Uganda CCDR Note

Mapping land use potential and future land use under a business-as-usual and aspirational economic scenario for Uganda

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1 INTRODUCTION

This report forms part of a note that will contribute to Uganda's Country Climate and Development Report (CCDR). The focus of the CCDR for Uganda is to capture the interplay between the country's development goals and climate change and to ensure that World Bank-supported engagements are aligned with the Paris Agreement. The CCDR will include an analysis of how Uganda's development goals can be achieved in the context of adapting to climate change and of the opportunities created by the global trend towards decarbonization.

The modeling conducted in this report generates the change in land use and land cover between 202X and 2050 to be used in the climate impact channel analysis for two economy futures considered in the CCDR. The two economy futures are:

- **Business-as-Usual (BAU):** Continuation of historical trends with limited intervention, emphasizing economic growth along current trajectories.
- **Aspirational (ASP):** Reflects Uganda's the Third National Development Plan (NDPIII; Republic of Uganda 2020), the Vision2040 (Government of Uganda 2013), prioritizing transformational development goals and climate resilience.

These scenarios are characterized by specific targets for the Gross Domestic Product (GDP) and Value Added (VAD) by the agricultural, industry, and services sectors in 2050, as outlined in Table 1.

The aim of this analysis was to project LULC changes for 2030, 2040, and 2050, under the two future economic scenarios, providing a spatially explicit foundation to evaluate the implications of climate change and policy decisions on land use. This required preparation of spatial layers to represent the baseline and the future scenarios, which were conceptualized in terms of the relative and absolute sizes of the sector, from 2021 to 2050 (Table 1), with a specific focus on the agricultural sector. The BAU Scenario was then reprojected to reflect interventions aimed at building resilience to climate shocks, resulting in a third set of spatial layers; BAU +Climate Action scenario. Assumptions about changes in LULC in this scenario were informed by interventions from Uganda's Nationally Determined Contribution (NDC; Uganda Ministry of Water and Environment 2022).

This analysis incorporated two key LULC aspects: (A) determining the areas available for specific land use and (B) determining land use under future scenarios. This involved a series of three tasks, as follows:

1. Map land use suitability for agriculture, forestry and livestock;
2. Project LULC spatial layers for the BAU and ASP economic scenarios to 2030, 2040, and 2050, aligning the potential agricultural output of the generated LULC layers with the economic targets for each scenario in 2050 (Table 1); and
3. Adapt the BAU spatial layer to account for climate change adaptation and mitigation interventions, whilst maintaining the BAU agricultural economic target.

Table 1. Economic targets, including total Value and GDP contributions of different sectors under the scenarios analyzed for Uganda's CCDR. Projections provided by the World Bank.

		Agriculture		Industry		Services	
Scenario	**Year**	**Contribution to GDP**	**Value (US$ Billion)**	**Contribution to GDP**	**Value (US$ Billion)**	**Contribution to GDP**	**Value (US$ Billion)**
BAU	2021	23.4%	9.5	26.4%	10.7	43.6%	17.8
	2050	17%	39.8	29.4%	69.9	49.2%	118.1
ASP	2021	23.4%	9.5	26.4%	10.7	43.6%	43.6
	2050	10%	44.7	31%	134.9	58%	250.1

2 MAPPING LAND USE SUITABILITY

2.1 Overview

The aim of this task was to generate spatially explicit layers depicting the maximum potential area for various agricultural land uses, including crop cultivation, pasture, and forestry, under current conditions, to inform the generation of the land use maps under the different development scenarios.

Although global layers are available for crop suitability, such as the FAO's Global Agroecological Zones (GAEZ) model (Fischer et al. 2021), these data were not adequate for the current assessment. For example, the GAEZ suitability maps have a low resolution of 9x9 km, which does not adequately capture fine-grained variability in factors like topography. Additionally, these data are based on global modelling, they may not adequately capture more locally-specific determinants of suitability for a given crop species. Hence, a national-scale suitability modelling assessment was conducted in this study, incorporating local information and studies where possible.

The analysis was broadly guided by the FAO's land evaluation framework (FAO 2007). This approach estimates the degree of limitation on agricultural production arising from both environmental (for example climate and soil) and anthropogenic factors. It can be used to classify areas as suitable and unsuitable for a given land use, as well as to estimate the degree of suitability within the suitable zone (for example, highly suitable, marginally suitable etc.).

Given that suitability niches for agricultural plant species differ widely, environmental suitability was mapped separately for six key crop species and seven major plantation forestry species. Environmental suitability alone still overestimates the area available for agricultural land uses, as some areas are unlikely to ever be used for agriculture even if climatic conditions are highly suitable (for example, towns). Hence, the second component of the analysis involved masking out selected parts of the country as unsuitable for agricultural land uses based on existing LULC and protected area status.

2.2 Methods

2.2.1 Mapping of Environmental Suitability

To estimate environmental suitability, the assessment used various readily available GIS layers that typically have a significant influence over agricultural production. Given that this study involved a rapid national-scale assessment, the analysis was relatively simple and does not incorporate all the environmental factors that determine suitability. Nevertheless, an effort was made to compare modelled results to production statistics and maps from Uganda, and to improve the initial suitability outputs to better align with actual production data where possible.

Various data sources were used to obtain spatial input data for the suitability modelling. Baseline climate data (annual and monthly temperature and precipitation) were downloaded from WorldClim at the finest possible spatial resolution of 30 arcseconds, or around 1x1 km (Fick & Hijmans 2017). Soil property data at a 250 m resolution was obtained from the Africa SoilGrids database (Hengl et al. 2015). Elevation data were obtained from the 30 m Shuttle Radar Topography Mission (SRTM) global Digital Elevation Model (DEM). The SRTM DEM was also used to generate a slope map for Uganda at 30 m resolution.

A separate suitability layer was generated for each input variable (e.g. temperature, rainfall etc.), indicating the extent to which each factor influences suitability for each crop type, forestry species etc. These layers were then overlayed, and the final overall suitability estimate for a given species or land use was taken from the layer with the lowest suitability score across the factors considered, based on the logic that productivity would be constrained by the most limiting factor. For example, if a location had marginal rainfall suitability for a given crop but high suitability across other metrics, it would be given a marginal overall suitability ranking since rainfall was the limiting factor. Further detail on the factors and values used to estimate suitability for individual crop and plantation species, as well as livestock collectively, is given in the following sections.

MAPPING ENVIRONMENTAL SUITABILITY FOR CROPS

To map environmental suitability for crop cultivation, seven key crop species were selected. These included the three dominant food crops in Uganda in terms of annual production (banana, maize and cassava), along with four major cash crops (Arabica coffee, Robusta coffee, tea, and sugarcane). In addition to being selected for their importance, these crops were chosen because they cover a broad range of environmental niches, ranging from relatively widespread crops that can be grown across much of Uganda (such as maize and cassava) to more localized species that are mostly limited to the cooler highlands (such as Arabica coffee). The differing environmental preferences of the selected crops should ensure that when the suitability layers are considered collectively, they will encompass the majority of conditions over which crops can be grown in Uganda.

The environmental suitability modelled here was mostly inclusive of the environmental niches required for other crops not modelled here, but still grown in Uganda, such as beans, groundnut, millet, rice, sesame, sorghum, soybean, and sweet potato (Sys et al. 1993; FAO EcoCrop 2019). Potatoes, in particular, may have a lower rainfall requirement over their growing season than the modelled crops, but they are grown on a relatively small-scale, with only 7% of households cultivating them and very little of Uganda received that little rain (UBOS 2020).

Several data sources were used to estimate the factors affecting the suitability of each crop. The values provided by Sys *et al.* (1993) were used as a starting point, along with information from the FAO EcoCrop database. Both data sources are widely used across numerous crop suitability mapping studies. The EcoCrop database provides estimates for the optimal and absolute climatic, soil, and (in some cases) elevational bands in which various crops can be grown. The suitability ranking in Sys *et al.* (1993) was generally more detailed, including a more detailed selection of environmental variables affecting suitability for each crop as well as a breakdown of suitability classes into different levels as follows:

- Class S_1: Optimal. Land with minor or no significant limitations on production. This class can be further subdivided into a "super-optimal" class (S_0) to capture areas where there was virtually no limitation on production, as distinct from areas where there are minor limits on production.
- Class S_2: Suitable. Land where conditions impose moderate constraints on sustained use of the land for a given crop type. The overall advantage to be gained from use of the land for a given crop remains attractive, albeit significantly lower than would be expected from Class S_1 land.
- Class S_3: Marginal. Land where the limitations on sustained use of the area for a given crop type are severe enough that expenditure will only be marginally justified, due to the low level of expected production and/or the increased requirement of inputs.
- Class N_1 and N_2: Unsuitable. Severe limits on production such that the amount of inputs required to overcome these would be unjustified.

While Sys *et al.* (1993) and the EcoCrop database ostensibly provide information that can be used for all crops in this study, the estimates of suitable environmental conditions may not adequately reflect local crop varieties or environmental niches in Uganda, as was evident with certain crops in the analysis. Hence, an effort was made to supplement and adjust these initial suitability estimates with studies from Uganda and/or the broader East and Central African region as far as possible. The following local and regional studies were used to refine the suitability parameters for each crop: banana (Karamura et al. 1998; Wairegi et al. 2016; Wichern et al. 2019; Manners et al. 2021), cassava (Manners et al. 2021), Arabica coffee (UCDA 2019a; Wichern et al. 2019), Robusta coffee (Bukomeko et al. 2018; UCDA 2019b; Wichern et al. 2019; Kath et al. 2020; Davis et al. 2022), maize (Jaetzold et al. 2006; WFP 2018; Wichern et al. 2019), and sugarcane (Blume 1985; Sogoni et al. 2019; Ajala et al. 2021).

Similar input variables were used for mapping suitability of the perennial and long-maturing crops, which included all crops in the sample aside from maize. As these crops mature over the course of a whole year, the mean annual temperature and precipitation were used as input climatic variables, along with soil pH and slope. Additionally, elevation was included as a factor to map suitability for banana and the two coffee species, since these crops tend to be grown over a defined altitudinal range, as confirmed in various local studies (Karamura et al. 1998; UCDA 2019a, 2019b; Davis et al. 2022). The values used for the different suitability ranges are summarized in Table 2, including the breakdown of values across the disaggregated suitability classes (S_0, S_1 and S_2) within the broader "suitable" range.

For maize, a more detailed approach was used since it has a shorter growth period (around five months), making it inappropriate to use annual climate data, with mean growing season temperature and growing season rainfall used instead (Table 2). Further complexity was created by the fact that Uganda has varying growing seasons, with most but not all the country experiencing a bimodal rainfall pattern which allows for two crop growing seasons. To address

Table 2. Estimated suitability ranges for crops included in the assessment based on climatic, soil and topographic constraints (see accompanying text for data sources).

Crop	Constraint	Suitable			Marginal	Not suitable
		S_0	S_1	S_2	S_3	N
Banana	Mean annual temperature (°C)	24.7-28.1	23-24.7	17.5-23	12-17.5	<12
			28.1-30	29.8-34.4	34.4-39	>39
	Annual precipitation (mm)	1689-2815	1126-1689	868-1126	610-868	<610
			2815-3378	3378-4160	4160-4942	>4942
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	6-7	5.5-6	4.8-5.5	4-4.8	<4
			7–7.5	7.5-8	8-8.4	>8.4
	Elevation (m)	1100-2070			<1100	
					>2070	
Cassava	Mean annual temperature (°C)	26.2-28.6	25-26.2	20-25	15-20	<15
			28.6-29.8	29.8-34.4	34.4-39	>39
	Annual precipitation (mm)	996-1217	885-996	664-885	443-664	<443
			1217-1328	1328-3000	3000-4675	>4675
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	5.5-6.5	5.2-5.5	4.8-5.2	4.5-4.8	<4.5
			6.5-7	7-7.6	7.6-8.2	>8.2
Arabica coffee	Mean annual temperature (°C)	18-20	20-22	22-24	24-26	>26
			16-18	15-16	14-15	<14
	Annual precipitation (mm)	1400-1600	1600-1800	1800-2000	>2000	
			1200-1400	1000-1200	800-1000	<800
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	5.8-6.2	5.6-5.8	5.4-5.6	5.3-5.4	<5.2
			6.2-6.6	6.6-7.4	7.4-7.8	>7.8
	Elevation (m)	1200-2500			>2500	<1200
Robusta coffee	Mean annual temperature (°C)	21.5-23	20.5-21.5	19.5-20.5	18-19.5	<18
			23-25	25-28	28-30	>30
	Annual precipitation (mm)	1500-2000	1300-1500	1000-1300	900-1000	<900
			2000-2400	2400-3000	3000-4000	>4000
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	5.8-6.2	5.6-5.8	5.4-5.6	5.3-5.4	<5.2
			6.2-6.6	6.6-7.4	7.4-7.8	>7.8
	Elevation (m)	900-1500			600-900	<600
					1500-1650	>1650
Maize	Mean growing season temperature (°C)	22-26	18-22	16-18	14-16	<14
			26-32	32-35	35-40	>40
	Growing season precipitation (mm)	600-900	500-600	400-500	300-400	<300
			900-1200	1200-1600	1600-1800	>1800
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	6.2-7	5.8-6.2	5.5-5.8	5.2-5.5	<5.2
			7-7.8	7.8-8.2	8.2-8.5	>8.5
Sugarcane	Mean annual temperature (°C)	26-27	24-26	20-24	20-18	<18
			27-32	32-34	34-35	>35
	Annual precipitation (mm)	1450-1950	1200-1450	1000-1200	800-1000	<800
			1950-2200	2200-3600	3600-5000	>5000
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	6-7	5.5 -6	5-5.5	4.5-5	<4.5
			7-7.5	7.5-8	8-8.5	>8.5
Tea	Mean annual temperature (°C)	19-23	17-19	15-17	13-15	<13
			23-24	24-26	26-30	>30
	Annual precipitation (mm)	1550-1850	1400-1550	1200-1400	1000-1200	<1000
			1850-2000	2000-3500	3500-5000	>5000
	Slope (%)	0-4	4-8	8-16	16-30	>30
	Soil pH	4.8-5.2	4.5-4.8	3.8-4.5	3-3.8	<3
			5.2-5.5	5.5-5.8	5.8-6	<6

this, a similar approach was used to Wichern et al. (2019), who also undertook national-scale modelling of maize and other crops in Uganda. A five-month crop cycle was assumed for maize, with temperature and rainfall suitability calculated across a five-month growth window, while allowing for the growing season start month to vary across the country.

Following Wichern et al. (2019), it was assumed that the possible starting date for growing season one ranges between February and April and that the start of the second growing season ranges between July and September. Seasonal rainfall and temperature suitability were then calculated using each possible starting month across the two seasons. For example, growing season one suitability with a February start date was obtained by calculating total rainfall and mean temperature from February to June, and repeated for the other start dates (March to July etc.). The optimal starting month per season was then obtained by selecting the five-month window with the highest suitability score. In this way, the model selected the optimal maize cultivation window across the country, thus capturing the variation in growing season start dates across the country. This process was repeated to calculate suitability for the second growing season. The overall maize map was then generated by selecting the maximum suitability value across the two growing seasons. In this way, an area that was suitable for maize in only one of the growing seasons would still be mapped as suitable overall.

MAPPING ENVIRONMENTAL SUITABILITY FOR LIVESTOCK

Environmental constraints on livestock are less clearly defined than for crops. For example, cattle are tolerant of a broad range of conditions and are reared throughout Uganda, thus occupying a wide environmental niche compared to a more specialized crop like coffee. As a result, little of Uganda was unsuitable for livestock production from a climatic perspective. Rainfall suitability for livestock production was estimated from other studies in tropical Africa (Jahnke 1983; Lawrence et al. 2023). With a minimum mean annual rainfall of around 500 mm in its most arid parts, no portion of Uganda was too dry for livestock. Pasture productivity and carrying capacity generally increase with rainfall (Jahnke 1983; Seo & Mendelsohn 2007). However, the response to increasing rainfall becomes less pronounced from around 700 mm onwards, partly due to increased competition with woody plants (Jahnke 1983). An additional nuance was that even though pasture may be more productive in wetter conditions, this also increases the profitability of land for crops, which can reduce the likelihood of rearing livestock (Seo & Mendelsohn 2007), though this was more a question of land use optimization than inherent environmental suitability for livestock.

Due to moderate to high potential for fodder production, areas with a mean annual rainfall above 900 mm were considered highly suitable for livestock production (Table 3). Based on the estimated relative reduction in fodder production and carrying capacity (Jahnke 1983), areas with 500-900 mm of rainfall were considered moderately suitable for livestock, while areas with less than 500 mm were considered marginal in terms of rainfall suitability (these account for a negligible portion of Uganda).

Temperature was also considered for mapping livestock suitability. Although tolerant of a broad range of temperatures, livestock productivity is diminished by heat stress, which can become lethal during severe heatwaves (Hahn 1999; Nardone et al. 2006; Carabaño et al. 2014; Ekou 2014). At the other end of the scale, conditions that are too cold can negatively impact or kill newborn and baby livestock in particular (Hahn 1999), though such temperatures are only reached at the upper elevations of Uganda's highest mountains. To estimate the degree to which hot and cold conditions could impact livestock production, maps of mean temperature across for the hottest and coldest months were generated by overlaying monthly temperature data from WorldClim and extracting the highest and lowest values in each location. In this way, the month with the highest and lowest monthly temperature was automatically selected and able to vary across the country. This was considered preferable to using mean annual temperature, which was likely to underestimate the degree of thermal stress during particularly hot or cold months of the year. Based on the studies reviewed (Hahn 1999; Nardone et al. 2006; Carabaño et al. 2014; Ekou 2014), areas where the mean temperature of the warmest month was more than 25 °C and the mean temperature of the coldest month was less than 15 °C were considered to have the highest temperature suitability for livestock production (Table 3).

Slope suitability for livestock was derived from studies of livestock movement patterns in hilly terrain and recommendations for stocking rates across different slope classes (Mueggler 1965; Miller et al. 1984; Holechek 1988; Bailey 2005; Hennig et al. 2022). Livestock preferentially graze gentler slopes but can forage in steeper terrain where necessary in more mountainous areas. Slopes of less than 15% gradient were considered to place no limit on stocking rates and thus were classed as highly suitable. Slopes with 15-30% gradient were classed as moderately suitable, slopes of 30-60% as marginal and slopes of more than 60% as unsuitable (Table 3).

Another potential limiting factor to livestock production was the presence of zoonotic disease. Areas of low tsetse fly prevalence appear to align with Uganda's cattle corridor, a broad zone stretching diagonally from southwestern to northeastern Uganda. Despite control efforts, tsetse infestation continues to have a negative impact on livestock production in Uganda, with tsetse fly are present across over 70% of Uganda's land area (MAAIF, 2014). Given that livestock are produced across the country, including in the zone where tsetse fly are present, this was not considered to impose a strong enough constraint on production to render these areas as marginal or unsuitable based on tsetse fly presence alone.

Table 3. Estimated suitability ranges for livestock based on climatic, soil and topographic constraints (see accompanying text for data sources).

Constraint	Suitable		Marginal	Not Suitable
	S_1	S_2	S_3	N
Mean temperature of hottest month (°C)	<25	25-29	>29	-
Mean temperature of coldest month (°C)	>15	10-15	5-10	<5
Mean annual rainfall (mm)	>900	500-900	200-500	<200
Slope (%)	0-15	15-30	30-60	>60

MAPPING ENVIRONMENTAL SUITABILITY FOR PLANTATION TREES

Like livestock, plantation trees can generally be grown over a broader range of conditions than particular crop species. Due to limited information on optimal growing conditions, the study largely relied on EcoCrop estimates for modelling temperature, rainfall and soil suitability for the selected plantation species. As EcoCrop only provides information on the optimal and absolute conditions for the growth of each species, no further disaggregation of the "suitable" range was undertaken for plantation species. It was assumed that the "suitable" range was equivalent to the optimal range in EcoCrop, while conditions outside of the optimal range but within the absolute limits of each species were considered to be marginal.

Pine and eucalyptus (gum) trees are the dominant commercial forestry trees in Uganda, accounting for 70% and 30% of commercial plantation area, respectively (World Bank 2022).

Several species of pine and eucalyptus are grown, each with differing environmental preferences. Hence, separate suitability models were run for four species of pine (Pinus caribaea, P. patula, P. oocarpa and P. elliottii) and three eucalyptus species (Eucalyptus camaldulensis, E. grandis, E. urophylla), as these are some of the most widely grown plantation species in Uganda (World Bank 2022). The values used to estimate suitability for each species are summarized in Table 4. Since the plantation tree species can grow well on both flat and hilly terrain, estimates of slope suitability were largely based on the ease and cost of harvesting. Slopes ranging from 0-35% were thus considered suitable as this falls within the slope limit range for wheeled harvesting equipment (Längin et al. 2010). Slopes with 35-60% gradient were classed as marginal, as these require more specialised tracked harvesting equipment. Slopes with gradients more than 60% are generally not suitable for ground-based harvesting, requiring the use of aerial extraction methods such as helicopters (Längin et al. 2010). Due to the high expense of aerial extraction, gradients more than 60% were considered unsuitable for forestry.

2.2.2 Masking Unsuitable Land Cover and Protected Areas

The outputs from the first modelling step were a set of suitability layers for various crops, livestock and plantation species based on climate, soil and topography. To generate final estimates of the potential extent of the different land uses, unsuitable LULC types and protected areas had to be masked out. LULC data were obtained from Uganda's national LULC dataset for 2019 (NFA 2022), which was the latest available to the team, while protected area extents were obtained from the World Database on Protected Areas (UNEP-WCMC & IUCN 2022).

The LULC classes masked out of the suitability layers differed slightly across the different agricultural land uses. All the modelled land uses were excluded from open water and built-up land cover, as it is not feasible to convert these areas to other land uses. Additionally, existing plantations were masked out of the potential extent layers for crops and grazing land. While this may not always be the case, the general assumption was that these areas had undergone a significant investment to establish plantation trees and that they would thus likely be maintained as plantations in the future. Additionally, areas of remaining natural forest were excluded from the potential extent of grazing land. While these areas could potentially be cleared for pasture, the cost of doing so would be high. It was thus assumed that if natural forest was converted to agricultural land use, this would typically be to make way for crops or plantation forestry, since these land uses typically generate more revenue than livestock. Natural forest was thus excluded from the potential extent of grazing land, but not the potential extent for crops or plantation forestry.

For the protected area mask, certain adjustments were made to the WDPA layer. The WDPA includes international protection designations such as UNESCO World Heritage Sites and Ramsar Sites. However, these designations may have little practical impact in areas where they do not overlap with a national protected area category. In such cases, international protection designations were excluded from the protected area mask. Additionally, a decision was made two final sets of land use potential layers, with one set permitting agricultural expansion into forest reserves and the other not. The reason for this was that analysis of LULC and satellite imagery shows that many forest reserves in Uganda have been partially or wholly converted to agriculture (Gizachew et al. 2018; Turpie et al. 2023). Hence, completely excluding forest reserves from the agricultural land use potential layers was considered unrealistic in light of the present reality. The layers presented in this report thus do not exclude forest reserves.

Table 4. Estimated suitability ranges for plantation forestry species based on climatic, soil and topographic constraints. Data obtained from FAO Ecocrop database and (Längin et al. 2010).

Species	Constraint	Suitable	Marginal	Not suitable
Pinus caribaea	Mean annual temperature (°C)	22-34	16-22	<16
			34-40	>40
	Annual precipitation (mm)	2000-3000	800-2000	<800
			3000-3500	>3500
	Slope (%)	0 - 35	35-60	>60
	Soil pH	5-5.5	4.5-5	<4.5
			5.5-6.5	>6.5
Pinus patula	Mean annual temperature (°C)	18-29	10-18	<10
			29-33	>33
	Annual precipitation (mm)	1000-2000	750-1000	<750
			2000-3000	>3000
	Slope (%)	0 - 35	35-60	>60
	Soil pH	5.5-6.5	4.5-5.5	<4.5
			6.5-7.5	>7.5
Pinus oocarpa	Mean annual temperature (°C)	16-30	10-16	<10
			30-34	>34
	Annual precipitation (mm)	1000-1700	700-1000	<700
			1000-3000	>3000
	Slope (%)	0 - 35	35-60	>60
	Soil pH	5.5-6.5	4.5-5.5	<4.5
			6.5-7.5	>7.5
Pinus elliottii	Mean annual temperature (°C)	23-32	8-23	<8
			32-36	>36
	Annual precipitation (mm)	1000-2000	650-1000	<650
			2000-2500	>2500
	Slope (%)	0 - 35	35-60	>60
	Soil pH	4.5-5.5	4-4.5	<4
			5.5-6.5	>6.5
Eucalyptus camaldulensis	Mean annual temperature (°C)	12-28	7-12	<7
			28-40	>40
	Annual precipitation (mm)	600-1000	250-600	<250
			1000-2500	>2500
	Slope (%)	0 - 35	35-60	>60
	Soil pH	5-7	4.5-5	<4.5
			7-8	>8
Eucalyptus grandis	Mean annual temperature (°C)	24-35	7-24	<7
			35-40	>40
	Annual precipitation (mm)	1000-2500	700-1000	<700
			2500-4000	>4000
	Slope (%)	0 - 35	35-60	>60
	Soil pH	5.5-6.5	5-5.5	<5
			6.5-7.5	>7.5
Eucalyptus urophylla	Mean annual temperature (°C)	18-28	8-18	<8
			28-34	>34
	Annual precipitation (mm)	1300-2500	800-1300	<800
			2500-3500	>3500
	Slope (%)	0 - 35	35-60	>60
	Soil pH	5.5-6.5	4.5-5.5	<4.5
			6.5-7.5	>7.5

2.3 Results

The final land use potential maps classify the country into three classes of suitability including suitable, optimal, and super-optimal (S_2, S_1, and S_0), marginal (S_3), and unsuitable (N). The suitability maps for the seven crop species indicate that most of Uganda is suitable for cultivated crop growth in some form, particularly for widely grown species like maize and cassava (Figure 2.2 and Figure 2.1). Rainfall only becomes marginal in the driest parts of northeast Uganda along the border with Kenya and in the semiarid portion of southwest Uganda. Cold temperatures also become a limiting factor on the higher mountain slopes. However, most of these areas also fall within protected areas where cultivation is not permitted anyway. Aside from protected areas and waterbodies, the only parts of the country where conditions are unsuitable for cultivation of maize and cassava correspond with areas with steep slopes and/or highly acidic soils, such as in parts of the southwest Uganda. This aligns with similar modelling work by (Wichern et al. 2019), where virtually all of Uganda was estimated to have moderate to high suitability for maize and cassava.

Arabica coffee had the narrowest suitable area of the crops modelled (Figure 2.2). This reflects the preference of the species for wet, relatively cool and higher-lying areas, including the higher altitude and wetter portions of south and western Uganda, the northern shores of Lake Victoria and the lower slopes of Mount Elgon. In contrast, suitable conditions for Robusta coffee are more widespread, in line with the broader distribution of this species in Uganda (UCDA 2019b; Davis et al. 2022).

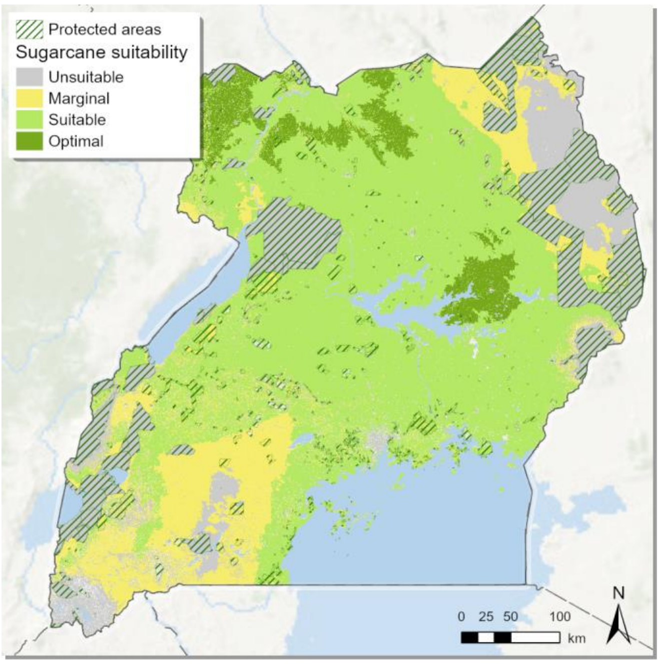

Figure 2.1. Suitability map for the cultivation of sugarcane.

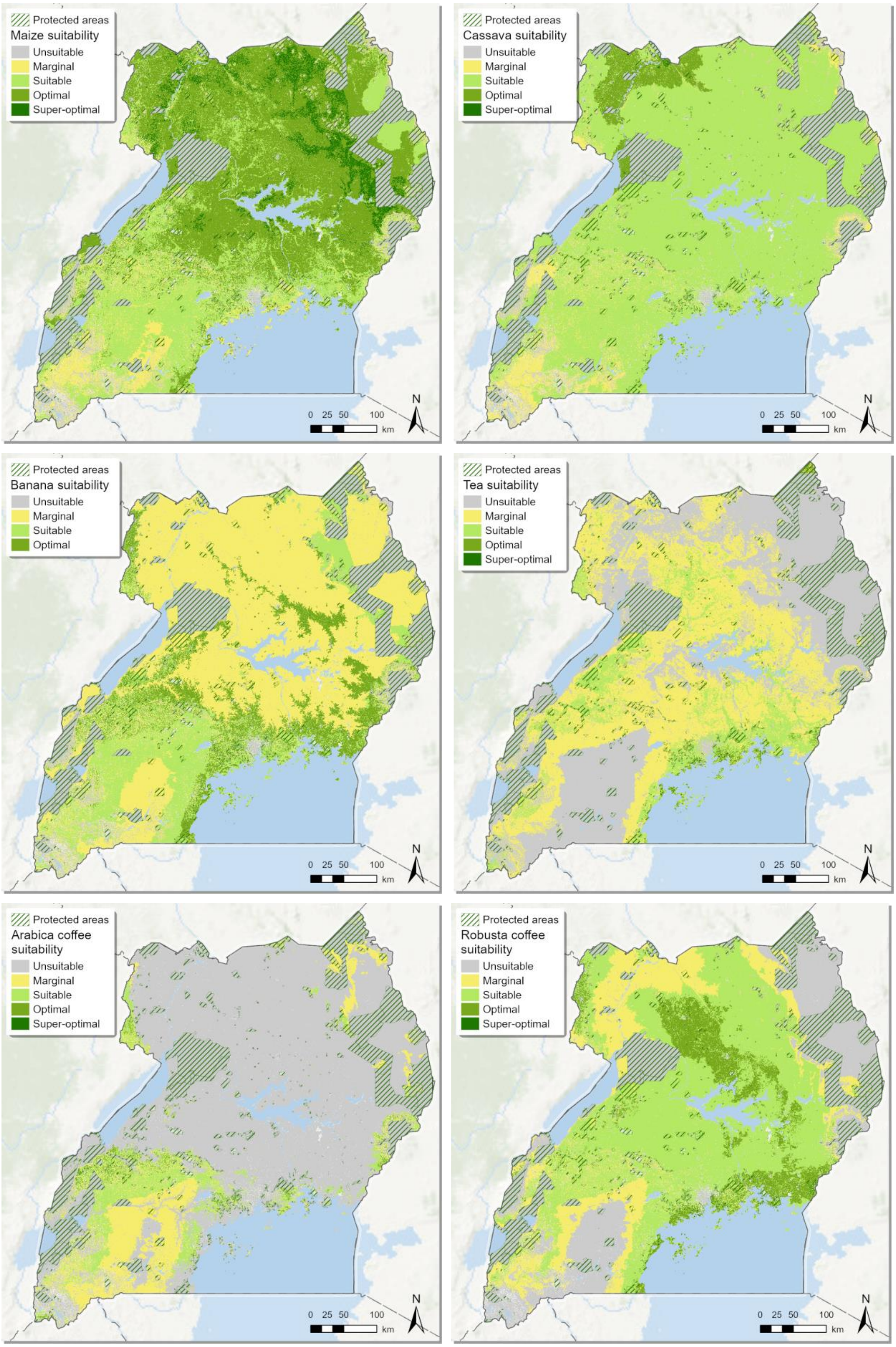

Figure 2.2. Suitability maps for cultivation of six crops included in the assessment.

The climate is suitable for livestock production over most of Uganda, limited only by cold conditions at high mountain elevations. As a result, very little of the country was mapped as unsuitable for livestock, limited to masked out LULC types (built-up areas, natural forests and plantations) as well as localized steep areas where slopes exceed 60% gradient (Figure 2.3). Elsewhere, small patches were classed as marginal, corresponding with moderately steep slopes (30-60% gradient) and/or cold areas at mid to high elevations where temperatures are less suitable for young livestock especially.

Separate suitability maps were generated for each of the four pine and three eucalyptus species included in the assessment. However, for ease of interpretability a single map is shown here, derived from taking the highest species suitability in each location across the seven species modelled (Figure 2.3). This assumes that tree choices are based on which species will be most appropriate for local conditions. The suitability map shows that conditions are either suitable or marginal for plantation species across virtually all of Uganda, with unsuitable areas limited to urban land cover, protected areas and very steep slopes (>60% gradient) where harvesting is impractical. Conditions were estimated to be marginal for plantation forestry over much of southwest and northeast Uganda, the northern shores of Lake Victoria and various patches of western Uganda.

For comparability purposes, the crops included in the assessment have been combined into two aggregated suitability layers for small-scale crops (bananas, cassava, coffee, and maize) and commercial crops (maize, tea, and sugarcane; Table 5). This was done by overlaying the layers and taking the maximum value in each location, thus showing areas that are suitable for at least one of the included small-scale crops and at least one of the included commercial crops. These maps are shown alongside the livestock and plantation suitability maps in Figure 2.3.

Table 5. Grouping of crop suitability to determine aggregate small-scale and commercial farmland LULC suitability.

LULC Type	**Crops**
Commercial farmland	Maize, sugarcane, tea
Small-scale farmland	Maize, bananas, Arabica coffee, Robusta coffee, cassava

The small-scale crop map shows that most of the country is suitable for growing at least of one of the five major crops considered. This aligns with the dominance of farmland in the LULC data, which covers over 50% of Uganda's land area, as well as similar crop suitability modelling work (Wichern et al. 2019). The suitable zone for the included commercial crops was somewhat narrower, with the dry northeast and southwest of the country having marginal to unsuitable conditions for coffee and sugarcane. However, the majority of Uganda was still suitable for these crops. Overall, the combination of maps in Figure 2.3 highlights that there was a high overlap in the suitable areas for crops, livestock, and forestry across the country.

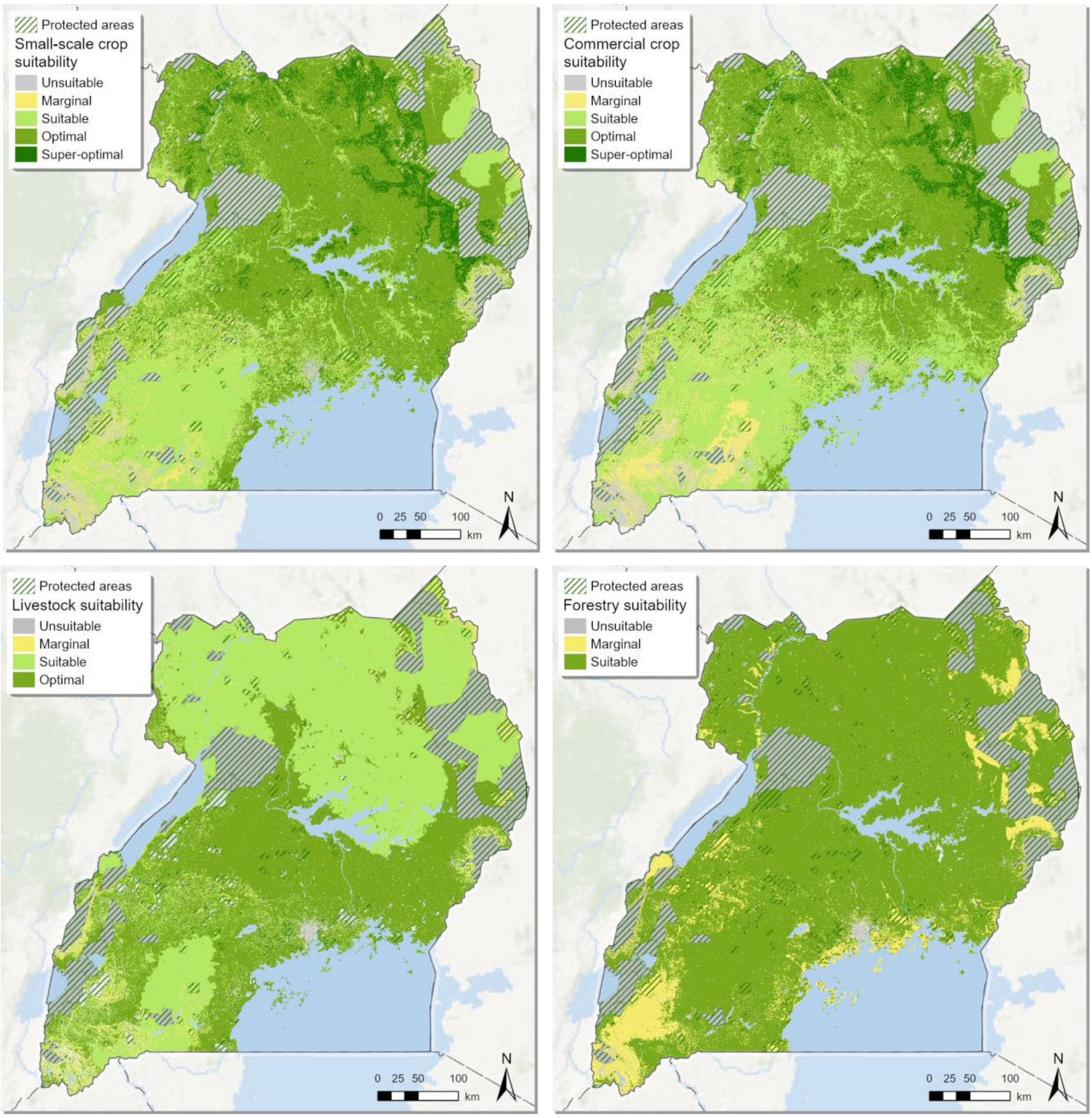

Figure 2.3. Comparison of suitability across small-scale crops, commercial crops, plantation forestry species, and livestock.

3 LAND COVER UNDER FUTURE SCENARIOS

3.1 Overview

The objective of this task was to project Uganda's LULC changes for 2030, 2040, and 2050, under two future economic scenarios, providing a spatially explicit foundation to evaluate the implications of climate change and policy decisions on land use. In addition to these scenarios, a third set of LULC datasets examines how mitigation and adaptation actions may influence land use outcomes, under these same economic scenarios. The assumptions made for each scenario were guided by three of Uganda's policy documents; namely, the Third National Development Plan (NDPIII; Republic of Uganda 2020), the Vision2040 (Government of Uganda 2013), and the Nationally Determined Contribution (NDC; Uganda Ministry of Water and Environment 2022).

The BAU Scenario assumes continuation of historical land use trends with minimal intervention, focusing primarily on economic growth driven by current trajectories. In contrast, the ASP Scenario incorporates proactive restoration efforts, increased agricultural productivity, and sustainable land management practices guided by Uganda's Vision2040 and the NDPIII. The Climate Action Scenarios included the climate change mitigation and adaptation actions required by the NDC.

The NDPIII is Uganda's comprehensive framework for achieving sustainable economic growth and social transformation with a five-year timeframe from 2020/21 to 2024/25. Its strategic objectives include enhancing value addition in key growth sectors, strengthening the private sector's capacity to drive economic growth and create jobs, expanding and improving the stock and quality of productive infrastructure, boosting the productivity and social well-being of the population, and reinforcing the state's role in guiding and facilitating development. Although the timeframe for these goals has passed, many of the targets have not been met yet and are still appropriate aspirations for Uganda.

Vision 2040 outlines Uganda's long-term development strategy aimed at transforming the country into an upper middle-income nation. It emphasizes sustainable economic development, infrastructure modernization, and human capital enhancement, while promoting sustainable management of natural resources. The updated NDC (2020–2030) represent Uganda's commitment to global climate goals under the Paris Agreement through both adaptation and mitigation, addressing the country's vulnerability to climate change while contributing to global efforts to limit greenhouse gas emissions.

Modelling future LULC areas under the various scenarios involved four steps. First, historical LULC trends were analyzed, using datasets from 1990 to 2017. These datasets provided insights into rates of change that were used to establish baseline projections. The second step projected the LULC areas for each scenario into 2030, 2040, and 2050, according to future scenario targets. In the third step, the agricultural output from the resulting LULC areas was calculated and compared to the target agricultural contribution to GDP under the BAU and ASP Scenario (Table 1). Projected LULC areas were then adjusted to align these two values. In the fourth step, the projected areas of the LULC layers were mapped spatially using a set of rules regarding priority order and limits.

3.2 Methods

3.2.1 Analysis of past land cover trends

Uganda's national LULC datasets for the years of 1990, 2005, 2010, 2015 and 2017 (NFA, 2022) were used to determine the historic changes in area of the different LULC types. The LULC types in the datasets are summarized in Table 6. The analysis focused on the human altered LULC types, specifically plantations, small-scale farmland, commercial farmland, and built-up areas.

Table 6. Ugandan land use/land cover type descriptions. Land cover class descriptions from Drichi (2002).

LULC type	**Description**
Plantations	Planted deciduous trees/broadleaves ("hardwood") and planted coniferous trees,
Well stocked THF	Tropical highland forest: tall multistorey trees, closed canopy cover – well stocked
Low stocked THF	Tropical highland forest: tall multistorey trees, closed canopy cover – stocks depleted
Woodland	Trees and shrubs (average height > 4m)
Bushland	Bush, thickets, scrub (average height < 4m)
Grassland	Rangelands, pastureland, open savanna; may include scattered trees shrubs, scrubs, and thickets.
Wetland	Wetland vegetation; swamp areas, papyrus, and other sedges
Small-scale farmland	Mixed farmland, small holdings in use or recently used, with or without trees
Commercial farmland	Uniform commercial farmland – mono-cropped, non-seasonal farmland usually without any trees for example tea and sugar estates
Built-up	Urban or rural built-up area
Impediment	Bare rock and soils

Although the 2019 LULC dataset was available, it was excluded from assessing historical trends. The higher resolution of 10 m, compared to 30 m in earlier datasets created inconsistencies in detecting smaller patches of land use types, such as plantations, and thus false patterns in LULC change. The LULC dataset from 2000 was also omitted from this assessment as many inconsistencies in the classification of certain areas were detected. For example, many areas classified as plantations or built-up in the 1990 dataset are absent in the 2000 dataset but present again in the proceeding years. Additionally, the area of commercial farmland appeared to be inconsistently classified in 2015 compared to other years. For example, large areas that were previously small-scale farmland in earlier years were classed as commercial farmland in 2015 but again classified as small-scale farmland in 2017. Often these areas do not appear to be notably different from the surrounding small-scale farmland. As such, the area of commercial farmland in 2015 was omitted from the data used to create the model to project farmland into the future.

3.2.2 BUSINESS-AS-USUAL SCENARIO

The BAU Scenario assumes that the LULC changes observed over the last 20 to 30 years (1990-2017) would continue at a similar rate over the next 30 years, resulting in the level of agricultural output defined for the scenario. This task therefore involved projecting land cover based on current rates and then adjusting the projection to ensure that the resulting land cover is aligned with the predicted macro-economic outputs in Table 1.

To project the historic trends into the 2030, 2040, and 2050, regression equations were fitted to the historic areas of four focal LULC types, namely built-up, commercial farmland, small-scale farmland, and plantation explored in the previous section. To use the 2019 LULC dataset as the baseline, these regression equations were adjusted to project the potential area of each LULC type forward from the areas covered in the 2019 LULC dataset and used to determine LULC areas for 2030, 2040 and 2050. After comparing the estimated agricultural GDP contribution of the 2050 land cover with the target for the BAU Scenario (US$ 39.8 billion), the area of farmland was refined through further conversion of small-scale farmland to commercial agriculture to better align with the target. The method for estimating the agricultural value of the land cover is described in section 4.

The spatial projection of the projected LULC changes was carried out using the 2019 LULC dataset as the baseline. The projection was undertaken using the Scenario Generator model from the InVEST® software (Version 3.14.1; Natural Capital Project, 2024). A series of twelve models was run in a stepwise process, each one emulating the growth of a single focal LULC type within a single year, one year at a time. The output from each model was used as the starting LULC for the next model. The focal LULCs were expanded sequentially, assuming built-up expansions would take preference, followed by commercial farmland, plantations, and then small-scale farmland. Only small-scale farmland and natural LULC types outside of protected areas were made available for conversion to the focal LULC types. In addition to the projected expansion, any area of small-scale farmland that was lost through conversion to one of the other focal LULC types, was reclaimed from natural areas during the expansion. To replicate organic growth, each LULC was made to expand from the borders of existing pre-existing patches.

The spatial expansion of each LULC type was subject to the limits of suitability of agriculture and forestry (see section 2), and the limits imposed by urban growth projected based on past trends. Expansion of small-scale farmland was limited to suitable, optimal, and super-optimal (S_2, S_1, S_0) growing conditions for at least one crop within maize, cassava, bananas, and Arabica and Robusta coffee. Similarly, potential expansion areas for commercial farmland were identified based on suitable, optimal, and super-optimal environmental conditions of maize, sugar, and tea. Plantations were limited to areas suitable for at least one of the four species of pine and three species of eucalyptus tree described in the previous chapter. This classification ensured a potential minimum yield of 60% for at least one crop or tree species in the new areas of farmland or plantation.

By categorizing crop suitability into two broader groups and assuming expansion patterns based on historical trends, this approach did not fully account for potential expansion driven by the productivity of the most valuable crops. However, by focusing on crops that are currently important and widely cultivated, the method reflected the likelihood that planting decisions are influenced by existing patterns rather than perfect optimization of value and productivity. As the suitability of the crops was mapped based on rainfall, the expansion of farmland was not limited by potential irrigation. The area of irrigated crops was assumed to expand proportionally to the expansion of farmland area between 2019 and 2050, All existing built-up land cover, open water, and protected areas were also excluded as potential areas for expansion of other land use types. Protected area extents were obtained from the World Database on Protected Areas (WDPA;UNEP-WCMC & IUCN 2022). The protected areas include 11 national parks and 11 wildlife reserves, four wildlife sanctuaries, and five community wildlife management areas (CWMAs). Since many forest reserves have been partially or completely converted to agriculture, they no longer effectively function as protected areas (Gizachew et al. 2018; Turpie et al. 2023) and were not excluded from suitable areas under the BAU Scenario. Areas of remaining natural forest were excluded from the potential extent of livestock. While these areas could potentially be cleared for pasture, the cost of doing so would be high.

In response to prolonged processing times and software limitations, the resolution (cell size) of the 2019 LULC dataset was converted from 10 m to 100 m. All generated future LULC datasets had a resolution of 100 m.

3.2.3 Aspirational Scenario

The targets set out for the ASP Scenario were guided by the goals outlined in Uganda's Vision2040, and its associated series of National Development Plans (NDPs), specifically the NDPIII, which has been subsequently updated by the NDPIV. The goals set out in these NDPs were used along with those of the NDC and the ASP economic targets to guide the assumptions of the various LULC area changes and agricultural sector productivity, as per Table 4. These all include the restoration and sustainable management of key ecosystems, including wetlands, forests, riparian zones, rangelands, and mountain areas, while addressing urbanization and agricultural development.

The NDPIII prioritized the development and implementation of wetland and forest management plans, including the demarcation and restoration of degraded wetlands. The targets included increasing wetland cover from 8.9% in 2020, to 9.57% in 2025 (NDPIII), and 10.2% by 2030 (NDPIV), while the NDC projected the NDPIII target to 12% by 2030. This study has used the 12% target. Based on the wetland cover in the baseline 2019 LULC dataset, this translates into 5.3% of the total land area.

Forest targets were to expand forest cover to 15% by 2025 and 15.5% by 2030 under NDP III and IV respectively, towards the eventual target of 24% of total land area by 2040 under Vision 2040. This was to be achieved through restoration and reforestation efforts to expand the cover of THF, plantations, and woodland. Forest expansion efforts also include establishing 200 000 ha of community woodlots, promoting rural and urban tree planting with indigenous species, and addressing invasive alien species with local community participation.

To model the forest area target, once the area needed for the expansion of plantations was accounted for, the remaining reforestation consisted of the conversion of brushland, grassland and small-scale farmland in the 2019 LULC dataset to tropical highland forest (THF). To represent the gradual progression of reforestation efforts, these natural reforested areas were represented as low stocked THF in 2030 and 2040 and then graduated to THF well stocked by 2050. Natural forest restoration was limited to historically deforested areas and was prioritized in WDPA protected areas and forest reserves. Deforested areas available for natural forest restoration were considered to be areas that fell within the historic distribution of forest ecosystems according to the potential natural vegetation map of Eastern Africa (van Breugel et al. 2015). Similarly, wetland restoration was limited to areas of bushland, grassland, and small-scale farmland within areas of historic wetland distribution (van Breugel et al. 2015).

Agricultural strategies focus on scaling up agricultural management as a climate-smart practice and increasing access to irrigation to reduce reliance on rainfed agriculture. Uganda's plans support the expansion of large- and small-scale irrigation schemes to enhance agricultural productivity. Improved agricultural productivity is promoted through technology improvements, such as better seeds and fertilizers, alongside reforms to agricultural extension services to support farmers. The resulting changes in crop productivity due to these interventions were accounted for in the valuation of the sectoral contribution to GDP. The area of commercial farmland was expanded to accommodate the new area of irrigated cropland and meet the target sectoral contribution to GDP under the ASP Scenario, US$44.7 billion. The area of small-scale farmland was not expanded, regardless of the loss to commercial farmland and ecosystem restoration.

With the growth in economic development under the ASP Scenario, the urban population was estimated to increase by 421% between 2021 and 2050, to 61.04 million people, in line with the World Banks' Development Indicator projections for a sample of middle-income countries (Uganda's CCDR in prep). This is higher than Uganda's BAU projection of 26.28 million people. This growth in urbanization was addressed through planned development and infrastructure improvements. The NDP emphasizes upgrading informal settlements, incentivizing low-income housing projects, and increasing access to affordable housing. Vision 2040 builds on these initiatives with strategies to manage urban sprawl through integrated planning, high-density settlements, and the establishment of Special Economic Zones (SEZs) to drive industrial and economic growth.

To emulate these targets, all built-up expansion was limited to areas within the ten SEZ and trade areas identified in the Vision 2040 (Figure 4**Error! Reference source not found.**). To reduce urban sprawl the density of people within bult-up areas was increased. Based on previous development plans, a target carrying capacity of ten thousand people/km^2 was ascribed to the built-up areas within the SEZs (Republic of Rwanda 2020). The population within the 2019 built-up footprint was determined using the constrained and UN adjusted WorldPop data for Uganda (Bondarenko et al. 2020), and adjusted to reflect the official urban population estimate (UBOS 2024). The area of built-up expansion was calculated considering the increase in urban population under the ASP Scenario and densification of urban areas. Using the new density targets within the SEZs the urban population was ascribed to the 2019 built-up footprint before expanding the built-up LULC within the SEZs to accommodate the remaining urban population.

With the same methods used for the BAU Scenario, the location of the projected LULC changes for the ASP Scenario was modelled from the baseline 2019 LULC dataset. First, the areas of wetland restoration and reforestation were modelled. The human-altered LULC types were then modelled in the same priority order as the BAU Scenario. Only small-scale farmland and natural LULC types outside of protected areas were made available for conversion to the human-altered LULC types. To replicate organic growth, each LULC was made to expand from the borders of existing pre-existing patches.

In line with the enhancement of agricultural practices under the ASP Scenario and the corresponding improvements in yield, the expansion of commercial farmland was limited to optimal, and super-optimal (S1, S0) growing conditions, ensuring a potential minimum yield of 85% for at least one crop in the expansion of farmland. Plantations were limited to areas suitable for at least one of the four species of pine and three species of eucalyptus tree described in the previous chapter. Once the projected areas for each LULC were determined in 2050 based on the assumptions, the LULC areas in 2030 and 2040 were calculated using regression equations.

If a target specified that a certain area of LULC must be achieved before 2050, based on the timeframe of Vision 2040 or the NDC, it was assumed to remain unchanged from that date until 2050. For example, the NDC aspires for the area of plantations to expand by 3000 ha by 2030, so this target is met by 2030 under the BAU+Climate Action Scenario and the area of plantations remains unchanged in 2040 and 2050.

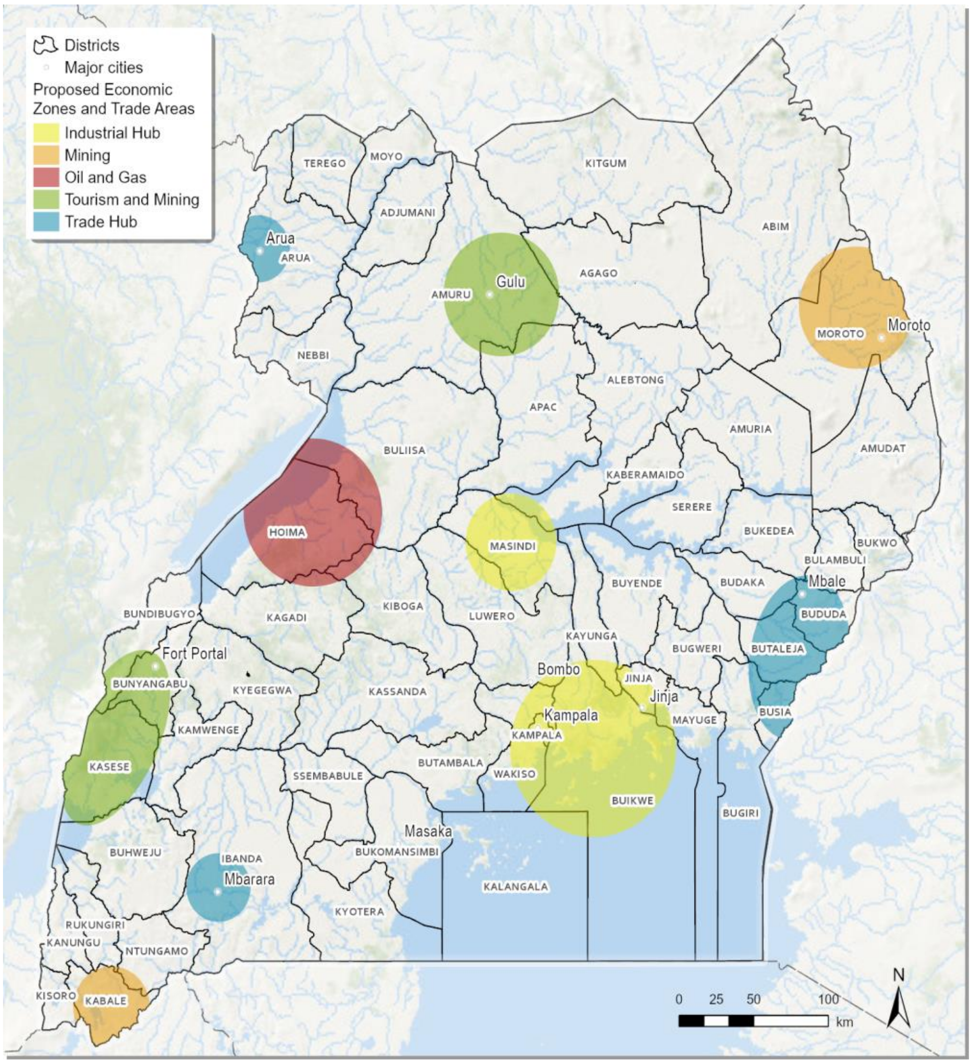

Figure 4. The Special economic zones (SEZ) and trade areas intended for economic development under Uganda's Vision 2040 agenda (Source: Uganda's Vision 2040)

3.2.4 CLIMATE ACTION SCENARIOS

A second set of future scenarios were intended to determine how climate change mitigation and adaptation actions might interact with Uganda's development goals under the two future economic scenarios; BAU + Climate Action and ASP + Climate Action. The mitigation and adaptation interventions, and resulting impact on LULC changes and agricultural productivity, under these scenarios were based on the commitments outlined in the NDC (Uganda Ministry of Water and Environment 2022; Table 7). These interventions are already incorporated in the Vision 2040 and NDP and so there was little to add to the ASP Scenario. For this reason, only The BAU + Climate Action scenario was mapped.

Table 7. Summary of the assumptions and projected changes to LULC area under three future scenarios derived from targets outlined in Uganda's NDP, Vision2040, and NDC.

Intervention focus	***BAU Scenario (2050)*** *Based on historic trends*	***BAU+ Climate action Scenario (by 2030)*** *Adapted from NDC*	***ASP Scenario (by 2040)*** *Adapted from NDPIII and V2040*
Wetland	- 66% decrease by 2050 - 1% land cover	- 33% increase in land cover (53k ha) - 12% land cover (4.9% on LULC) - No further loss	- 46% increase in land cover - 13% land cover (5.3% on LULC) - No further loss
Forest	- 12% decrease THF well stocked - 47% decrease THF low stocked - 47% decrease woodland - Total 8% land cover by woodland and forest	- No loss - Expand by 1.9 million ha - 21% land cover by forest, and woodland - Total of 24% land cover by forest, woodland, and plantations	- No loss - Expand by 2 million ha - 21.4% land cover by forest, and woodland - Total of 24% land cover by forest, woodland, and plantations
Agriculture	- 1000% increase in commercial farmland cover - 18% increase in small-scale in line with historic trends less the conversion to commercial cropland - Commercial farmland expansion to meet target VAD - Expansion prioritized in optimal growing conditions (S0-S2)	- Commercial farmland expansion to meet target VAD - Small-scale farmland change according to historic trends accounting for increases in crop productivity and loss to forest/wetland restoration - Expansion limited to optimal growing conditions (S0-S2) - Productivity increased due to improved climate smart seed	- Commercial farmland expansion to meet target VAD - Small-scale farmland loss to wetland/forest restoration and commercial cropland expansion - Expansion limited to super-optimal growing conditions (S0-S1) - Productivity increased due to improved climate smart seed and increased inputs
Plantations	- 479% increase - Expansion limited to suitable areas - 9% of land area	- 300k ha increase (91%) - Expansion prioritized in suitable areas - 3% of land area coverage - Total of 24% land cover by forest, woodland, and plantations	- 200k ha increase (61%) - Expansion prioritized in suitable areas - 2.6% of land area coverage - Total of 24% land cover by forest, woodland, and plantations
Irrigation	- Irrigation expansion proportional to farmland area expansion - 84 k ha under irrigation by 2050	- 190 k ha under irrigation by 2040	- 560k ha under irrigation by 2040
Built-up	- 57% increase in land area - Growth from all existing built-up	- Same as BAU	- Growth only within SEZs - Urban densification (10k people/km^2) - Built-up expansion according to urban population increase
Urban population	- 26.28 million people by 2050 (World Development Indicators prediction) - 104% increase in urban pop by 2050 - Average of 8.3 k people/ km^2	- Same as BAU	- 61.04 million people by 2050 ((based on sample of middle income countries in World Development Indicators) - 421% increase in urban pop by 2050 - 10k people/km^2 (in SEZ)

Uganda's NDC outlines a comprehensive plan to address climate change through both adaptation and mitigation measures, focusing on enhancing resilience and promoting sustainable development. The targets prioritize restoration and conservation of vital ecosystems, including wetlands and forests. Wetland coverage is set to increase from 9% in 2020 to12% by 2030, with 70,000 hectares targeted for restoration. Forest conservation efforts aim to rehabilitate 100 000 ha of forests and the target of 24% forest cover is also reported as an NDC goal. Accounting for the target area of plantations, the total land cover of natural forests (woodland and THF) would be 21%. This scenario also integrates riparian and montane ecosystem restoration to improve water resource management and biodiversity conservation, with 1550 hectares of riparian zones and 7500 ha of montane areas restored by 2030. These targets were absorbed by the forest and wetland LULC expansion targets, as all THF expansion fell within montane ecosystems and wetland expansion occurred mostly along river and waterbody edges.

Plantation development under the NDC plan includes expanding woodlots and managed plantations for fuelwood, pole, timber, and sawlog production. The NDC calls for an additional 300,000 hectares of area under planted forests by 2030. As with the BAU Scenario, all cropland and plantation expansion were limited to areas with optimal growing conditions (S0-S2).

In agriculture, the NDC emphasizes strengthening water harvesting and irrigation systems, with a goal of achieving 50% of Uganda's irrigation potential by 2040, while also fostering the adoption of climate-resilient crop varieties. By 2030, irrigation systems are planned to cover 152,000 hectares, improving water use efficiency and supporting food security. The changes in crop productivity due to the changes in irrigation and seed variety were accounted for in the valuation of the sectoral VAD. The future farmland LULC areas were based on those projected in the BAU Scenario. The area of small-scale farmland was adjusted to account for the increase in crop productivity due to the use of improved climate-resilient seed varieties and the area lost through the restoration of natural forest and wetlands. The area of commercial farmland was adjusted to account for the increase in irrigated cropland area and ensure the agricultural VAD of this LULC matched the target sectoral GDP contribution under the BAU Scenario.

The NDC adaptation goals emphasize sustainable urbanization and reducing informal settlements, while the NDC mitigation plan supports integrated urban planning and efficient water management systems. Goals include reducing urban sprawl and ensuring efficient water and waste management systems in cities. There is, however, no mention of densification efforts and thus expansion of built-up areas was not adjusted to an increased carrying capacity.

The BAU + Climate Action Scenario incorporates Uganda's NDC targets into the BAU Scenario, aiming to mitigate climate impacts by 2030. Extensive overlap in the targets set out under the ASP Scenario and the BAU + Climate Action Scenarios meant that the latter was akin to an intermediate scenario between the BAU and ASP Scenarios.

The ASP + Climate Action Scenario combines the ambitious Vision 2040 targets with the climate-smart interventions of the NDC, aiming to balance development with resilience. Wetland, forest, riparian, and montane conservation efforts mirror those in the ASP Scenario, ensuring no additional losses and prioritizing restoration. Similarly, agricultural development strategies and built-up land growth remained consistent with ASP assumptions, collectively contributing to the combined objectives of climate mitigation and sustainable development by 2040. Any LULC changes that would occur under the ASP + Climate Action Scenario were accounted for in the ASP Scenario LULC changes. As such, a fourth set of spatial LULC layers would be redundant and the ASP Scenario layers are representative of the ASP + Climate Action Scenario as well.

Once the projected areas for each LULC in 2050 were determined based on the assumptions, the LULC areas in 2030 and 2040 were calculated using regression equations. If targets were met by 2030, as per the NDC, then these areas were kept constant between 2030 and 2050.

3.3 Results

3.3.1 Past land cover trends

The area and percentage of each LULC type in each of the years examined from 1990 to 2017 are summarized in Table 8.

Table 8. The area and percentage of each land use/land cover type across Uganda from 1990-2017.

	1990		2005		2010		2015		2017	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Plantations	32 333	0.16%	33 152	0.16%	65 507	0.32%	107 866	0.53%	161 283	0.79%
Forests	970 527	4%	824 187	3%	683 899	3%	631 187	3%	630 570	3%
Woodland	3 544 793	15%	2 364 297	10%	1 444 910	6%	1 214 478	5%	1 278 778	5%
Bushland	1 557 185	6%	3 035 877	13%	2 377 605	10%	1 972 325	8%	1 675 754	7%
Grassland	5 340 431	22%	4 289 042	18%	5 085 925	21%	5 105 157	21%	5 083 096	21%
Wetland	502 091	2%	751 364	3%	808 677	3%	760 346	3%	785 323	3%
Small-scale farmland	8 405 204	35%	8 936 373	37%	9 787 857	41%	10 274 975	42%	10 462 647	43%
Commercial farmland	68 580	0.34%	107 004	0.52%	134 301	0.66%	256 746	0.80%	181 741	0.89%
Built-up	36 185	0.18%	96 450	0.47%	95 979	0.67%	136 002	0.68%	139 386	0.90%
Open water	3 691 730	15%	3 707 598	15%	3 658 138	15%	3 686 401	15%	3 746 217	16%
Impediments	5 103	<0.1%	8 789	<0.1%	11 421	<0.1%	7 856	<0.1%	8 427	<0.1%

As can be seen in Figure 3.2 and Figure 3.3, small-scale farmland was the predominant land cover across Uganda from 1990 to 2017, accounting for 35-43% of the country's area (Table 8), increasing by 24%. Although covering the least amount of area in 1990 at less than 1% (Table 8), plantations had the greatest change in area, increasing exponentially by almost 400% from 1990 to 2017. Built-up areas and commercial farmland also expanded substantially during that time frame, at 285% and 165% respectively. Built-up areas are the only LULC of the four that exhibited a linear increase, rather than exponential. Together, these focal LULCs expanded from 35% in 1990 to cover 45% of Uganda's surface area in 2017. The marked reduction in natural LULCs as a result of this expansion is apparent in Figure 3.2.

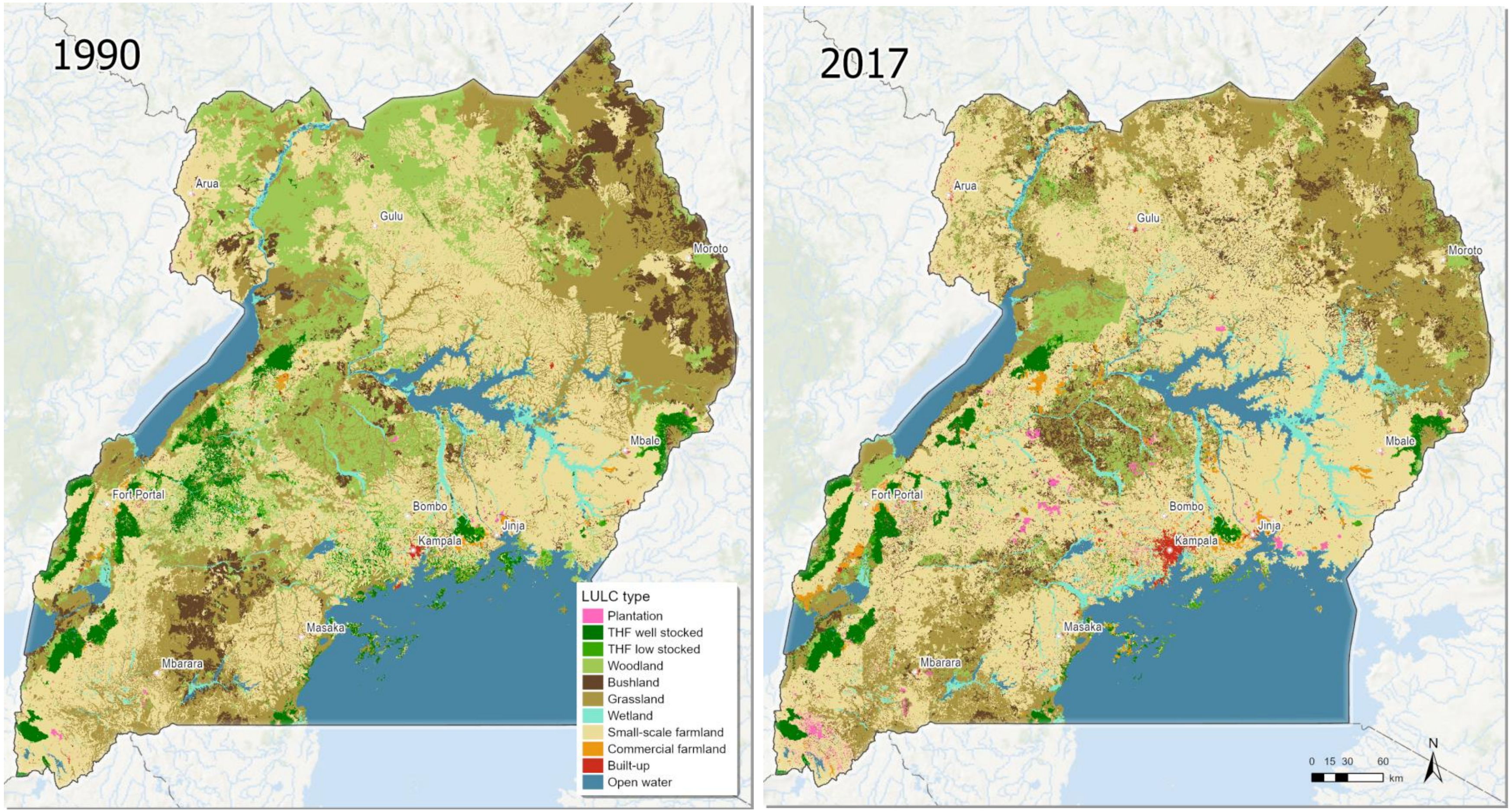

Figure 3.2. Land use/land cover of the study area in 1990 and 2017 (Data source: UBOS).

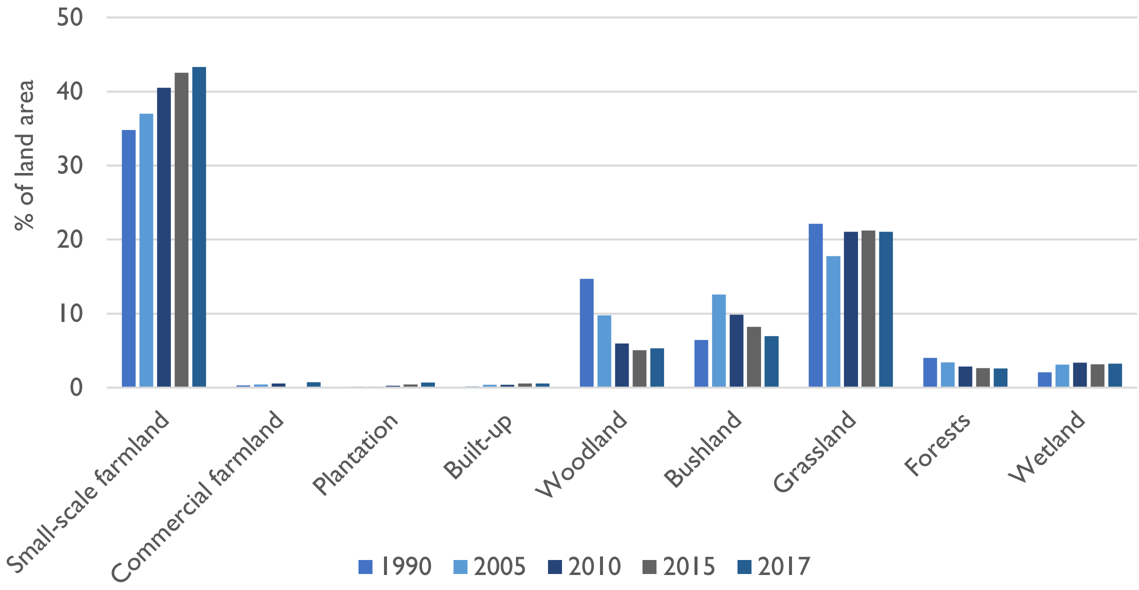

Figure 3.3. Historic changes in the extent of various land use/land cover across Uganda between 1990 and 2017.

3.3.2 Business-As-Usual Scenario

The BAU Scenario was grounded in historical trends, projecting LULC changes based on past rates of land use and ecological degradation. In order to align the resulting LULC with the economic targets of the scenario (Table 1. Economic targets, including total Value and GDP contributions of different sectors under the scenarios analyzed for Uganda's CCDR. Projections provided by the World Bank.Table 1), additional conversions of small-scale farmland to commercial farmland were necessary. The projected changes in LULC areas based solely on historic trends and under the BAU Scenario derived from the above analysis are shown in Figure 3.4 and Figure 3.5. The resulting LULC dataset under the BAU Scenario is summarized in Table 9 and shown in Figure 3.6.

Based on historic trends alone, plantations were projected to change the most in land area with an increase of 479% from 2019 to 2050 (Figure 3.6). The extent of this change was only surpassed by the expansion of commercial farmland, which was projected to increase tenfold to meet the target agricultural GDP contribution. Based on historic trends, small-scale farmland was projected to increase by 29% by 2050, however the additional conversion to commercial farmland resulted in only an 18% increase in small-scale farmland area, just less than 2 million hectares. Built-up areas were projected to expand by 63%.

To accommodate these changes a total of 56% (5.2 million hectares) of the natural LULC types, (forests, woodland, bushland, grassland, and wetlands), were converted to human-altered land covers. Wetlands experienced a dramatic reduction, with a 66% decrease in cover by 2050. Natural forest ecosystems, including THF and woodlands, are also projected to decline by 35%, resulting in an 8% total forest cover by 2050. Uganda's Vision2040 and NDC call for the forest estate to be restored to the extent present in 1990. This area, which includes plantations as well as woodlands and THF, covered 24% of the total land area. Despite the extensive expansion of plantation area under the BAU Scenario, the total projected forest estate, covering 17% of Uganda in 2050, does not exceed this goal.

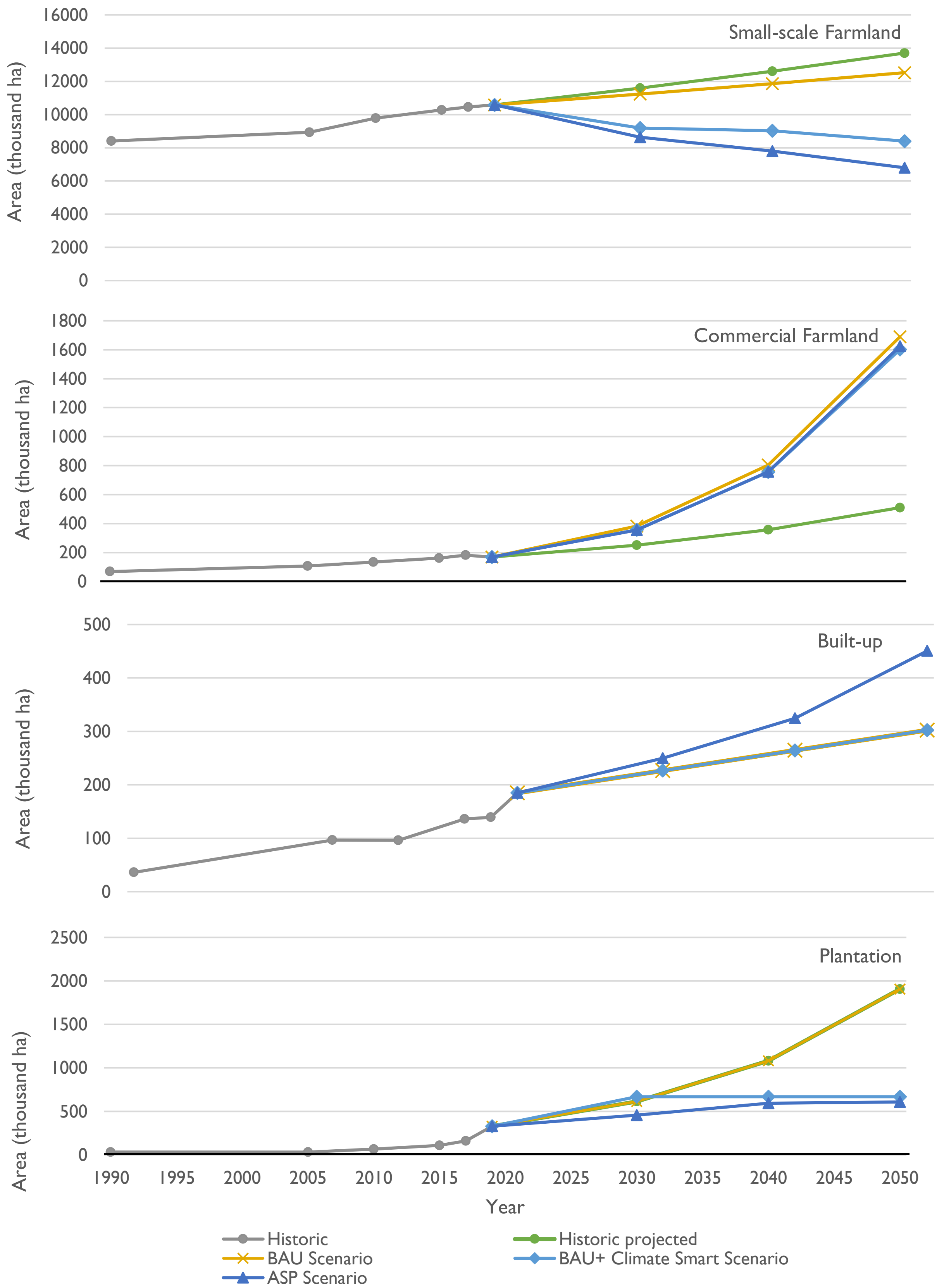

Figure 3.4. The historic and projected changes in area of human-altered LULC types across Uganda under various future scenarios.

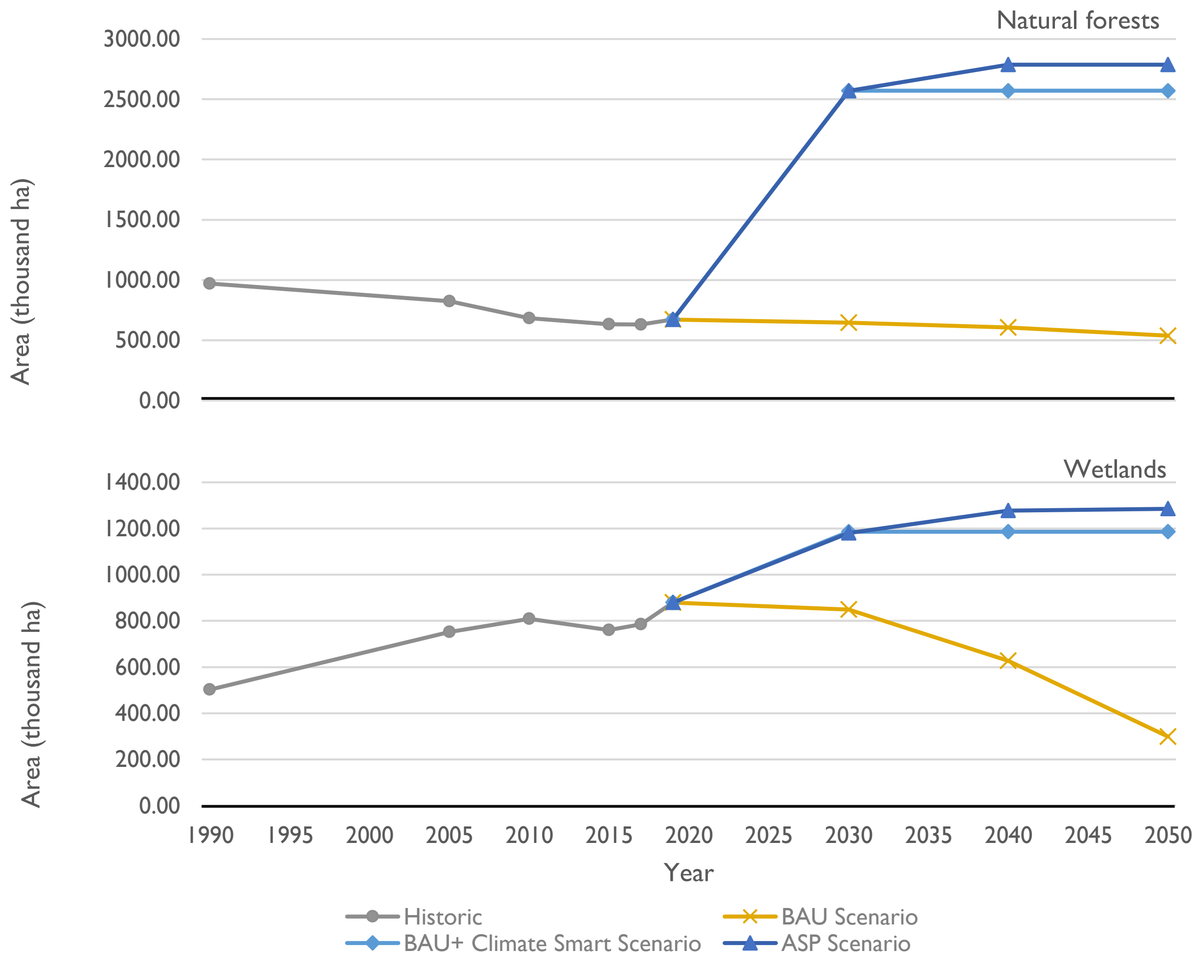

Figure 3.5. The historic and projected changes in area of tropical highland forest and wetland LULC types across Uganda under various future scenarios.

Table 9. The actual (2019) and projected (2030-2050) area and percent national land area coverage of each LULC type across Uganda under the BAU Scenario.

	2019		2030		2040		2050	
	Area (ha)	**% of land area**	**Area (ha)**	**% of land area**	**Area (ha)**	**% of land area**	**Area (ha)**	**% of land area**
Plantations	329 076	1.6%	613 748	3.0%	1 081 637	5.3%	1 906 216	9.4%
THF well stocked	517 460	2.5%	509 739	2.5%	494 607	2.4%	456 209	2.2%
THF low stocked	153 605	0.8%	135 126	0.7%	111 854	0.5%	81 459	0.4%
Woodland	1 710 911	8.4%	1 524 415	7.5%	1 306 353	6.4%	1 002 959	4.9%
Bushland	462 887	2.3%	412 398	2.0%	358 252	1.8%	217 871	1.1%
Grassland	5 450 913	26.8%	4 553 040	22.4%	3 531 805	17.4%	1 963 241	9.6%
Wetland	879 233	4.3%	849 067	4.2%	627 133	3.1%	298 737	1.5%
Small-scale farmland	10 582 031	52.0%	11 233 378	55.2%	11 860 240	58.3%	12 522 082	61.5%
Commercial farmland	68 580	0.3%	382 322	1.9%	803 515	3.9%	1 688 785	8.3%
Built-up	184 863	0.9%	226 564	1.1%	264 401	1.3%	302 238	1.5%

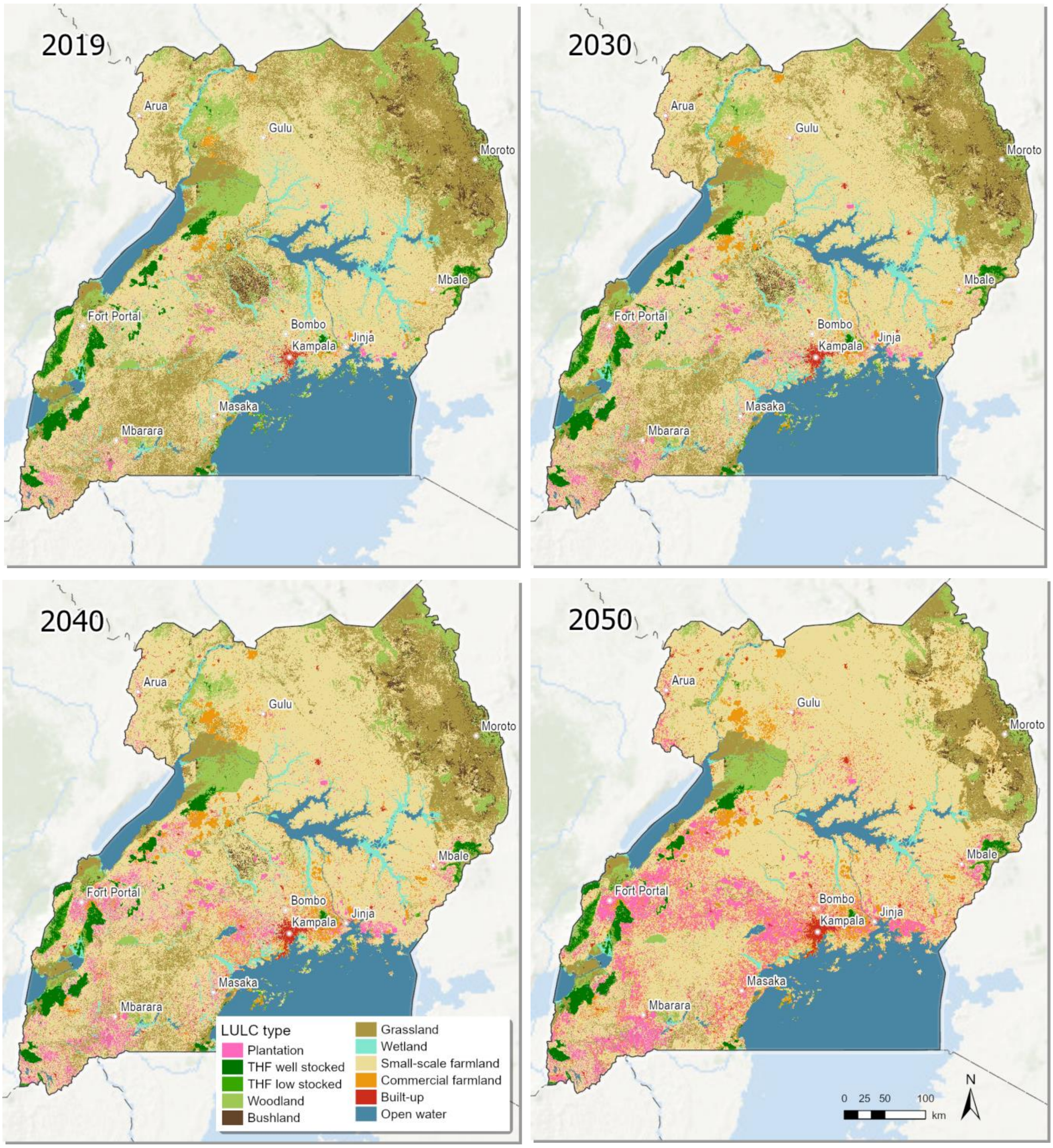

Figure 3.6. Land use/land cover (LULC) use of Uganda in 2019 (Data source: UBOS). Projected LULC of Uganda under a BAU Scenario in 2030, 2040, and 2050.

3.3.3 Aspirational Scenario

The ASP Scenario represents an optimistic future where sustainable development and ecological resilience has been prioritized. Major LULC changes were projected reflecting vast areas of ecosystem restoration. The location of urban and agricultural expansion was also guided by optimized development. The resulting LULC dataset under the ASP Scenario is summarized in Table 10 and shown in Figure 3.7. The projected changes in LULC areas under the ASP Scenario are shown in Figure 3.4 and Figure 3.5. While the BAU Scenario reflects moderate growth driven by historical trends, the ASP Scenario demonstrates the potential for significant economic transformation through sustainable development initiatives. Under the ASP Scenario, the assumptions of targeted restoration, urban population growth, and productivity improvements led to a markedly different pattern of LULC change compared to the BAU Scenario.

The greatest change in LULC area between 2019 and 2050 took the form of conversion of small-scale farmland to other LULC types, primarily THF and commercial farmland. By 2050, the area of small-scale farmland was projected to be 3.8 million hectares less than in 2019. Commercial farmland was projected to expand by 861% by 2050, including areas of irrigated and non-irrigated crops. With the increase in urban densification and the size of the urban population, built-up areas were projected to expand by 140%, which occurred only within the SEZs. Plantations increased by 85% to cover an area of 600 thousand hectares in 2050. Wetlands were projected to expand by 46% from 2019 to 2040 and, due to reforestation, areas of THF almost quadrupled in this time. With this growth, the total area of THF, woodland, and plantations covered 24% of the Uganda by 2040.

Table 10. The actual (2019) and projected (2030-2050) area and percent national land area coverage of each LULC type across Uganda under the ASP Scenario.

	2019		2030		2040		2050	
	Area (ha)	**% of land area**	**Area (ha)**	**% of land area**	**Area (ha)**	**% of land area**	**Area (ha)**	**% of land area**
Plantations	329 076	1.6%	456 400	2.2%	594 500	2.9%	608 054	3.0%
THF well stocked	517 460	2.5%	516 957	2.5%	735 206	3.6%	2 515 757	12.4%
THF low stocked	153 605	0.8%	2 053 678	10.1%	2 051 774	10.1%	153 678	0.8%
Woodland	1 710 911	8.4%	1 679 564	8.3%	1 677 834	8.2%	1 710 861	8.4%
Bushland	462 887	2.3%	447 507	2.2%	440 162	2.2%	445 402	2.2%
Grassland	5 450 913	26.8%	4 878 001	24.0%	4 786 034	23.5%	4 852 641	23.8%
Wetland	879 233	4.3%	1 180 013	5.8%	1 278 007	6.3%	1 285 149	6.3%
Small-scale farmland	10 582 031	52.0%	8 629 125	42.4%	7 800 440	38.3%	6 798 098	33.4%
Commercial farmland	68 580	0.3%	354 288	1.7%	757 555	3.7%	1 623 696	8.0%
Built-up	184 863	0.9%	249 986	1.2%	324 534	1.6%	450 618	2.2%

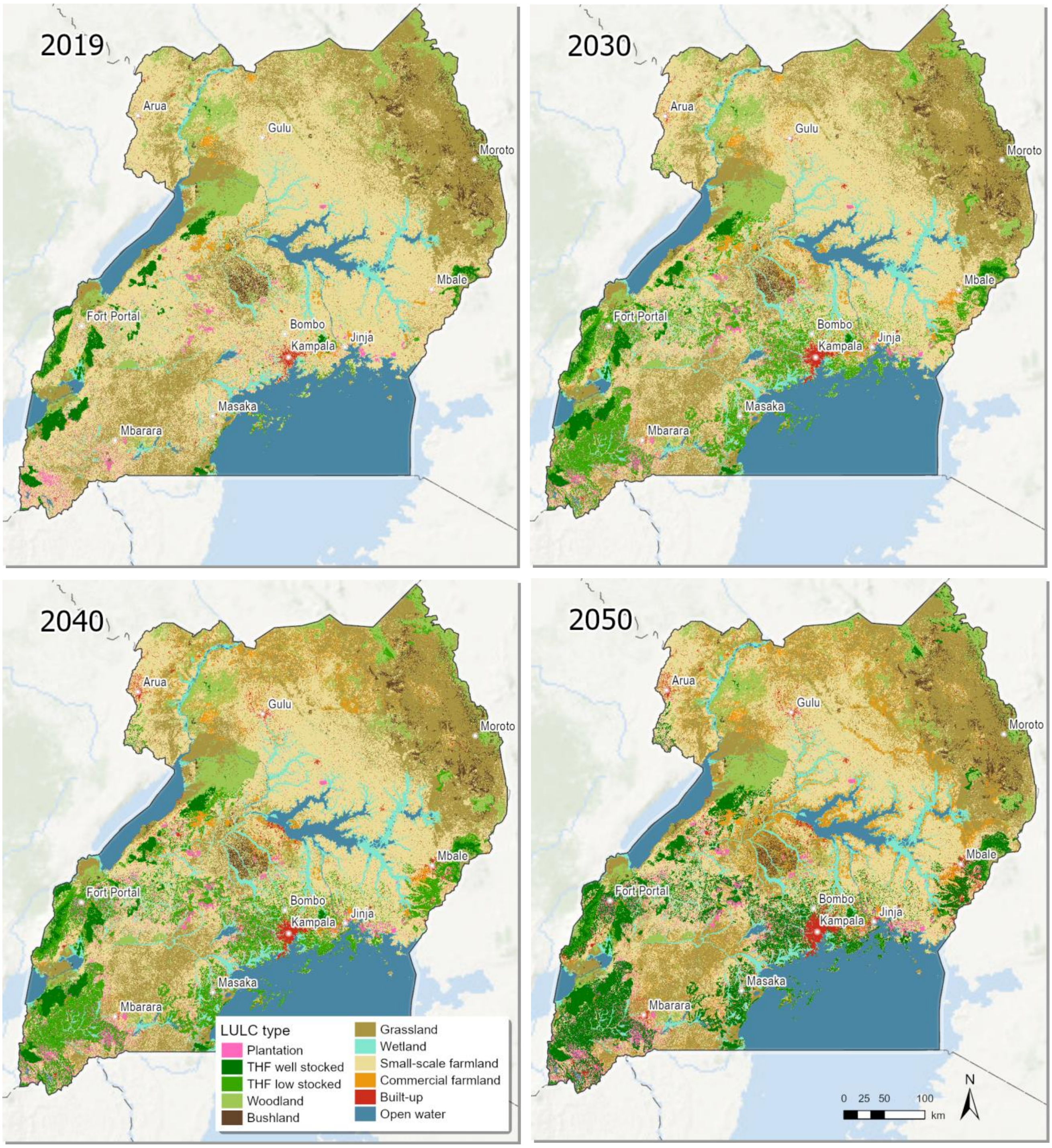

Figure 3.7. Land use/land cover (LULC) use of Uganda in 2019 (Data source: UBOS) and the projected LULC of Uganda under an ASP Scenario in 2030, 2040, and 2050.

3.3.4 CLIMATE ACTION SCENARIO

The BAU + Climate Action Scenario represents a BAU trajectory where climate change mitigation and adaptation action are prioritized. As with the ASP Scenario, large LULC area changes were projected reflecting the substantial ecosystem restoration action. The resulting LULC areas under this scenario in 2030, 2040, and 2050 are summarized in Table 11 and shown in Figure 3.8. The trajectories of each LULC under each scenario are shown in Figure 3.4 and Figure 3.5.

Due to the target reforestation efforts, by 2050 the high stocked THF was projected to increase by 370%. Wetland restoration resulted in a 35% increase in cover. Accounting for the increase in crop productivity as a result of expanded irrigation and improved climate smart seed varieties, the area of commercial farmland was projected to increase by 848% between 2019 and 2050. The loss of small-scale farmland area to wetlands, THF, and commercial farmland resulted in a 21% decline in its cover. The area of built-up cover was projected to expand by 63%. With a greater land cover target than under ASP Scenario, plantations were projected to double in area.

Table 11. The actual (2019) and projected (2030-2050) area and percent national land area coverage of each LULC type across Uganda under the BAU+ Climate Action scenario.

	2019		2030		2040		2050	
	Area (ha)	**% of land area**	**Area (ha)**	**% of land area**	**Area (ha)**	**% of land area**	**Area (ha)**	**% of land area**
Plantations	329 076	1.6%	668 558	3.3%	668 558	3.3%	668 558	3.3%
THF well stocked	517 460	2.5%	517 779	2.5%	517 779	2.5%	2 417 779	11.9%
THF low stocked	153 605	0.8%	2 053 313	10.1%	2 053 313	10.1%	153 313	0.8%
Woodland	1 710 911	8.4%	1 710 720	8.4%	1 710 720	8.4%	1 710 720	8.4%
Bushland	462 887	2.3%	410 184	2.0%	394 217	1.9%	381 525	1.9%
Grassland	5 450 913	26.8%	4 117 488	20.2%	3 873 280	19.0%	3 616 939	17.8%
Wetland	879 233	4.3%	1 186 018	5.8%	1 186 018	5.8%	1 186 018	5.8%
Small-scale farmland	10 582 031	52.0%	9 193 185	45.2%	9 015 951	44.3%	8 401 173	41.3%
Commercial farmland	68 580	0.3%	356 069	1.7%	755 641	3.7%	1 601 453	7.9%
Built-up	184 863	0.9%	226 483	1.1%	264 320	1.3%	302 319	1.5%

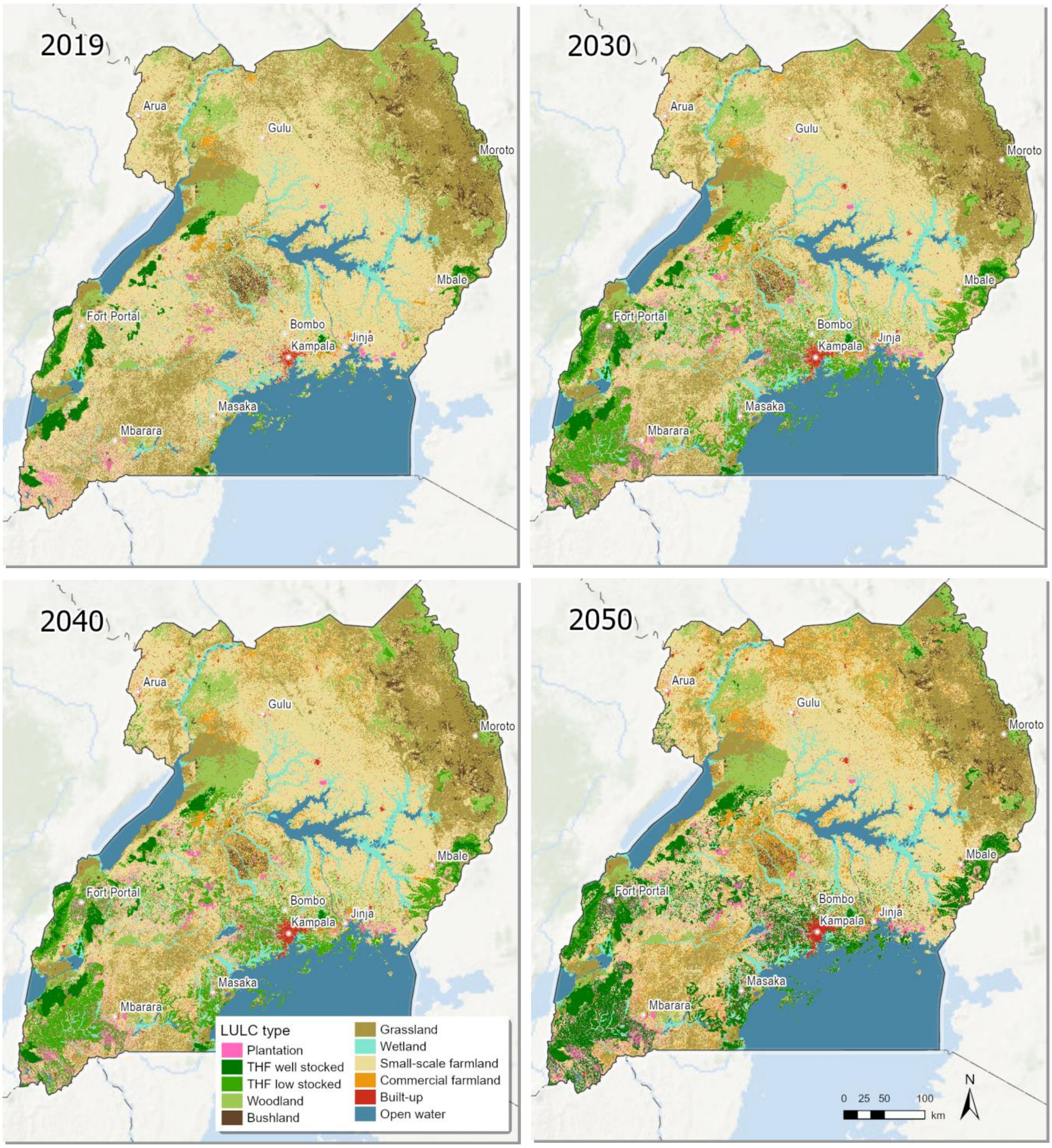

Figure 3.8. Land use/land cover (LULC) of Uganda in 2019 (Data source: UBOS), and the projected LULC of Uganda under a BAU +Climate Action Scenario in 2030, 2040, and 2050.

4 ESTIMATION OF AGRICULTURAL VALUE

To align the projected LULC datasets from the previous chapter to the future economic scenarios, the potential agricultural output based on the LULC in 2050 was calculated and compared to the target GDP contribution of the agricultural sector for 2050 under the BAU and ASP Scenarios (Table 1). Under the BAU Scenario, Uganda's GDP is estimated to grow at an annual rate of 6%, with the agricultural sector contributing 17% to the GDP at US$ 39.8 billion. Under the ASP Scenario, Uganda's GDP is estimated to grow at an annual rate of 8.5%. By 2050 the agricultural sector is estimated to contribute 10% to the GDP at US$ 44.7 billion

4.1.1 Methods

The agricultural sector's total contribution to GDP (expressed as value-added, or VAD), is defined as the gross output of agricultural activities minus intermediate inputs. To estimate the agricultural VAD in 2021 and 2050 based on the projected LULC layers from this analysis, agricultural production values were sourced from the National Ecosystem Services and Asset Accounts (UBOS 2023), hereafter the "Ecosystem Accounts". These included crops (categorized into commercial and small-scale/subsistence), livestock, wood products (separated by non-plantation and plantation resources), and fish. These values, aligned to the 2015 LULC map, were reported in terms of resource rent[1] in 2017 UGX prices. For this study, the resource rent values were converted to gross output values using the resource rent factors reported in the Ecosystem Accounts. The total agricultural contribution to GDP was estimated by subtracting an estimated proportional contribution of intermediate input costs from the gross output value for each of the above activities.

Adjustments for changes in prices and productivity were made based on inflation rates and agricultural output trends from 2015 to 2021, ensuring alignment with updated economic data. These adjustments were based on the annual changes in VAD reported for each resource from 2015 to 2021, as reported in the 2022 Ugandan Statistical Abstract (UBOS, 2022; Table 7). As the production values in the Ecosystem Accounts are expressed in 2017 prices, they were further adjusted to 2021 prices using the annual inflation rate for this time period.

The potential agricultural VAD was estimated for each projected 2050 LULC dataset under each scenario. This involved adjusting the 2021 values to account for anticipated real changes in prices, and productivity improvements based on the projected LULC changes. These adjustments varied by resource, as detailed in the following sections. As LULC maps for 2021 were not explicitly created, the 2021 LULC areas were approximated by projecting changes from 2015 to 2021 using historical regression equations developed in the preceding analysis. Due to the level of uncertainty in climate change projections, this analysis used current climate conditions when assessing future suitability and agricultural production estimates.

1 Resource rent is defined as a surplus value, i.e., the difference between the price at which a resource, or the output from it, can be sold, and its respective extraction and/or production costs, including normal returns. In the Ecosystem Accounts, the resource rent was calculated as the value of the final resource (farmgate price) less the cost of all other inputs, including labor, produced assets and intermediate inputs (UBOS 2023).

CROPS

Crop values were taken from the Ecosystem Accounts (UBOS 2023), which separate crops produced by households from small-scale farmland, and industrial crop production from commercial farmland. Although the suitable crop areas were based on selected crops, the valuation used the fuller range of crop types reported in the accounts. The resource rent calculations for each crop in the Ecosystem Accounts were informed by labor and input costs reported by Kraybill & Kidoido (2009), and differed for small-scale and commercial farmland. Using the same information, the overall resource rent values of small-scale and commercial farmland were reverted to gross outputs, taking the proportional contributions of different crop types to output value into account (UBOS 2023).

Under the BAU Scenario, production per hectare remained unchanged, and the proportion of irrigated area was also assume to remain unchanged. Therefore, aggregate increases in crop production from 2021 to 2050 were due to increased production area.

The ASP and BAU + Climate Action scenarios included explicit **irrigation expansion** targets, so commercial farmland was explicitly separated into irrigated and rainfed production areas. In irrigated areas, the crop mix of maize, rice, sesame, sugarcane, and vegetables was assumed to remain constant (World Bank CCDR in prep). Overall commercial farmland production value took into account the increased production and costs associated with the expanded irrigation areas.

Under the ASP and BAU + Climate Action scenarios, both small-scale and commercial farmers were expected to adopt the use of **improved climate smart seed varieties**. It was assumed that 100% of commercial farmers would adopt the improved seed, whereas a more probable adoption rate of 50% was assumed for small-scale farmers.

Under the ASP Scenario, small-scale farmers were also expected to **transition from low input to high input farming**, including an increase in fertilizers, other chemicals, and high input technology. It was assumed that all commercial farmers were already using high inputs.

Regionally-specific data from various studies were used to calculate the **changes in physical production** of each crop in small-scale and commercial farmland as a result of increased inputs, improved seed, and irrigation (Sys et al. 1993; Nabbumba & Bahiigwa 2004; Kraybill & Kidoido 2009; Sebuwufu et al. 2015; Hill et al. 2018; World Bank 2018; National Planning Commission 2021; Global Yield Gap Atlas 2022). These changes in production were weighted according to the contribution of each crop to the value of small-scale, rainfed commercial, and irrigated commercial farmland. **Crop prices** were projected to decrease annually by 2.0% between 2021 and 2050 in real terms, based on the Price Index for non-energy crop prices from the integrated assessment models from the IPCC's Sixth Assessment Report (AR6) Scenario Database Hosted at IIASA, refined to the Sub-Saharan region under the C7 climate change trajectory (Byers et al. 2022). The resulting changes in the gross output value of commercial and small-scale farmland under the different scenarios are summarized in Table 12**Error! Reference source not found.**.

The calculation of aggregate VAD from commercial and small-scale farmland took into account the changes from low to high inputs, the use of improved seeds, and irrigation costs where appropriate. Irrigation costs were based on the annualised implementation and operational costs of gravity canal systems as reported by Smith et al. (n.d.). These costs are summarized in

Table 12. Average per hectare intermediate input costs (UGX 2021/ha) for various interventions to farmland LULC types implemented under three different scenarios, and the percentage of gross output value. Note that small scale farmland is as per the land cover and includes fallow area.

LULC type	Variable	BAU (2050)	BAU +Climate Action (2050)	ASP (2050)
Small scale farmland	Assumptions	Current methods	50% adoption of improved seed	50% adoption of improved seed + high input farming
	Gross income/ha	760 000	1 153 000	2 797 000
	Intermediate input costs/ha	9 000	22 000	1 890 000
	Value added/ha	751 000	1 131 000	907 000
Commercial dryland	Assumptions	Current methods	Full adoption of improved seed	Full adoption of improved seed
	Gross income/ha	59 207 000	70 326 000	70 326 000
	Intermediate input costs/ha	8 138 000	8 243 000	8 243 000
	Value added/ha	51 069 000	62 083 000	62 083 000
Commercial irrigation	Assumptions	Current methods	Full adoption of improved seed	Full adoption of improved seed
	Gross income/ha	95 666 000	113 633 000	113 633 000
	Intermediate input costs/ha	10 411 000	10 516 000	10 516 000
	Value added/ha	85 255 000	103 116 000	103 116 000

LIVESTOCK

In line with the Ecosystem Accounts, the LULC types that were considered to contribute to the value of livestock were woodland, bushland, grassland, small-scale farmland, and wetland (UBOS 2023). However, to ensure changes only in areas suitable to livestock production were considered, the initial area available to livestock in 2015 was calculated as the area of these natural LULCs within the optimally suitable areas. This calculation used the livestock suitability layer created in the first task, and the 2015 LULC layer. The area contributing to livestock production in 2021 and 2050 was calculated as their combined area in 2015 less the increase in the unsuitable LULCs. Although the Ecosystem Accounts uses different livestock production values for the different natural LULCs, combining the natural LULCs in this way assumed a uniform production value per unit area across all of the suitable LULCs. According to Nampanzira *et al.* (2019), livestock forage is extracted from forests in negligible amounts, and livestock are not taken into forests to graze. As such, and as with the Ecosystem Account, forest land cover was considered to contribute to other resources, but not livestock production.

The resource rent for livestock production used in the Ecosystem Accounts was calculated as the gross output value less intermediate input costs, including practicing controlled mating, paying for feed and water, using vaccines, using anti-parasites, and applying curative treatments (UBOS 2023). As such, the VAD of livestock production was maintained as the reported resource rent value.

The productivity per unit area of livestock production was not projected to change under any of the scenarios. The projected average annual change in the price of livestock between 2021 and 2050 used in this analysis was 3.01%. This estimate was calculated from the Price Index for livestock prices from the integrated assessment models from the IPCC's Sixth Assessment

Report (AR6) Scenario Database Hosted at IIASA, refined to the Sub-Saharan region under the C7 climate change trajectory (Byers et al. 2022).

WOOD PRODUCTS

The wood resources reported in the Ecosystem Accounts include timber, poles, charcoal, and firewood (UBOS 2023). The contribution of all four of these was maintained in calculating the valued added by wood products. In this analysis, the value of wood products was separated by their production in plantations and other LULCs. As in the Ecosystem Accounts, the LULC types that are considered to contribute to the value of non-plantation wood products were woodland, bushland, grassland, small-scale farmland, wetland, and forests (UBOS 2023). However, to ensure changes only in areas suitable to non-plantation wood production were considered, the initial area available to wood production in 2015 was calculated as the area of these natural LULCs less the area of protected areas. The area contributing to non-plantation wood production in 2021 and 2050 was calculated as their combined area in 2015 less the increase in the focal LULCs. As with the livestock production, the Ecosystem Accounts used different wood production values for the different natural LULCs and combining the natural LULCs assumed a uniform production value per unit area across all of the suitable LULCs.

The resource rent value of plantations, reported in the Ecosystem Accounts was calculated as 73% of farmgate price for timber and charcoal, and 95% for poles and firewood (UBOS 2023). Once converted to gross output, values for all plantation products were adjusted according to the cost breakdown by Muhumuza et al. (2007) which provided information on the cost per tree, feeling fees, felling labour charges, making a platform, sawing pieces and the cutting of trees into logs, as well as transport and maintenance. It was assumed that labour costs were around 25% of total costs of log cutting, construction of a platform and sawing (Silayo, Dos Santos A. Shemwetta & Migunga 2007; Silayo 2015). Based on the data it was estimated that plantation VAD was around 33% of the wood gross output value. The resource rent of wood resources sourced from outside of plantations was also adjusted back to gross output values. To obtain the VAD for non-plantation wood, the intermediate input costs were assumed to be 5% of the gross output value.

The productivity per unit area of wood resources was projected to remain constant into the future under all scenarios. The projected average annual increase in the price of wood resources between 2021 and 2050 was 1.83%, taken as the projected average annual price increase of raw materials, including timber and other non-timber materials, between 2023 and 2026 from the World Bank 2024 commodity price forecast (World Bank 2024).

FISH

For fisheries, it was assumed that no increase in production would occur over time between 2015 and 2050, under any scenario. The resource rent factor used in the National Ecosystem Accounts was calculated from the physical and monetary supply and use tables in the Fishery Accounts (NEMA 2021). Resource rents were assumed to be 43% of market price based on revenue and cost data published for all waterbodies in 2015 in the Fishery Accounts (NEMA 2021). Based on the intermediate consumption and fixed capital consumption values reported in the Fishery Accounts, the VAD of fisheries was calculated to be 79% of the total revenue (NEMA 2021). The projected average annual change in the price of fish between 2021 and 2050 of 1.7% was calculated from the projected 18% growth in the average price of internationally traded aquatic products between 2020 and 2030 reported in the FAO state of world fisheries and aquaculture projections (FAO 2022).

4.1.2 RESULTS

The total calculated sectoral VAD for the agricultural resources, consisting of commercial and small-scale crops, plantation wood, livestock, fish, and non-plantation wood in 2021, the baseline year, was US$ 9.7 billion. This is 98% similar to the target value of US$ 9.5 billion, thus validating the initial resource VAD calculations (Table 13).

Under the BAU, based on the projected changes in LULC area and changes in prices, the agricultural VAD increased to US$ 35.4 billion, in 2050. This is 11% lower than the expected VAD of US$ 39.8 billion. Under the BAU +Climate Action Scenario, the agricultural VAD increased to US$ 39.9 billion, which is almost the same as the expected value. Under the ASP Scenario the agricultural VAD increased to US$ 43.7 billion in 2050, which differs from the target VAD of US$ 44.7 billion by 3%. The calculated VAD values for all scenarios closely align with Uganda's economic targets, deviating by no more than 2%. This validation supports the robustness of the projected LULC datasets in capturing the economic implications of future land use changes.

Table 13. Total agricultural and resource VAD in 2021 and 2050 under three future scenarios from the current analysis, as well as target values for each scenario.

Scenario	Resource/commodity	2021 UGX billions	2021 US$ billions	Total change (2021-2050)	Average annual change (2021-2050)
Baseline (2021)	Small-scale crops	8 570	2.4		
	Commercial crops	10 548	2.9		
	Plantation wood	288	0.1		
	Livestock	10 213	2.8		
	Non-plantation wood	5 203	1.5		
	Fish	2.9	0.001		
	Calculated total	**34 825**	**9.7**		
	Scenario target		**9.5**		
BAU (2050)	Small-scale crops	9 404	2.6	10%	0.3%
	Commercial crops	89 119	24.9	938%	8.4%
	Plantation wood	2 424	0.7	743%	7.6%
	Livestock	18 469	5.2	81%	2.1%
	Non-plantation wood	7 045	2	35%	1.1%
	Fish	8.4	0.002	326%	5.1%
	Calculated total	**126 470**	**35.4**	**322%**	**5.1%**
	Scenario target		**39.8**	**319%**	**5.1%**
ASP (2050)	Small-scale crops	9 505	2.7	82%	2.1%
	Commercial crops	107 220	29.9	974%	8.5%
	Plantation wood	850	0.2	169%	3.5%
	Livestock	18 014	5	83%	2.1%
	Non-plantation wood	7 691	2.1	46%	1.3%
	Fish	8.4	0.002	192%	3.8%
	Calculated total	**143 287**	**39.9**	**348%**	**5.3%**
	Scenario target		**39.8**	**371%**	**5.5%**
BAU+ Climate Smart (2050)	Small-scale crops	6 165	1.7	38%	1.1%
	Commercial crops	123 783	34.5	860%	8.1%
	Plantation wood	773	0.2	196%	3.8%
	Livestock	18 639	5.2	76%	2.0%
	Non-plantation wood	7 621	2.1	48%	1.4%
	Fish	8.4	0.002	192%	3.8%
	Calculated total	**156 989**	**43.7**	**301%**	**4.9%**
	Scenario target		**44.7**	**319%**	**5.1%**

REFERENCES

Ajala ON, Adjadeh TA, Olaniyan JO, Isimikalu TO, Nartey EK, James FO. 2021. Characterization, classification and suitability evaluation of soils under sugarcane (Saccharum officinarum L.) cultivation at the Sugar Research Farm, University of Ilorin, Nigeria. Agro-Science **20**:14–23.

Bailey DW. 2005. Identification and creation of optimum habitat conditions for livestock. Rangeland Ecology and Management **58**:109–118. Elsevier.

Blume H. 1985. Geography of Sugar Cane.

Bondarenko M, Kerr D, Sorichetta A, Tatem AJ. 2020. Census/projection-disaggregated gridded population datasets, adjusted to match the corresponding UNPD 2020 estimates, for 51 countries across sub-Saharan Africa using building footprints. WorldPop, University of Southampton, UK.

Bukomeko H, Jassogne L, Kagezi GH, Mukasa D, Vaast P. 2018. Influence of shaded systems on Xylosandrus compactus infestation in Robusta coffee along a rainfall gradient in Uganda. Agricultural and Forest Entomology **20**:327–333.

Byers E et al. 2022, November. AR6 Scenarios Database. Zenodo. Available from https://doi.org/10.5281/zenodo.5886911.

Carabaño MJ, Bachagha K, Ramón M, Díaz C. 2014. Modeling heat stress effect on Holstein cows under hot and dry conditions: Selection tools. Journal of Dairy Science **97**:7889–7904. Elsevier.

Davis AP, Kiwuka C, Faruk A, Mulumba J, Kalema J. 2022. A review of the indigenous coffee resources of Uganda and their potential for coffee sector sustainability and development. Frontiers in Plant Science **13**:1–16.

Drichi P. 2002. National Biomass Study Technical Report of 1996-2002. Forest Department, Kampala, Uganda.

Ekou J. 2014. Dairy production and marketing in Uganda: current status, constraints and way forward. African Journal of Agricultural Research **9**:881–888.

FAO. 2007. Land evaluation: towards a revised framework; Land and Water Discussion Paper 6. Page Land and Water Discussion Paper 6. Food and Agriculture Organisation of the United Nations, Rome.

FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. FAO, Rome.

FAO EcoCrop. 2019. EcoCrop Database.

Fick SE, Hijmans RJ. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology **37**:4302–4315.

Fischer G, Nachtergaele F, van Velthuizen HT, Chiozza F, Franceschini G, Henry M, Muchoney D, Tramberend S. 2021. Global Agro-Ecological Zones v4 – Model documentation. Food and Agriculture Organisation, Rome.

Gizachew B, Solberg S, Puliti S. 2018. Forest Carbon Gain and Loss in Protected Areas of Uganda: Implications to Carbon Benefits of Conservation. Land **7**:1–14. Available from http://www.mdpi.com/2073-445X/7/4/138.

Global Yield Gap Atlas. 2022. Description of cropping systems, climate, and soils in Uganda.

Government of Uganda. 2013. Uganda Vision 2040.

Hahn GL. 1999. Dynamic responses of cattle to thermal heat loads. Journal of animal science **77 Suppl 2**:10–20.

Hengl T et al. 2015. Mapping soil properties of Africa at 250 m resolution: Random forests significantly improve current predictions. PLoS ONE **10**.

Hennig JD, Rigsby W, Stam B, Scasta JD. 2022. Distribution of Salers cows in contrasting rangeland pastures relative to established slope and water guidelines. Livestock Science **257**. Elsevier B.V.

Hill R, Mejia-Mantilla C, Vasilaky K. 2018. Vanishing returns? Potential returns and constraints to Input Adoption among smallholder farmers in Uganda. The World Bank Group, Washington, D.C.

Holechek JL. 1988. An Approach for Setting the Stocking Rate. Rangelands **10**:10–14.

Jaetzold R, Schmidt H, Hornetz B, Shisanya C. 2006. Farm Management Handbook of Kenya Vol. II. Part B: Central Kenya. Nairobi.

Jahnke HE. 1983. Livestock production systems and livestock development in Tropical Africa. Page Agricultural Systems. Kieler Wissenschaftsverlag Vauk, Kiel.

Karamura E, Frison E, Karamura DA, Sharrock S. 1998. Banana Production systems in Eastern and Southern Africa. Bananas and Food Security International Symposium:401–412.

Kath J, Byrareddy VM, Craparo A, Nguyen-Huy T, Mushtaq S, Cao L, Bossolasco L. 2020. Not so robust: Robusta coffee production is highly sensitive to temperature. Global Change Biology **26**:3677–3688.

Kraybill D, Kidoido M. 2009. Analysis of relative profitability of key Ugandan agricultural enterprises by agricultural production zone. International Food Policy Research Institute.

Längin D, Ackerman P, Krieg B, Immelmann A, Rooyen J van, Potgieter C, Upfold S. 2010. South African Ground Based Harvesting Handbook. Forest Engineering Southern Africa and Institute for Commercial Forestry Research, Scottsville.

Lawrence TJ, Vilbig JM, Kangogo G, Fèvre EM, Deem SL, Gluecks I, Sagan V, Shacham E. 2023. Spatial changes to climatic suitability and availability of agropastoral farming systems across Kenya (1980–2020). Outlook on Agriculture **52**:186–199.

Manners R, Vandamme E, Adewopo J, Thornton P, Friedmann M, Carpentier S, Ezui KS, Thiele G. 2021. Suitability of root, tuber, and banana crops in Central Africa can be favoured under future climates. Agricultural Systems **193**:103246. Elsevier Ltd.

Miller RF, Gillen RL, Krueger WC. 1984. Cattle Distribution on Mountain Rangeland in Northeastern Oregon. Journal of Range Management **37**:549–553.

Mueggler WF. 1965. Cattle Distribution on Steep Slopes. Journal of Range Management **18**:255.

Muhumuza F, Kutegeka S, Wolimbwa A. 2007. Wealth Distribution, Poverty and Timber Governance in Uganda: A case of Budongo Forest Reserve. ACODE Policy Research Series **26**:74.

Nabbumba R, Bahiigwa G. 2004. Agricultural Productivity Constraints in Uganda: Implications for Investment. IFPRI Eastern Africa Food Policy Network, Kampala.

Nampanzira DK, Katongole CB, Muwanka VB, Tabuti JRS. 2019. Are Livestock Keepers in and Around Forests Key Stakeholders in Forest Management? Experiences from Mabira Central Forest Reserve, Uganda. Pages 343–355 Climate Change Management. Springer.

Nardone A, Ronchi B, Lacetera N, Bernabucci U. 2006. Climatic effects on productive traits in livestock. Veterinary Research Communications **30**:75–81.

National Planning Commission. 2021. Cost Benefit Analysis of Stimulating Farmer Uptake of Irrigation in Malawi - Technical Report. Malawi Priorities, National Planning Commission (Malawi), Copenhagen Consensus Center (USA) and African Institute for Development Policy (Malawi). Available from www.copenhagenconsensus.com.

Natural Capital Project. 2024. InVEST . Stanford University, University of Minnesota, Chinese Academy of Sciences, The Nature Conservancy, World Wildlife Fund, Stockholm Resilience Centre and the Royal Swedish Academy of Sciences. .

NEMA. 2021. Fisheries resources accounts for Uganda. Government of Uganda, National Environmental Management Authority, Kampala, Uganda.

NFA. 2022. Uganda land use/land cover. National Forestry Authority, Kampala.

Republic of Rwanda. 2020. National Land Use and Development Master Plan 2020-2050.

Republic of Uganda. 2020. Third National Development Plan (NDPIII) 2020/21 - 2024/25. National Planning Authority, Kampala.

Sebuwufu G, Mazur R, Ugen M, Westgate M. 2015. Using improved varieties and fertility enhancements for increasing yield of common beans (Phaseolus vulgaris L.) grown by small-landholder farmers in Uganda. African Journal of Agricultural Research **10**:4795–4805. Academic Journals.

Seo SN, Mendelsohn R. 2007. Climate Change Adaptation in Africa: a Microeconomic Analysis of Livestock Choice. Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Silayo, Dos Santos A. Shemwetta DT, Migunga GA. 2007. Optimizing productivity on multistage timber harvesting systems. A case of Shume/Mkumbara system. Discovery and Innovation **19**:76–84.

Silayo DSA. 2015. Modeling Productivity and Costs of Timber Harvesting in Plantation Forests Using Two Man Crosscut Saws under Learning Experiments, Tanzania. American Journal of Operational Research **5**:29–38.

Smith M, Muñoz G, Sanz J, Series A, Sanz Alvarez J, O´brien E. (n.d.). Irrigation Techniques for Small-scale Farmers: Key Practices for DRR Implementers. Available from www.fao.org/publications.

Sogoni EK, Oindo B, Ogindo H. 2019. Effects of seasonal and annual rainfall variability on sugar cane yields in Mumias Sub County, Kakamega County, Kenya. East African Scholars Journal of Education, Humanities and Literature **7250**:728–738.

Sys C, van Ranst E, Debayeye J, Beernaert F. 1993. Land Evaluation, part III, Crop requirements. Page Agricultural Publications. General Administration for Development Cooperation, Belgium. General Administration for Development Cooperation, Brussels.

Turpie JK, Wilson LJ, Letley GK, Gardner K. 2023. Making the case for investing in indigenous forest restoration and protection in western Uganda: a scenario analysis. Report prepared by Anchor Environmental Consultants for the World Bank, on behalf of the Government of Uganda.

UBOS. 2020. Annual Agriculture Survey 2018. Uganda Bureau of Statistics, Kampala, Uganda.

UBOS. 2022. Ugandan Statistical Abstract 2022. Uganda Bureau of Statistics (UBOS), Government of Uganda, Kampala, Uganda.

UBOS. 2023. Physical and Monetary Ecosystem Services and Asset Accounts for Uganda 1990-2015. Available from www.bradtguides.com.

UBOS. 2024. 2024 National population and housing census 2024 preliminary report. Uganda Bureau of Statistics (UBOS), Kampala.

UCDA. 2019a. Arabica Coffee Handbook. Uganda Coffee Development Authority, Kampala.

UCDA. 2019b. Robusta Coffee Handbook. Uganda Coffee Development Authority, Kampala.

Uganda Ministry of Water and Environment. 2022. Updated Nationally Determined Contribution (NDC).

UNEP-WCMC, IUCN. 2022. Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM). United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK.

van Breugel P et al. 2015. Potential natural vegetation map of Eastern Africa (Burundi, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia). Version 2.0. Forest & Landscape Denmark and World Agroforestry Centre (ICRAF).

Wairegi L, Van Asten P, Giller K, Fairhurst T. 2016. Banana-coffee system cropping guide 2015 Revised Edition. Africa Soil Health Consortium, Nairobi.

WFP. 2018. Growing rainfed crops in Dryland Zones: Field Practitioners Guide No.6. World Food Programme, Nairobi.

Wichern J, Descheemaeker K, Giller KE, Ebanyat P, Taulya G, van Wijk MT. 2019. Vulnerability and adaptation options to climate change for rural livelihoods – A country-wide analysis for Uganda. Agricultural Systems **176**.

World Bank. 2018. Closing the potential-performance divide in Ugandan agriculture . World Bank Group, Washington, D.C.

World Bank. 2022. The Ugandan Commercial Forestry Sector: Review of the Value Chains and Markets. World Bank, Washington DC.

World Bank. 2024. Commodity Markets Outlook, October 2024. World Bank Group, Washington, DC.