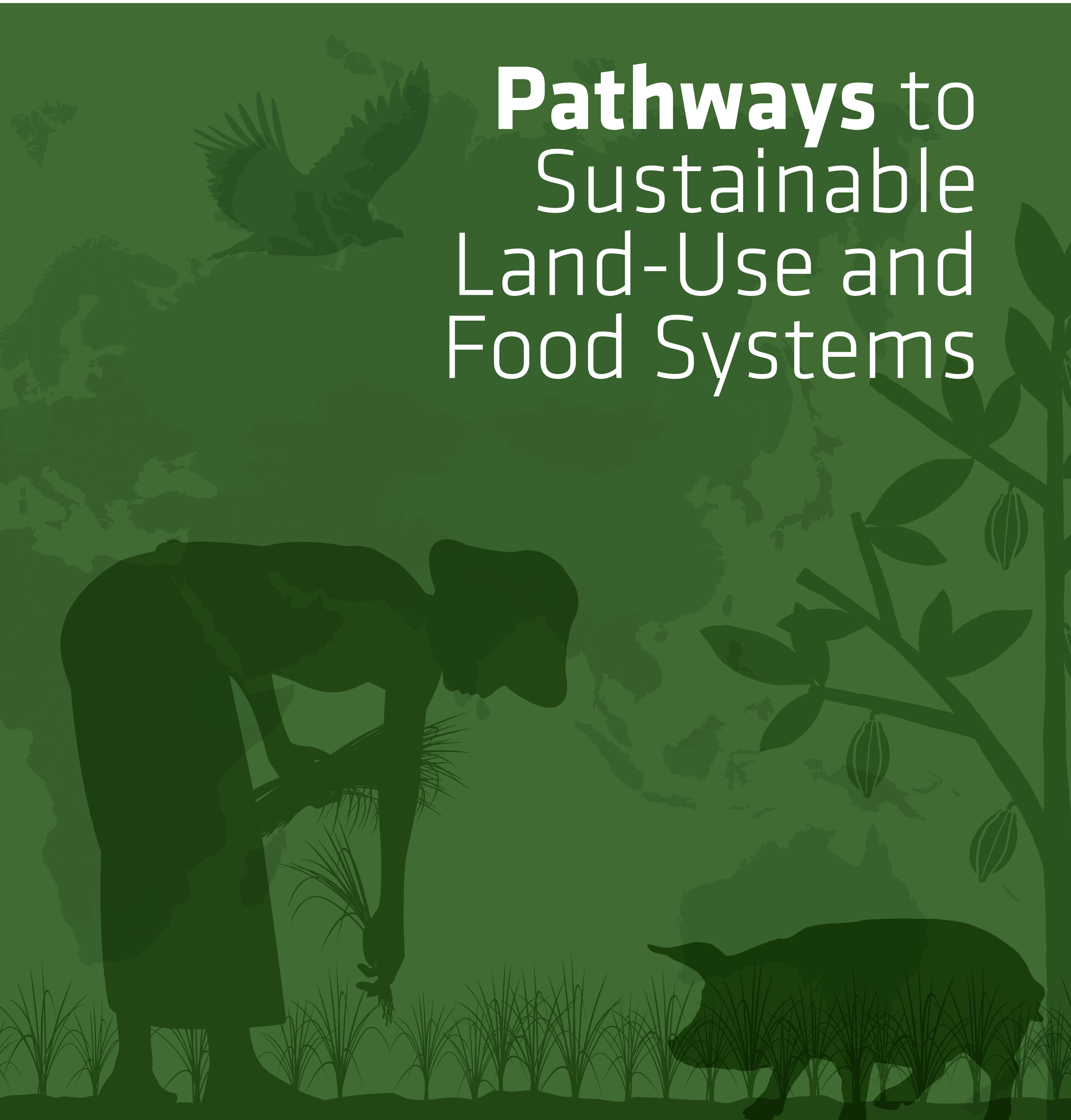
The Food and Land Use Coalition

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: Imanirareba D., Niyitanga F and Naramabuye F.X. (2020), "Pathways to Sustainable Land-Use and Food Systems in Rwanda 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. 540-567.
https://doi.org/10.22022/ESM/12-2020.16896

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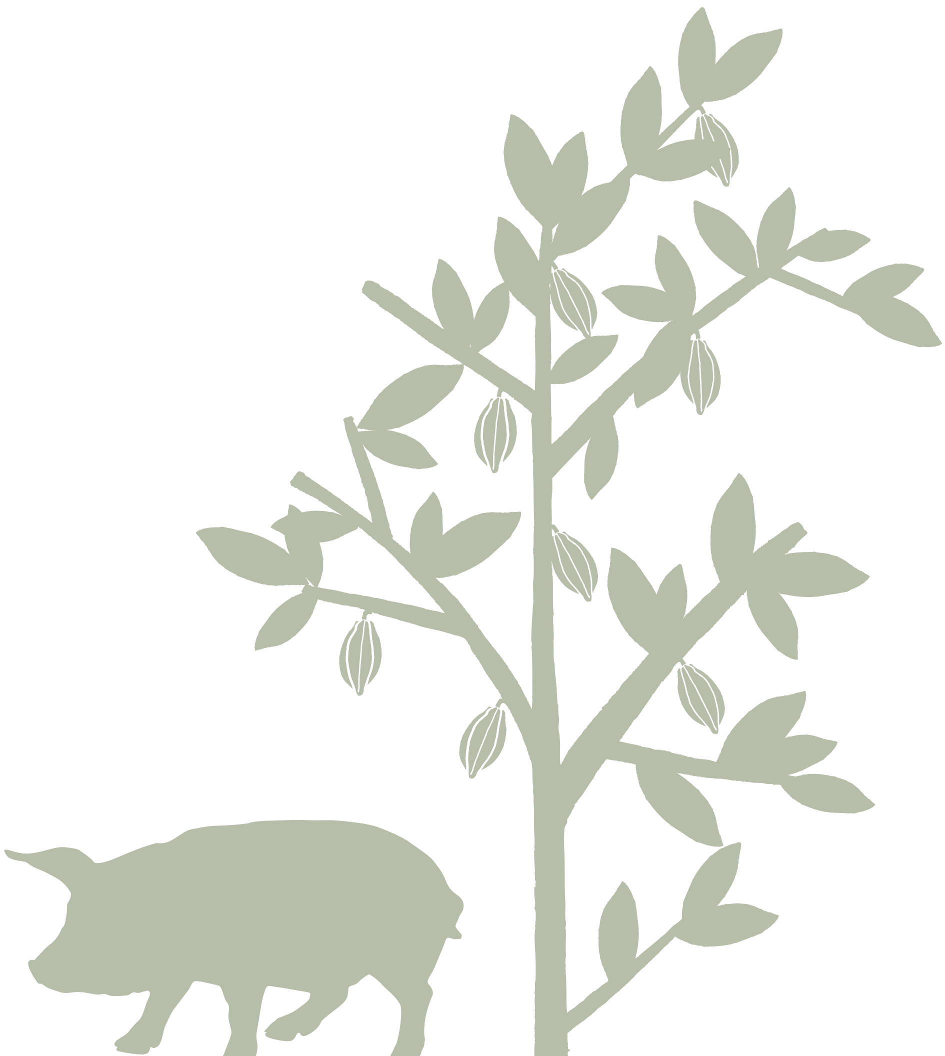
2020 Report of the FABLE Consortium

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



Rwanda

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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 Rwanda. 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 from Ministry of Agriculture and Animal Resources, Rwanda Agriculture Board, National Agricultural Export Development Board, Rwanda Environment Management Authority, Forestry Authority, Land authority, Water authority, University of Rwanda, Mining authority, National Institute of Statistics of Rwanda (NISR), and modeled them with the FABLE Calculator (Mosnier, Penescu, Thomson, and Perez-Guzman, 2019).

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 Rwanda's Nationally Determined Contribution (NDC) and Urban Low Emissions and Development Strategy (Urban-LEDS) treat the FABLE domains. In the AFOLU sector, Rwanda's NDC targets to reduce GHG emissions from agriculture, despite the potential for increased productivity. Agricultural output is expected to be limited due to land availability, thereby limiting the emissions growth from this sector, without an emissions target from forestry or land use change. Envisaged mitigation measures from agriculture and land-use change include mainstreaming agroecology techniques using spatial plant stacking as in agroforestry; promoting kitchen gardens, nutrient recycling, and water conservation to maximize sustainable food production; utilizing resource

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

	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 (2020)	2015	5.33 (2.94 for agriculture)	2030	Three scenarios: 1. BAU projects 12.1 (5.1) 2. A 16% unconditional from BAU = 10.2 3. A 38% combined unconditional and condition reduction from BAU =7.5	Energy, Transport, Industry, Waste and Forestry	Only agriculture	Y	N	food security, water, deforestation
Urban-LEDS (2019)	2015	0.5	2030	18.8	Energy, Transport, Industry, Wastes, Agriculture, and Animal Husbandry	Y	Y	N	food security, water, deforestation

Note. "Total GHG Mitigation" and "Mitigation Measures related to AFOLU" columns are adapted from IGES NDC Database (Hattori, 2019).
Sources. Compiled from Updated Nationally Determined Contribution (INDC) (Republic of Rwanda, 2020)

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

recovery and reuse through organic waste composting and wastewater irrigation; using fertilizer enriched compost; mainstreaming sustainable pest management techniques to control plant parasites and pathogens; soil conservation and land husbandry; irrigation and water management; adding value to agricultural products through processing to meet its own market demand for food stuffs; employing an integrated approach to planning and sustainable land use management and improving spatial data by harnessing ICT and GIS (Geographic Information System) technology. Under its current commitments to the UNFCCC, Rwanda mentions biodiversity conservation.

Table 2 provides an overview of the targets listed 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. In comparison with FABLE Targets, there is a linkage between both targets in terms of area covered by forests and zero net deforestation from 2030 onwards. Compared to the FABLE target of having at least 30% of global terrestrial area protected by 2030, our assumption is below the Government of Rwanda's target to increase the percentage of land designated for biodiversity conservation from 10.13% in 2017 to 10.3% in 2020 of its total land.

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

NBSAP Target	FABLE Target
(5) **By 2020, at least 50% of natural ecosystems are safeguarded, their degradation and fragmentation significantly reduced.**	**BIODIVERSITY:** No net loss by 2030 and an increase of at least 20% by 2050 in the area of land where natural processes predominate
(9) **By 2020, at least 10.3% of land area is protected to maintain biological diversity.**	**BIODIVERSITY:** At least 30% of global terrestrial area protected by 2030
(14) **By 2020, 30% of the country is covered by forests hence increasing carbon stocks and contributing to climate change mitigation and adaptation.**	**DEFORESTATION:** Zero net deforestation from 2030 onwards

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 Rwanda.

Our Current Trends Pathway corresponds to the lower boundary of feasible action. It is characterized by medium population growth from (8 million in 2000 to 22 million in 2050), no constraints on agricultural expansion, no-afforestation target, 9% change in the extent of protected areas, medium productivity increases in the agricultural sector, an evolution towards national healthy diets, and high livestock productivity (see Annex 1). This corresponds to a future based on current policy and historical trends that would also see considerable progress in measures and national strategies that support agriculture through subsidies; livestock and livelihoods through the One Cow per Poor Family Program, and food security, through the improvement of soil fertility. Moreover, capacity building of government personnel will have a significant impact in supporting these pathways. Furthermore, the government's adoption of agroforestry practices is complementing the afforestation/reforestation efforts as reported by Ministry of Lands and Forestry (2018). 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 for corn, wheat, rice, and soybean (see Annex 1).

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 no deforestation beyond 2030, stronger measures for protected areas, higher livestock productivity along with a high-fat diet, higher criteria for agricultural expansion formalized in government master plans for proper land use allocation, lower population growth, and no-afforestation target for both models (see Annex 1). This corresponds to a future based on the improvement of policies already in place and the integration of new ambitious policies that would also lead to considerable progress in the management of environment and natural resources. These policies include the adoption of irrigation systems to cope with climate change impacts, the banning of plastic bags, the promotion of tree planting, the establishment of green funds, the inclusion of environmental considerations into policy making ("green politics") and landscape restoration; which would help Rwanda become a low-carbon economy and climate-resilient by 2050 (World Economic Forum, 2016). 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.

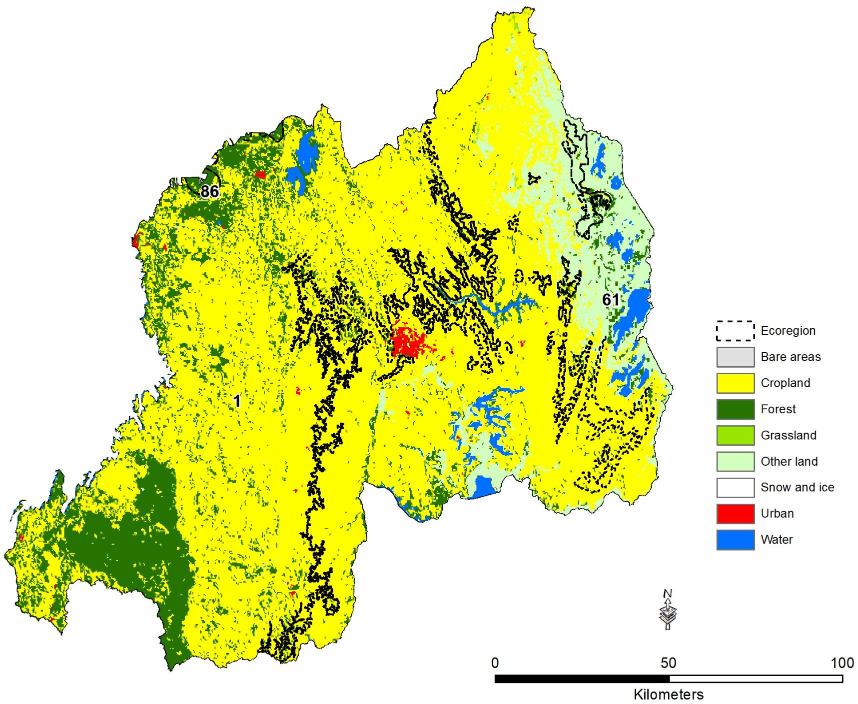
Land and Biodiversity

Current State

In 2010, Rwanda was covered by 58% cropland, 17% grassland, 14% forest, 1% urban and 10% other natural land. Most of the agricultural area is located in the Northern part of Rwanda while forest and other natural land can be mostly found in the Southern part (Map 1). We know that biodiversity is life as it is part of us as human beings, it is our air, our food and our water. Despite the government's conservation efforts, Rwanda's biodiversity remains under pressure due to natural habitat degradation, climate change, pollution, mining, poaching, and invasive alien species. Moreover, we still observe gaps as biodiversity is not integrated into national development policies and programs.

We estimate that land where natural processes predominate[2] accounted for 14% of Rwanda's terrestrial land area in 2010 (Map 2). The *86-Rwenzori-Virunga montane moorlands* hold the greatest share of land where natural processes predominate, followed by *61-Victoria Basin forest-savanna* and *1-Albertine Rift montane forests* (Table 3). Across the country, while 0.23 Mha of land is under formal protection, falling short of the 30% zero-draft CBD post-2020 target, only 64% of land where natural processes predominate is formally protected. This indicates that *61-Victoria Basin forest-savanna* and *1-Albertine Rift montane forests* are likely to remain important into the future due to their roles in the ecological, economic, social and cultural sphere. Moreover, these ecoregions fulfill a central role in the conservation of species and biodiversity habitats for educational, tourism and research purposes.

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



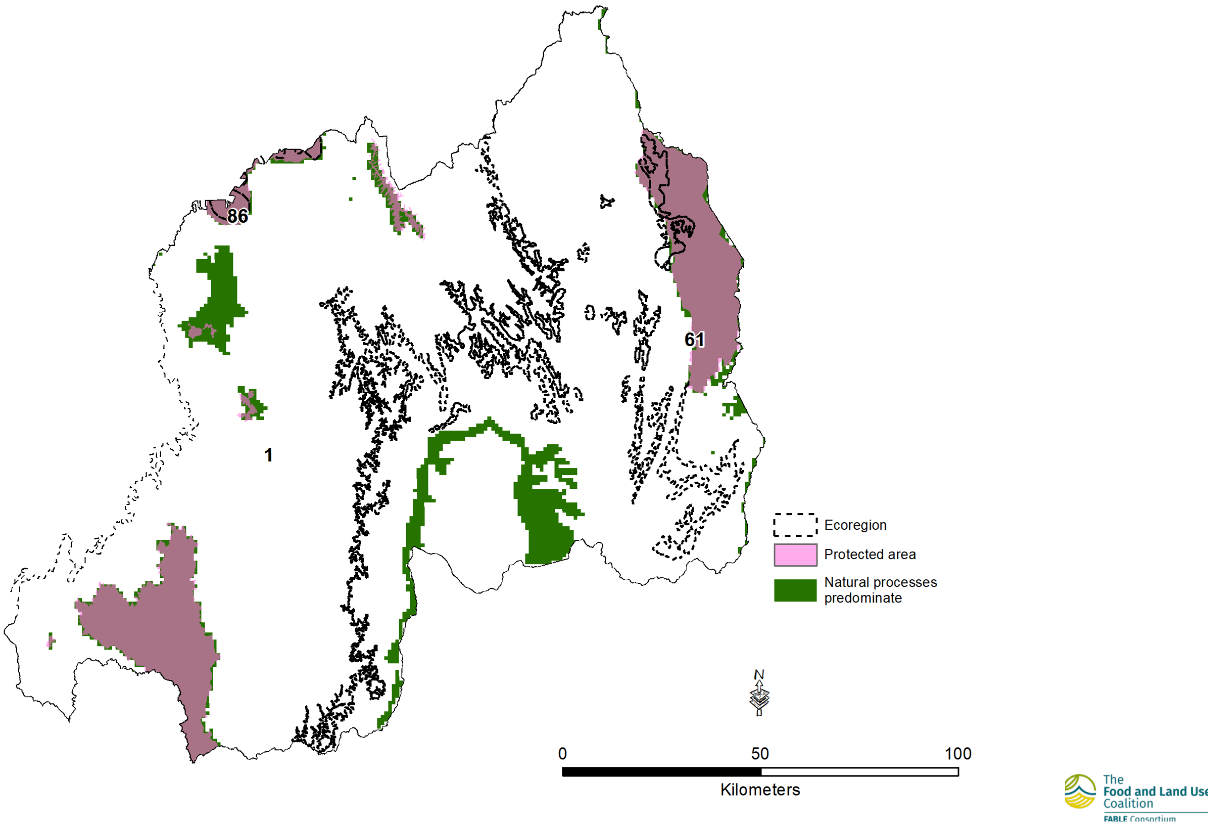
Note. countries - GADM v3.6; ecoregions – Dinerstein et al. (2017); land cover – ESA CCI land cover 2015 (ESA, 2017)
Sources. Correspondence between original ESA CCI land cover classes and aggregated land cover classes displayed on the map can be found in Annex 2.

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".

However, *86-Rwenzori-Virunga montane moorlands* and wetlands areas may be at risk without actions to better protect them.

Approximately 28% of Rwanda's cropland was in landscapes with at least 10% natural vegetation in 2010. These relatively biodiversity-friendly croplands are most widespread in *86-Rwenzori-Virunga montane moorlands,* followed by *1-Albertine Rift montane forests* and 61-*Victoria Basin forest-savanna.* The regional differences in extent of biodiversity-friendly cropland can be explained by regional production practices.

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)

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)	Share of Cropland with >10% Natural Vegetation within $1km^2$ (%)
1	Albertine Rift montane forests	1345.107	9.7	12.7	74.6	25.4	989.358	32.5
61	Victoria Basin forest-savanna	1087.637	8.3	15.6	52.3	47.7	757.079	22.2
86	Rwenzori-Virunga montane moorlands	8.564	97.5	99.7	97.7	2.3	1.716	86.4

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

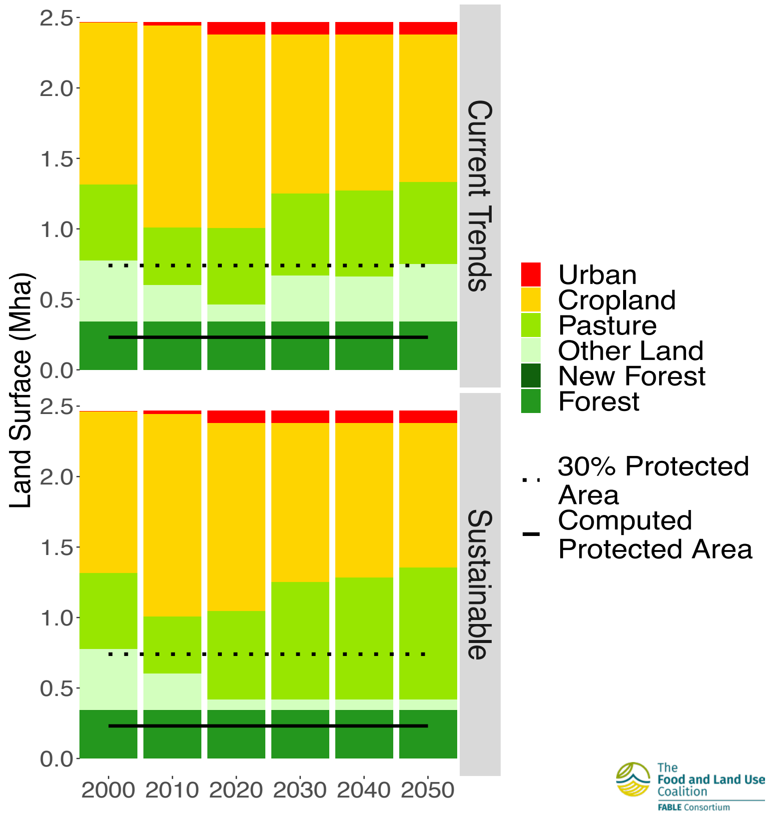
Projected land use in the Current Trends Pathway is based on several assumptions, including no constraints on land conversion beyond protected areas, no planned afforestation or reforestation, and protected areas remain at 0.23 Mha, representing 9% of total land cover (see Annex 1).

By 2030, we estimate that the main changes in land cover in the Current Trends Pathway will result from an increase of pasture and other land area, as well as a decrease of cropland area. This trend evolves over the period 2030-2050: cropland area further decreases, urban area stabilizes, and pasture area begins to decrease as well.

Pasture expansion is mainly driven by the increase in internal food consumption of cattle (beef, milk) while livestock productivity per head increases and ruminant density per hectare of pasture remains constant over the period 2020-2030. Between 2030-2050, pasture change is explained by a strong increase in internal demand for livestock products and high population growth. This results in the expansion of land where natural processes predominate by 60% by 2030 and by 88% by 2050 compared to 2010, respectively.

In the Sustainable Pathway, assumptions on agricultural land expansion have been changed to reflect the National Land Use Development Master Plan which designates areas in Rwanda that are most suitable for agricultural development. The Master Plan also seeks to improve the land use sustainability of the country and to enhance the quality of the

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

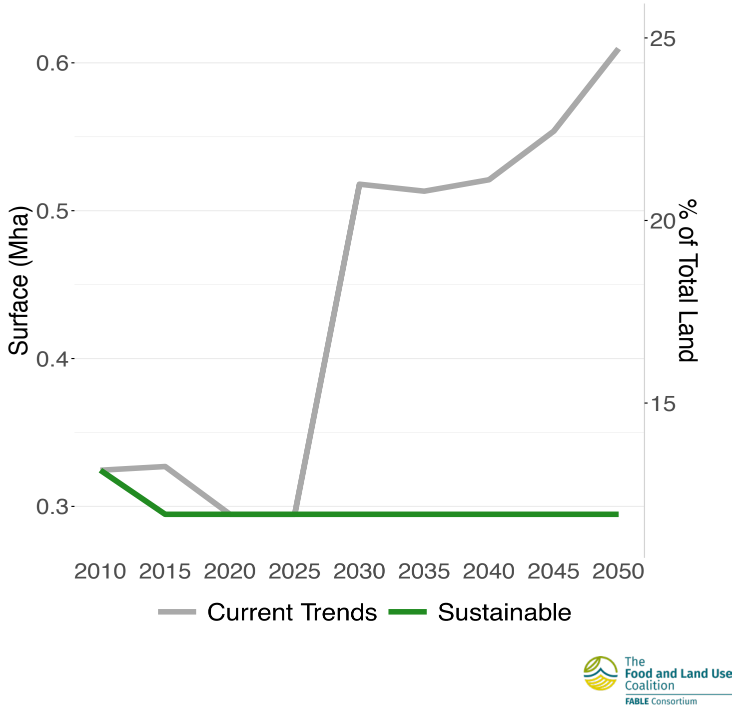


Source: Authors' computation based on FAOSTAT (FAO, 2020) for the area by land cover type for 2000, and the World Database on Protected Areas (UNEP-WCMC & IUCN, 2020) for protected areas for years 2000, 2005 and 2010.

built environment (Ministry of Natural Resources, 2017). Moreover, the adoption of professional agriculture would increase the yield on small plots and compensate for the land expansion. The main assumptions also include the prevention of deforestation by 2030 (see Annex 1).

Compared to the Current Trends Pathway, we observe the following changes regarding the evolution of land cover in Rwanda in the Sustainable Pathway: there is a decrease in cropland and other land from 2010 and 2030 and an increase in pasture from 2030 to 2050. In addition to the changes in assumptions regarding land-use planning, these changes compared to the Current Trends Pathway are explained by an increase in exports of tea and coffee, an increase in demand for various feed products and an increase in food consumption of milk, coupled with a decrease in production of potatoes, cassava and beans between 2010 and 2030. This leads to a stabilization in the area where natural processes predominate: the area stops declining by 2015 and remains the same by 9% between 2015 and 2050 (Figure 2).

Figure 2 | Evolution of the area where natural processes predominate



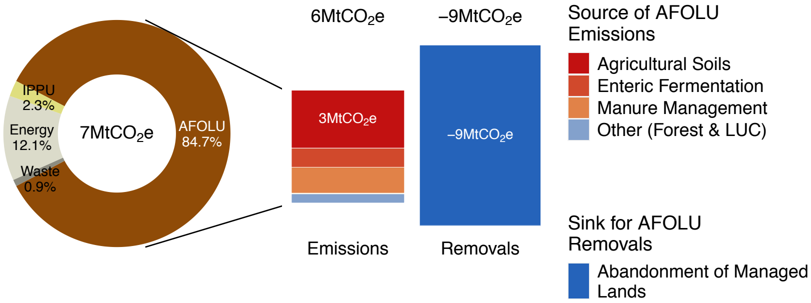
GHG emissions from AFOLU

Current State

The Agriculture, Forestry, and Other Land Use (AFOLU) sector is a critical component of the Malaysian plan to address climate change largely due to the extent of carbon sinks in the region such as forests and peatlands. The effort to balance economic concerns, food security, and the preservation of the country's vast carbon sinks remains a point of debate to this day. In particular, peatlands pose a unique challenge due to the lack of national data available.

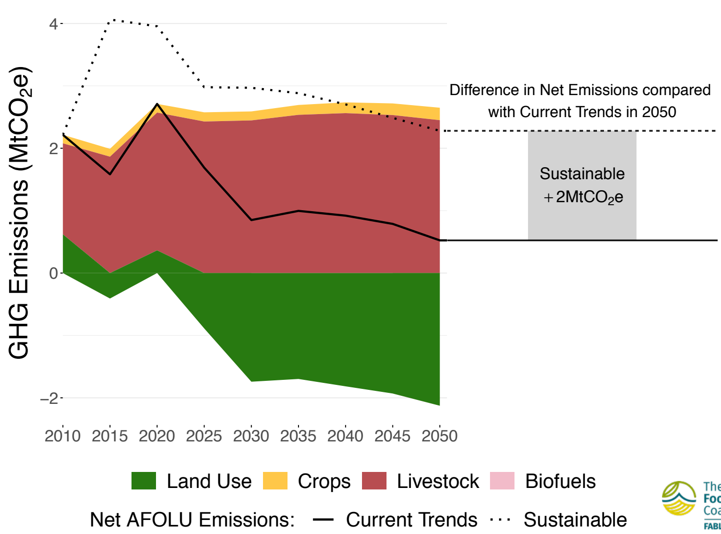
Direct GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) accounted for 84.7% of total emissions in 2010 (Figure 3). Agricultural soils are the principle source of AFOLU emissions, followed by manure management, enteric fermentation, and other (agriculture). This can be explained by the fact that Rwandan soil is inherently acidic, and steep slopes expose the soil to erosion, fertility loss and landslides. Additionally, the Crop Intensification Programme (CIP), launched by the government of Rwanda in 2007, focuses on the consolidation of land use to increase the productivity of high potential staple food crops, and ultimately ensure the country's food security and self-sufficiency. CIP also promotes the increased use of fertilizers which could be a reason for the rise in agricultural emissions (Nilsson, 2018). Another reason can be linked to the One Cow per Poor Family

Figure 3 | Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2005



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

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



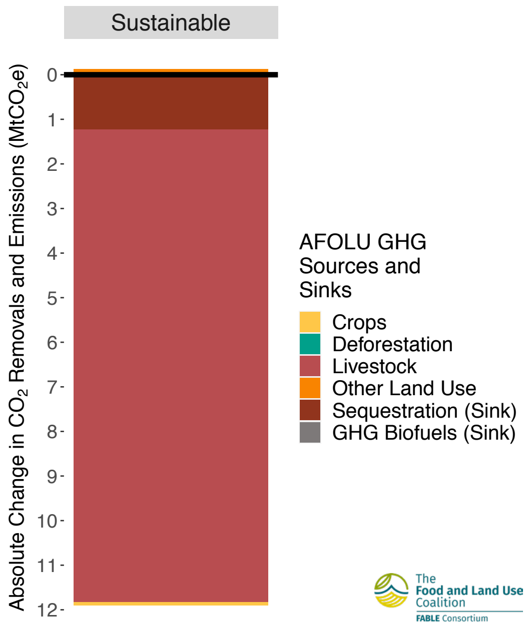
program which aims to reduce the rate of child malnutrition and increase household incomes for poor families in Rwanda (Rwanda Governance Board, 2018). However, the program has also led to high quantities of manure produced that are not appropriately managed to minimize Nitrogen losses and environmental pollution.

Pathways and Results

Under the Current Trends Pathway, annual GHG emissions from AFOLU decrease to 0.8Mt CO_2e/yr in 2030, before declining to 0.5Mt CO_2e/yr in 2050 (Figure 4). In 2050, livestock is the largest source of emissions (2.5Mt CO_2e/yr) while sequestration acts as a sink which almost offsets emissions (-2.1 Mt CO_2e/yr). Over the period 2020-2050, the strongest relative increase in GHG emissions is computed for N20 emissions from crop production (63%) while a reduction is computed for methane emissions from crop production (52%).

In comparison, the Sustainable Pathway leads to an increase of AFOLU GHG emissions compared to the Current Trends Pathway reaching 3 Mt CO2e in 2030 and 2.3 Mt CO_2e in 2050 (Figure 4). The emissions increase under the Sustainable Pathway is dominated by an increase in GHG emissions in the livestock sector. The change assumed in diets i.e. an increase in the total average calorie intake per capita including an increase of the consumption of livestock products have induced an increase in emissions from domestic cattle production.

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



Rwanda's commitments under the UNFCCC (Table 1) forecast a doubling of total GHG emissions over the 2015-2030 period under BAU projections (from 5.33 Mt CO_2e/yr to 12.1 Mt CO_2e/yr). For the AFOLU sector, the NDC does not include emissions from forestry or land-use change, only emissions from agriculture which amount up to 2.94 Mt CO_2e for the baseline year 2015 and add up to 5.1 Mt CO_2e in 2030 under a BAU Scenario. The NDC also projects two different pathways, one with a 16% and a second one with a 38% reduction in total emissions from the BAU scenario by 2030; which would lead to a total emissions projection of 10.2 Mt CO_2e and 7.5 Mt CO_2e, respectively. Each sector was estimated to have different mitigation potentials. In the pathway with 38% reduction in total emissions, the agriculture sector's mitigation potential accounted for 44% in emission reductions.

In comparison, it seems that we underestimate the GHG emissions from agriculture in the Current Trends Pathway. For the 2030 projection, the agriculture BAU scenario in the NDC (5.1 Mt CO_2e) doubles the results of the FABLE Calculator (2.1 Mt CO_2e) under the Current Trends Pathway but are slightly higher than our results in the Sustainable Pathway, where emissions from agriculture increase to 4.5 Mt CO_2e.

Moreover, we need to compare our assumptions in the evolution of the livestock herd and productivity with the assumptions used for the NDC. In the NDC, most of the mitigation potential of the agriculture sector is estimated to come from soil conservation through terracing (20%) and rotation (24%), and compost production (28%) (Republic of Rwanda, 2020). Unfortunately, these measures are not yet represented in our FABLE Calculator.

Food Security

Current State

The "Triple Burden" of Malnutrition

Undernutrition	Micronutrient Deficiency	Overweight/ Obesity
45.2% of the population undernourished in 2007. This share has decreased since 2014 (FAO, 2016).	17% of women and 37% of children suffer from anemia in 2015, which can lead to maternal death (Compact2025, 2016; NISR, Ministry of Health, & ICF International, 2015).	16% of women, and 11% of adults and 7% of children were obese in 2010. These shares have increased since 2016 (UNICEF, 2019).
36.7 % of children under 5 stunted and 1.7% wasted in 2015 (Hjelm, 2016).	7% of women/the population are deficient in vitamin A (Rwanda National Nutrition Policy, 2007), which can notably lead to blindness (Rwanda National Nutrition Policy, 2007) and child mortality, and 26% are deficient in iodine, which can lead to developmental abnormalities (Rwanda National Nutrition Policy, 2007).	17% of women, and 20% of adults and 11% of children, were overweight in 2016. These shares have decreased since 2019 (UNICEF, 2019).

Disease Burden due to Dietary Risks
5.55% of deaths are attributable to dietary risks, or 3,783.19 deaths per year (per 100,000 people) (World Health Organization, 2017).
Dietary risks also lead to/cause 5 disability-adjusted life years (DALYs), or years of healthy life lost due to an inadequate diet (Institute for Health Metrics and Evaluation, 2010).
2.8% of the population suffers from diabetes and 14% from cardiovascular diseases, which can be due to/caused by dietary risks (Kabeza et al., 2019 and WHO, 2018).

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)	2,082 (1,950)	2,142 (2,021)	2,428 (2021)	2,247 (2057)	2,804 (2,057)
Fats (g) (recommended range	24 (46-69)	48 (48-71)	71 (54-81)	72 (50-75)	117 (62-93)
Proteins (g) (recommended range	55 (52-182)	60 (54-187)	66 (61-21)	66 (56-197)	78 (70-245)

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 6% higher in 2030 and 9% higher in 2050 (Table 4). The current average intake is mostly satisfied by roots (30%), cereals (22%), fruits and vegetables (17%), and pulses (17%). We assume that the consumption of animal products namely poultry and eggs will increase by 277% and 218%, respectively, between 2020 and 2050. The consumption of cereals and sugar will also increase while roots and red meats consumption will decrease by 58% and 33%, respectively.

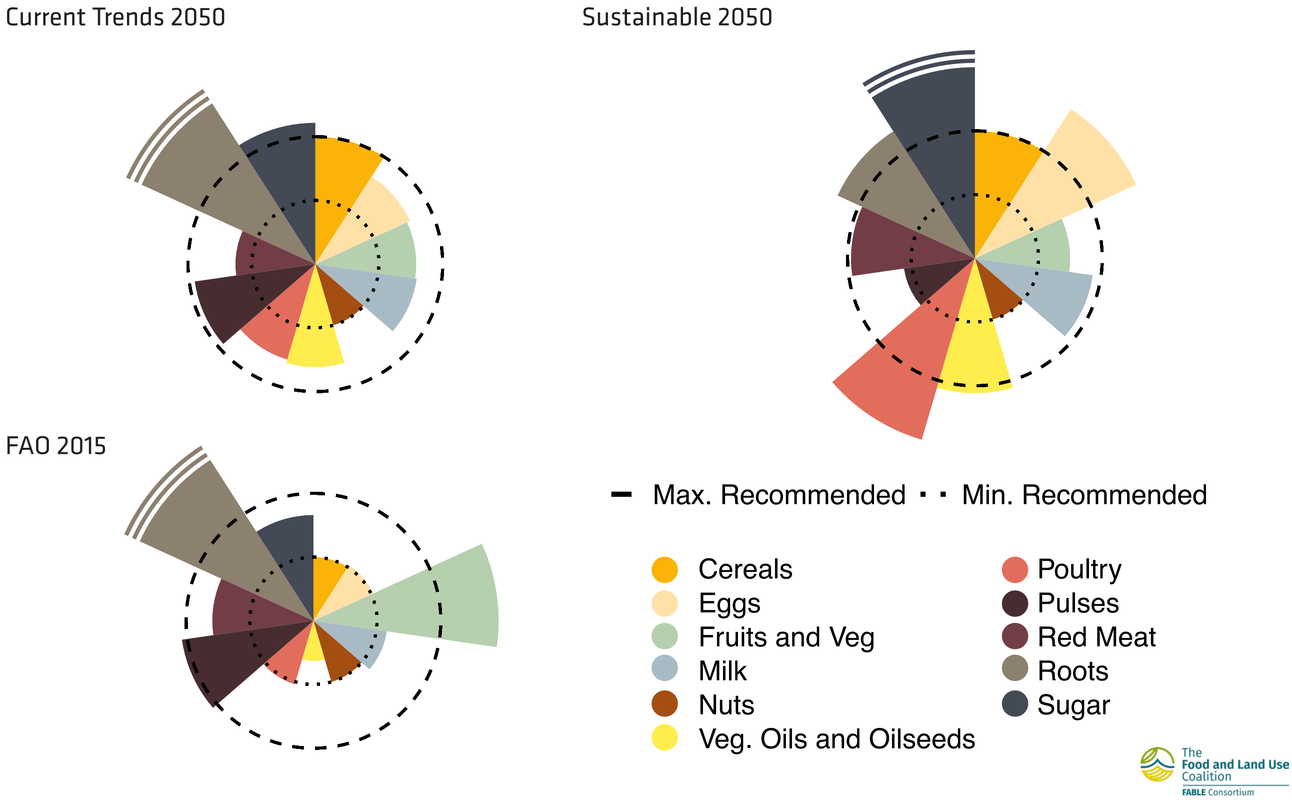
Compared to the EAT-*Lancet* recommendations (Willett et al., 2019), roots and cereals are over-consumed while nuts and red meats under-consumed in 2050 (Figure 6). Moreover, protein intake per capita is within range of the dietary reference intake (DRI) for all years, while in 2010 fat intake per capita (24 g fat per capita per day) is inferior to the range of the DRI (46-69 grams) but comes within range by 2030 and 2050. This can be explained by the increase in the consumption of poultry (277%) and eggs (218%) between 2020 and 2050 (Figure 6).

Under the Sustainable Pathway, we assume that diets will transition towards a diet higher in meat, milk, sugar, and fat. We assume that roots, pulses and fruits and vegetables oils are over-consumed whereas the remained food categories are inferior to the average recommended except red meats. With these assumptions, the ratio of the computed average intake over the MDER increases to 20% in 2030 and 36% in 2050 under the Sustainable Pathway.

Compared to the EAT-Lancet recommendations, only the consumption of eggs, poultry, roots and sugar remains outside of the recommended range; and the consumption of animal fat, cereals, fish, fruit and vegetables, milk, nuts, oilseeds and vegetable oils, pulses and red meat being now within the recommended range in 2050 (Figure 6). However, fat intake per capita continues to be outside of the recommended range throughout the entire period, while protein intake per capita does fall within recommended range except for 2050, showing little improvement compared to the Current Trends Pathway.

Rwanda intends to mainstream agro-ecology techniques using spatial plant stacking as in agro-forestry, kitchen gardens, nutrient recycling, and water conservation in its current agriculture intensification program and other natural resource-based livelihood programs. The total households involved in agriculture production are expected to be implementing agro-forestry sustainable food production by 2030 (Republic of Rwanda, 2015).

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 sugar and roots indicate that the average kilocalorie consumption of these food categories is significantly higher than the maximum recommended.

Water

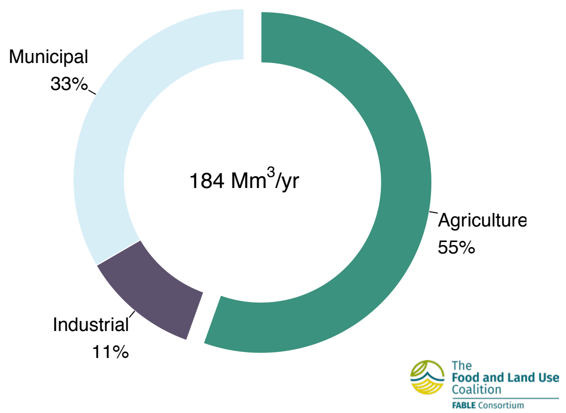
Current State

Rwanda is characterized by high altitude ranging between 915m and 4,486m – it is also known as the *'country of a thousand hills'* – with a tropical temperate climate. The average annual temperature ranges between 16°C and 20°C, with 1,156 mm average annual precipitation that mostly occurs over the period of March-May. The agricultural sector represented 55% of total water withdrawals in 2000 (Figure 7; FAO, 2017). Moreover in 2007, 0.7% of agricultural land was equipped for irrigation, representing 5.8% of the estimated-irrigation potential (FAO, 2017). The most important irrigated crop is rice which accounts for 46% of total harvested irrigated area.

Pathways and Results

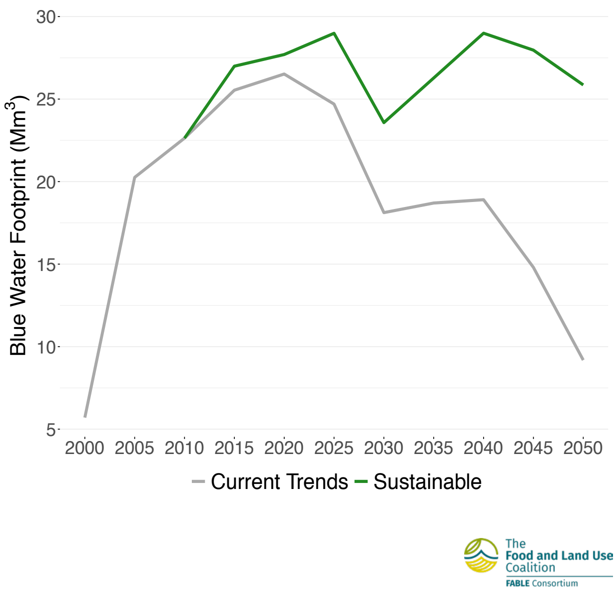
Under the Current Trends Pathway, annual blue water use increases between 2000-2015 (from 5.7 Mm^3/yr to 25.5 Mm^3/yr), before reaching 18 Mm^3/yr and 9.2 Mm3/yr in 2030 and 2050, respectively (Figure 8), with rice, sweet potato, and other vegetables accounting for 59%, 6%, and 34% of computed blue water use for agriculture by 2050[4]. In contrast, under the Sustainable Pathway, blue water footprint in agriculture reaches 23.5 Mm^3 in 2030 and 25.8 Mm^3 in 2050.

Figure 7 | Water withdrawals by sector in 2000-2005



Source. Adapted from AQUASTAT Database (FAO, 2017) with data from 2000 (agriculture water withdrawals) and 2005 (municipal and industrial water data)

Figure 8 | Evolution of blue 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

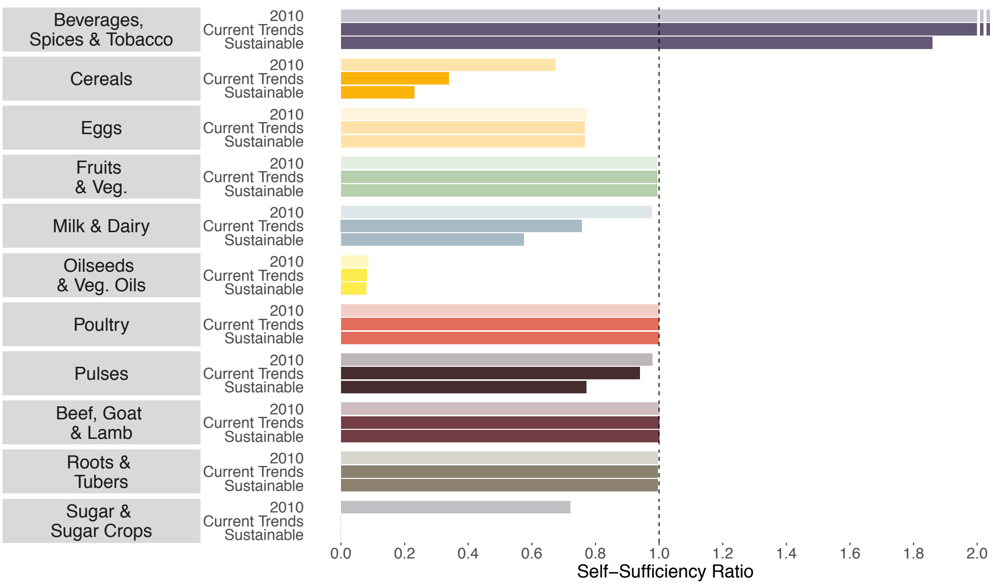
The COVID-19 crisis exposes the fragility of food and land-use systems by bringing to the fore vulnerabilities in international supply chains and national production systems. Here we examine two indicators to gauge Rwanda's resilience to agricultural-trade and supply disruptions across pathways: the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

In 2010, Rwanda appeared to be self-sufficient mostly in livestock products including poultry meat, beef, goat lamb, and fruits and vegetables, roots and tubers. It is also self-sufficient in beverages, spices and tabacco, which will be exported; and an importer of other remaining products for both Current Trends and Sustainable Pathways.

Under the Current Trends Pathway, we project that Rwanda would be self-sufficient in beverages, spices and tobacco, poultry meat, beef, goat lamb, fruits and vegetables, and roots and tubers in 2050, with self-sufficiency by product group remaining stable for the majority of products from 2010 – 2050 (Figure 9). The product groups where the country depends the most on imports to satisfy internal consumption are cereals, eggs, milk and dairy, oilseeds and vegetables, pulses, sugar and sugar crops, and this dependency will increase until 2050. In contrast, under the Sustainable Pathway, Rwanda remains self-sufficient in beverages, spices and tobacco, poultry meat, beef, goat lamb and for fruits and vegetables and roots and tubers, but would not be self-sufficient in cereals, eggs, milk and daily, oilseeds and vegetable oils, pulses, sugar and sugar crops by 2050, representing lower self-sufficiency. This is explained by changes in volume of productivity and change 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

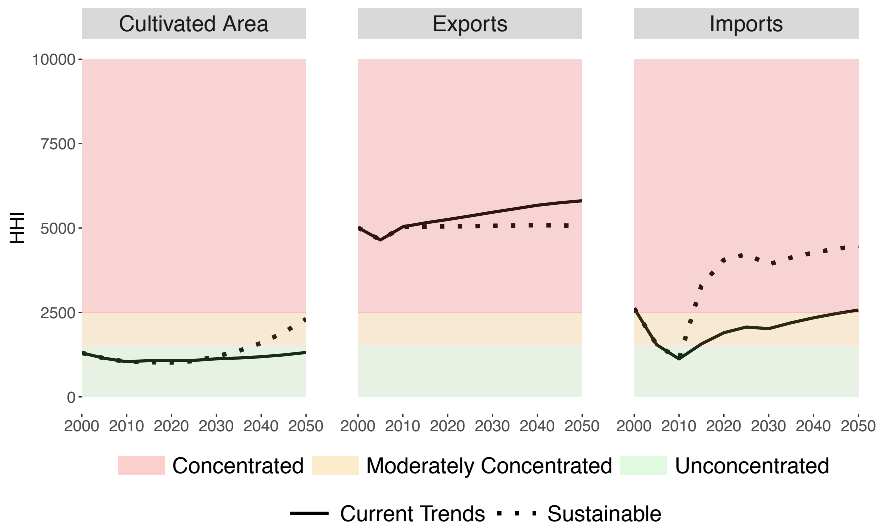
The Herfindahl-Hirschman Index (HHI) measures the degree of market competition using the number of firms and the market shares of each firm in a given market. We apply this index to measure the diversity/concentration of:

- **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, moderate concentration between 1,500 and 2,500, and high concentration above 2,500.

According to the HHI, the planted crop area in 2010 is unconcentrated. While imports are not concentrated, exports are concentrated. Under the Current Trends Pathway, we project high concentration of crop exports and imports and low concentration in the range of crops planted in 2050, trends which increase over the period 2010 - 2050. This indicates low levels of diversity across the national production system and imports and exports. In contrast, under the Sustainable Pathway, we project high concentration of crop exports and imports, and medium concentration in the range of crops planted in 2050, indicating moderate levels of diversity across the national production system and imports and exports (Figure 10). This is explained by changes in the types of crops planted and political economy considerations.

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

Rwanda is fighting to become a developed, climate-resilient, low-carbon economy by 2050 (Parker Helen, 2015). Under these Pathways, we assume that moving towards more sustainability should focus first and foremost on increasing the quality of diets for Rwanda's growing population. According to our results, this may lead to an unwanted tradeoff in terms of GHG emissions from AFOLU, which increase by 335% by 2050 between our Current Trends and Sustainable Pathways. This tradeoff may also be explained by the absence of afforestation, such as those suggested by the Bonn Challenge (Rwanda has pledged 2 Mha by 2030). We do not consider afforestation in the FABLE Calculator for Rwanda as afforestation could cause both a decrease in available calories and overall agricultural production due to the reduction of croplands and pasture.

Moreover, we do not change the extent of protected areas in either the Current Trends or Sustainable Pathways due to land shortages and an increasing population that depends on a small area of land. Instead, we recommend stronger measures to ensure the effectiveness of existing protected areas and the integration of biodiversity into national development policies and programs. Finally, we also assume that the consumption of animal products and, in particular, poultry and eggs will increase by 277% and 218%, respectively, between 2020 and 2050 due to the increase in pasture area, though cropland will continue to decrease due to pressure from population growth. While we find that livestock productivity will increase, livestock production will remain the largest source of emissions from AFOLU, making its proper management critical.

Though our assumptions do not respond to the objective of reducing GHG emissions, these tradeoffs and changes show that the adoption of an integrated approach to planning and sustainable land use management should be considered. It is important to note that we were unable to include agroforestry in this analysis due to the limitations of our model, though agroforestry is a common agricultural practice in Rwanda. This may influence our results and will be addressed in future analyses.

Moreover, Rwanda has proposed various actions and goals to support forests to mitigate GHG emissions as part of its NDC. These actions and goals include the deployment of improved forest management for degraded forest resources without converting additional land, as well as the use of mixed-species approaches (agroforestry) that contribute significantly to achieving mitigation objectives and adaptation benefits of ecosystem resilience and biodiversity conservation (Republic of Rwanda, 2015). Furthermore, Rwanda's Green Growth and Climate Resilience Strategy, Clean Development Mechanism (CDM), and Nationally Appropriate Mitigation Actions (NAMAs) are also important policies for achieving important climate goals. In the future, we will seek to better capture these policies in our analysis and will explore with stakeholders how to address them while still balancing the need to ensure food security and better nutrition. One viable pathway is climate-smart agriculture, which aims to achieve the triple win of improving food security and climate change adaptation, while contributing to mitigation, if possible.

Additional policies and programs to improve land use are already being implemented in Rwanda. These include measures to modernize Rwanda's agriculture sector. The Crop Intensification Programme (CIP) is the main policy adopted by the Rwandan government to bring about agricultural modernization. It has led to encouraging results in terms of productivity for staple crops (Cioffo et al., 2016). This program could be interlinked with government efforts to store and manage production to support domestic food security. Additional measures could help Rwanda raise the level of ambition of its objectives for sustainable land-use and food systems: strengthening its adaptive capacity to manage and mitigate the impact of disasters, including insurance and building storage at the national and household level; adopting technologies for the efficient use of irrigation water and fertilizer; promoting organic farming and conservation agriculture; advancing food processing technologies; and promoting farmer education focused on developing adaptive capacities and the rapid uptake of new technologies, as well as family planning.

Such measures may help address some of the several challenges of Rwanda's agricultural sector, which faces increasing environmental degradation that results in declining productivity. This problem will likely be further aggravated by the growing population pressure. Moreover, over the near term, due to COVID-19, the unemployment rate is likely to rise. This will further increase the pressure on land without incorporating farm inputs and lead to a decrease in yields, causing food shortages, and increases in poverty and malnutrition rates. In addition, COVID-19 had a negative impact on certain links along the agricultural value chain. Some products, including livestock products such as meat, milk, and eggs, and horticulture products such as vegetables, fruits, and roses, have suffered from limitations to domestic markets mainly due to the lockdown, and the temporary closure of hotels and restaurants. The goods meant for exports have also faced challenges linked to a decreasing market niche. Thus, the government has deployed additional efforts to ensure that all potential lands are cultivated, and that the production yield improves at the end of the season. For instance, in the Eastern Savanna region, the government has provided farmers with mechanization facilities to increase the cropped land as well as irrigation solutions for the upcoming dry season.

All this may impact the government's goal to reduce Rwanda's poverty rate to 20% by 2020 (Republic of Rwanda, 2017). Analysis of poverty trends by the National Institute of Statistics of Rwanda (2016) has shown that 39.1% of the population still lives in poverty, including 16.3% who live in extreme poverty. This trend will be aggravated due to COVID-19, which will have a large impact on food accessibility, given the low cash flow induced by the high rate of unemployment in the mid-term. Therefore, measures on how land can be used sustainably must be urgently taken into consideration. Otherwise, the processes of land fragmentation and soil degradation will accelerate. To reduce the pressure on the land, the government should design and implement policies to further develop the non-farm economy. Education and capacity building programs that support self-employment and entrepreneurship could help achieve this. Lastly, addressing the weaknesses in the agri-food value chain such as food distribution will also be essential to mitigate the impacts of COVID-19 on food security.

Annex 1. Underlying assumptions and justification for each pathway

POPULATION Population projection (million inhabitants)	
Current Trends Pathway	**Sustainable Pathway**
The population is expected to reach 22 million by 2050. Based on the projections that the population will more than double from 11 million today to 22 million by 2050, due to their growing rate of 2.8% per year. Based on Republic of Rwanda (2011). (SSP2 scenario selected)	The population is expected to reach 20 million by 2050. The population growth rate is estimated at 2.37% for 2013 and it is estimated to decrease to 1.89% in 2032. Based on National Institute of Statistics of Rwanda, and Rwanda's Ministry of Finance and Economic Planning (2012). (SSP2 scenario selected)

LAND Constraints on agricultural expansion	
Current Trends Pathway	**Sustainable Pathway**
We assume that there will be no constraint on the expansion of the agricultural land outside beyond existing protected areas and under the total land boundary. Based on land shortage, about 30% of the households cultivate less than 0.2 ha, accounting for about 5% of total arable land, while about 25% cultivate more than 0.7 ha, accounting for 65% of the national farmland. 15% of rural households farm less than 0.1ha, many of which are female-headed households who cultivate 1.32% of national cultivable land. Based on Michigan State University (2016) and Rwanda's Ministry of Agriculture and Natural Resources (2018).	We assume that deforestation will be halted beyond 2030. Based on readiness proposal prepared by Rwanda to Reduce Emissions from Deforestation and Forest Degradation (REDD+) which goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. Based on Rwanda's Ministry of Natural Resources (2017).
LAND Afforestation or reforestation target (1000 ha)	
We do not expect afforestation/reforestation. Based on the Ministry's report noting that the role of forest is complemented by Agroforestry. Based on Rwanda's Ministry of Lands and Forestry (2018). (No Afforestation scenario selected)	Same as Current Trends

BIODIVERSITY Protected areas (1000 ha or % of total land)	
Current Trends Pathway	**Sustainable Pathway**
Protected areas remain stable: by 2050 they represent 9% (0.23Mha) of total land. Based on Rwanda's Ministry of Natural Resources (2017).	Same as Current Trends

Current Trends Pathway	Sustainable Pathway
PRODUCTION Crop productivity for the key crops in the country (in t/ha)	
By 2050, crop productivity reaches: • 2.4 tons per ha for beans. • 10.2 tons per ha for rice. • 6.8 tons per ha for wheat. The above results are in line with the national targets of increasing crop productivity through an intensification program. Based on Rwanda's Ministry of Agriculture and Animal Resources (2012).	By 2050, crop productivity reaches: • 2.4 tons per ha for beans. • 10.7 tons per ha for rice. • 6.0 tons per ha for wheat. The above results are in line with the national targets of increasing crop productivity through an intensification program. Based on Rwanda's Ministry of Agriculture and Animal Resources (2012).
PRODUCTION Livestock productivity for the key livestock products in the country (in t/head of animal unit)	
By 2050, livestock productivity reaches: • 2.4 tons per head for chicken. • 14.2 tons per head for eggs. • 1.9 tons per head for milk. Based on the International Livestock Research Institute (2017), these results are in accordance with national targets for increasing productivity and total production in livestock value chains for cow dairy, red meat-milk, poultry, and pork based on using better genetics, feed, and the adoption of health services, among others.	Same as Current Trends
PRODUCTION Pasture stocking rate (in number of animal heads or animal units/ha pasture)	
By 2050, the average ruminant livestock stocking density is 2.35 TLU/ha per ha. Based on FABLE (2019), there is no data on national average livestock stocking densities to compare this value with.	Same as Current Trends
PRODUCTION Post-harvest losses	
By 2050, the share of production and imports lost during storage and transportation is 25% for corn, 10% for plantain and 4% other cereals. The above values are not in line with Rwanda's targets aiming to provide 100% farmers with access to services for post-harvest treatment and storage of food crops, and reduce post-harvest losses to at least 1% by 2030 from 10.4%, 27.4% and 8.3% in 2014 for maize, beans and rice respectively (Republic of Rwanda, 2015).	Same as Current Trends

TRADE Share of consumption which is imported for key imported products (%)	
Current Trends Pathway	**Sustainable Pathway**
By 2050 the share of total consumption which is imported is: • 69% for wheat. • 124% for raw sugar. • 81% for rice. Rwanda's Ministry of Trade and Industry (2010) reported that the country's main commodity imports are animal, vegetable fats and oils, wheat, sugar, maize, rice, and palm oil. Thus, there is an increase in imports for the above-mentioned commodities.	Same as Current Trends.
TRADE Evolution of exports for key exported products (1000 tons)	
By 2050, the volume of exports is: • 33 tons by 2050 for tea • 26 tons by 2050 for coffee Based on Ministry of Agriculture and Animal Husbandry (2008) and the Ministry of Agriculture and Animal Resources (2008), the government prioritizes the progress in the coffee and tea sectors by increasing the quantity and the quality of tea and fully and semi-washed coffee exported. (For Scenario: E3 where exports are multiplied by 1.5 by 2050)	By 2050, the volume of exports is: • 66 tons by 2050 for tea. • 52 tons by 2050 for coffee. Based on the Ministry of Agriculture and Animal Resources (2018), there is expected to be a significant increase in fertilizer application, increase in the land area covered by coffee and tea, the introduction of drought and disease resisting varieties, and an increase of mulched coffee up to 80%. (*For Scenario: E1 where exports are multiplied by 3 by 2050*)

FOOD Average dietary composition (daily kcal per commodity group or % of intake per commodity group)	
Current Trends Pathway	**Sustainable Pathway**
By 2030, the average daily calorie consumption per capita is 2,171 kcal and is: • 454.8 kcal for roots • 536.4 kcal for cereals • 286.2 kcal for fruits and vegetables • 251 kcal for oilseeds and vegetables oils • 94 kcal for milk • 17 kcal for red meat Based on FABLE Calculator (2020). (*National Health Diet scenario selected*)	By 2030, the average daily calorie consumption per capita is 2,548 kcal and is: • 379.9 kcal for roots • 605.6 kcal for cereals • 278.02 kcal for fruits and vegetables • 360 kcal for oilseeds and vegetables oils • 135 kcal for milk • 34 kcal for med meat Based on FABLE Calculator (2020). (*For Scenario: Fat Diet scenario selected*)
FOOD Share of food consumption which is wasted at household level (%)	
By 2030, the share of final household consumption which is wasted at the household level is 5%. Based on FABLE (2019), there is very little research on food waste in Rwanda, thus there is no data to compare this value with.	Same as Current Trends

BIOFUELS Targets on biofuel and/or other bioenergy use

Current Trends Pathway	Sustainable Pathway
There is no data available for Rwanda.	There is no data available for Rwanda.

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 2. 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), Needle leaved tree cover (70,71,72,80,82,82), Mosaic trees and shrub >50% - herbaceous <50% (100), Tree cover flooded water (160,170)
Grassland	Mosaic herbaceous >50% - trees and shrubs <50% (110), Grassland (130)
Other land	Shrubland (120,121,122), Lichens and mosses (140), Sparse vegetation (150,151,152,153), Shrub or herbaceous flooded (180)
Bare areas	Bare areas (200,201,202)
Snow and ice	Snow and ice (220)
Urban	Urban (190)
Water	Water (210)

Units

°C – degree Celsius

% – percentage

/yr – per year

cap – per capita

CO_2 – carbon dioxide

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

g – gram

GHG – greenhouse gas

Gt – gigatons

ha – hectare

kcal – kilocalories

kg – kilogram

kha – thousand hectares

km^2 – square kilometer

km^3 – cubic kilometers

kt – thousand tons

m – meter

Mha – million hectares

Mm^3 – million cubic meters

Mt – million tons

t – ton

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

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

t/TLU, kg/TLU, t/head, kg/head- ton per TLU, kilogram per TLU, ton 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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