PART 1

Agriculture and Land Use Sector

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Abbreviations

ADP	Agricultural Development Project
AFAN	All Farmers Association of Nigeria
AFOLU	agriculture, forestry, land use
AGB	above-ground biomass
ATA	Agricultural Transformation Agenda
CCA	Climate Change Assessment
CGIAR	Consultative Group on International Agricultural Research
CGIAR CSI	Consortium for Spatial Information
CO_2e	CO_2 equivalent
CPS	World Bank Country Partnership Strategy
CSA	climate smart agriculture
DM	dry matter
EX-ACT	EX Ante Appraisal Carbon-balance Tool
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO database
FGN	Federal Government of Nigeria
FMARD	Nigerian Federal Ministry of Agriculture and Rural Development
GAFSP	Global Agriculture and Food Security Program, FGN
GHG	greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
LAC	low active clay
LC	low-carbon
LUC	land use change
LULUC	land use and land use change
MACC	Marginal Abatement Cost Curve
METI	Japan's Ministry of Economy, Trade and Industry
M ha	millions of hectares
NAIP	National Agriculture Investment Plan
NASA	National Aeronautics and Space Administration

NBS	National Bureau of Statistics (Nigeria)
NFLUC	Non-Forest Land Use Changes
NFSP	National Food Security Program (Nigeria)
NPV	net present value
NRDS	National Rice Development Strategy (Nigeria)
NTPF	non-timber forest product
NV	Nigeria Vision
SGM	sustainable grazing management
SLM	sustainable land management
SOC	soil organic content
SRI	sustainable rice intensification

All currency values are in constant 2009 US$ unless otherwise specified.

Executive Summary

In Vision 20: 2020 the Federal Government of Nigeria laid out ambitious targets for increasing the domestic agricultural production sixfold by 2020. Output growth would be achieved through reduction in postharvest losses, increased yields, and expansion of cropland. The present study analyzes the climate change mitigation potential of the agricultural sector within the constraint of meeting these growth targets. The EX Ante Appraisal Carbon-balance Tool (EX-ACT), developed by the Food and Agriculture Organization of the United Nations (FAO), was used for the analysis. The tool enables comparison of emissions between scenarios involving different land use and management choices. The analysis was conducted for a 25-year period, 2010–35, with a 15-year *implementation* period for land management changes and a 10-year *capitalization* period during which no further land management changes are considered but emissions effects deriving from the earlier changes are assessed.

The team constructed a *reference scenario* to provide a plausible pathway for achieving the Vision 20: 2020 growth targets in 2025, based on government policies and expert opinion. First, a growth model was established to estimate expected contributions of cropland expansion and yield increases to meet the overall sector output growth targets. Then more detailed land use and technology change projections were developed in line with the broad parameters set by the growth model. Net greenhouse gas (GHG) emissions were calculated from the detailed land use and technology models, which also incorporated a spatial analysis of land suitability and specific government policies (for example, on afforestation, expansion of irrigation and rural roads, and other land use changes).

The reference scenario produces emissions of about 2.7 billion t CO_2e for 2010–35, at an average of 1.2 t CO_2e/ha/yr. Annual emissions are 6 times lower by 2035, reaching 25 Mt CO_2e from an initial 161 Mt CO_2e in 2010. The difference is due mainly to reduction in emissions from land use change (LUC), as land use patterns stabilize and in particular deforestation slows down and is eventually halted, although 50 percent of secondary forest area is still lost by the end of the simulation period, leaving only 5 percent of the country being covered by secondary forest. By 2035, grassland (–16 percent compared to 2010), fallow (–67 percent), and other land classes (–30 percent) are also reduced to make room for cropland expansion (+45 percent). However, because croplands are better managed with less use of fire on perennial plantations, and with improved seeds and water management on irrigated surfaces, they provide a net sink of 44 Mt CO_2e per yearby 2035. The results show that by improving land management to meet the ambitious Vision 20: 2020 growth targets, significant reductions in GHG emissions are already achieved, but further improvements are possible. Roughly two-thirds of the emissions are due to LUCs, and one-third come from livestock; therefore these activities should be the focus for improvements under the low-carbon scenarios.

A revised growth model demonstrates that the same sector output targets can be met with reduced expansion of cropland if yield growth is accelerated by a realistic amount following the increased adoption of improved and conservation agriculture techniques. Based on the reduced rate of cropland expansion (1.2 percent on average, rather than 1.6 percent) built into the revised growth model, two low-carbon scenarios were explored. Both involve the introduction of a range of sustainable land management (SLM) technologies, which raise agricultural productivity, increase density of trees in the landscape, or both. Under the constraint of fixed maximum average land area (assumed at 800,000 hectare per year) that can be converted to SLM technologies, one scenario (A) selects SLM options so as to maximize the emissions reduction potential, while the alternative scenario (B) maximizes the net benefits accruing to farmers.

All SLM technology options are associated with positive costs for the government, which is assumed to provide technical support and some financial support for their implementation. The balance of costs to private farmers and landowners is very different and depends greatly on the specific type as well as form of production. Scenario A focuses on those options that maximize the emission reduction potential per ha of land, as most notably avoided deforestation and agroforestry. Scenario B, however, focuses on the options that provide the highest private return, particularly conservation agriculture, which increases crop yields for a relatively low investment. (Note that agroforestry also provides significant yield increases, but requires more intense up-front investment from farmers, particularly in labor, and is therefore only marginally profitable for them). Overall, scenario A results in a mitigation potential of 1.0 billion t CO_2e (compared to the reference scenario) entailing costs to the Government of US$ 3.2 billion (in NPV terms), while generating a net return of US$ 5.7 billion to farmers (also NPV). Scenario B generates roughly half the emission reductions, at slightly more than 0.6 billion t CO_2e, at a similarly reduced public cost of about US$ 2.2 billion, while private returns are roughly increased by one-third, reaching US$ 7.3 billion.

Finally, a revised model demonstrates that introduction of carbon payments to private farmers/landowners at a minimum price of $ 6.1 per t CO_2e would be sufficient to achieve the same overall private returns as in scenario B, even when adopting the same mix of SLM options as in scenario A. Nevertheless, even with such moderate payment schemes, some options, such as avoided deforestation, remain economically unattractive to farmers when assessed in isolation.

The results outline the broad potential for sector growth targets to be achieved with greatly reduced carbon emissions through the adoption of appropriate SLM technologies. Some combination of technologies or practices generates net benefits to farmers, while others are not so financially attractive but involve even greater emission reductions and other environmental benefits. Despite their benefits, however, the large-scale introduction of SLM technologies pose significant practical obstacles—mostly associated with convincing risk-averse farmers to adopt new practices and providing a supportive environment for making up-front investments that will pay off a few years after the initial investment. Chapter 4 reviews some of the steps that may be necessary for SLM to take off, including development of the required agricultural research and extension services, and providing a stable, conducive policy framework. Decentralization, reallocation of funding, and increased cooperation and interaction between diverse stakeholders are some of the institutional steps required.

CHAPTER 1

Introduction

The Federal Government of Nigeria (FGN) and the World Bank have agreed to carry out a Climate Change Assessment (CCA) within the framework of the Bank's Country Partnership Strategy (CPS) for Nigeria (2010–13). The CCA includes an analysis of options for low-carbon development in selected sectors, including power, oil and gas, transport, and agriculture. The goal of the low-carbon analysis is to define likely trends in carbon emissions up to 2035, based on government sector development plans, and to identify opportunities for achieving equivalent development objectives with a reduced carbon footprint.

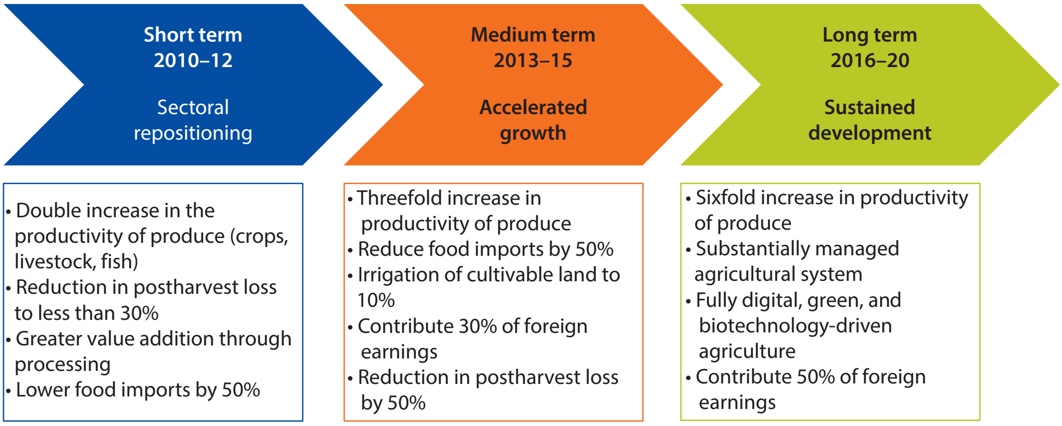
Agriculture and land use change are major contributors to Nigeria's total greenhouse gases (GHG) emissions. According to FAOSTAT (2013) estimates, agriculture alone, excluding land use change (LUC), accounted in 2010 for emissions of 48,154.36 gigagrams (Gg) CO_2e, while the average annual emissions from net forest conversions 2000–10 are estimated at 180,228 gigagrams CO_2e and recent estimations of emissions from drained cultivated organic soils are not available.[1] At the same time, agriculture also offers various mitigation options, essentially through enhanced carbon storage in soil and vegetation.

The agriculture sector currently contributes 33 percent of national income and almost 70 percent of employment (CBN 2002; World Bank 2007), and is likely to remain a major economic sector, even if current stagnant or declining sector output is not reversed.

Agriculture features prominently in Vision 20: 2020 (FGN 2010a), the overall growth strategy adopted by the Government in 2008, which aims for Nigeria to become one of the world's 20 leading economies by 2020. Vision 20: 2020 establishes targets for threefold and sixfold increases in domestic agricultural productivity by 2015 and 2020, respectively. These targets are to be achieved through (1) reduction of postharvest losses; (2) increasing yields (by expansion of irrigation and greater use of improved and disease-resistant crop varieties); and (3) expansion of cropland. Figure 1.1 illustrates the Vision 20: 2020 phased approach to achieve these objectives.

More recently, the FGN adopted the Agricultural Transformation Agenda (ATA) (FGN 2011) for transformation of the sector through processes including

Figure 1.1 Implementation of the Vision 20: 2020 Roadmap



Source: Design based on FGN 2009.

import substitution, export orientation, and value-addition through processing and backward integration linkages. Emphasizing the role of the private sector, the ATA focuses on a selected number of value-chains (including rice, cassava, sorghum, cocoa, and cotton), on complementary investments in infrastructure, and on providing improved access to credit and steps toward an enabling policy environment.

Scope and Limitations of the Analysis

This section analyzes greenhouse emissions from agriculture, forestry, and land use (AFOLU). Emissions from agro-industries are not included. This part of the low-carbon study comprises the following components:

- Development of a reference scenario of GHG net emissions for the agriculture sector, consistent with Vision 20: 2020 and other government plans
- Identification of opportunities for reduced net emissions—reduced emissions and/or enhanced carbon sequestration—while achieving the same development objectives as in the reference scenario
- Economic assessment of low-carbon options in order to help the Nigerian government to prioritize policy options.

The analysis does *not* intend to evaluate the feasibility of government policy targets incorporated into the reference scenario, but rather to investigate whether—and at what cost to farmers and to the government—those targets could be achieved with lower net carbon emissions. The agriculture targets under Vision 20: 2020 are ambitious and will be affected by many uncertain variables. Hence the reference scenario is not necessarily the most likely to actually materialize, but does serve as a basis of comparison with the low-carbon alternative.

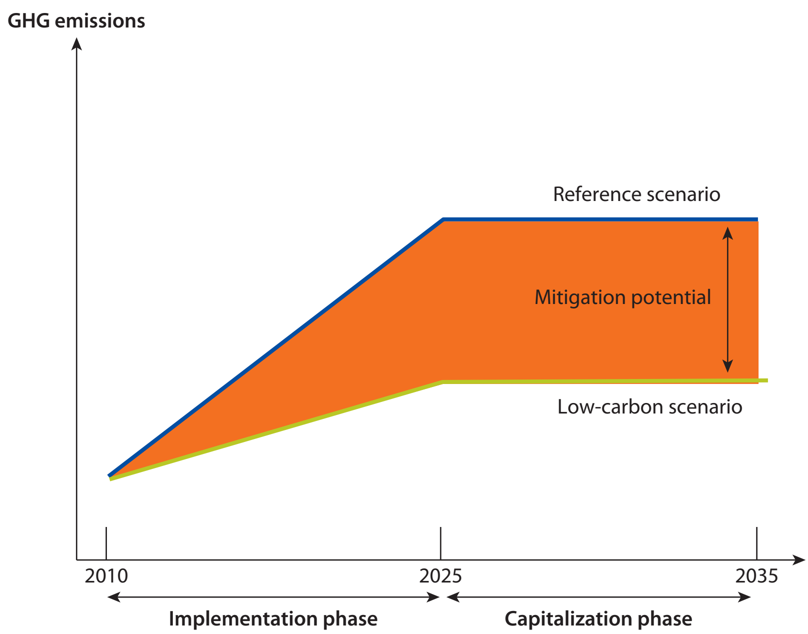
The study evaluates costs and benefits in a partial equilibrium setting, with no attempt to capture the indirect, general equilibrium effects of adopting low-carbon technologies or management practices. The results of this analysis (the first of its kind in Nigeria) should be considered as a first approximation of the potential for low-carbon development in the Nigerian agriculture sector. The study aims at providing policy makers with an order-of-magnitude estimate of mitigation potential, and an understanding of the value of dedicating further efforts (including through specific projects) at pursuing low-carbon development in agriculture, but is not meant to inform the design of specific, project-level interventions.

Methodology and Data Sources

GHG emissions under the reference and low-carbon scenarios are estimated using EX-ACT (Ex Ante Appraisal Carbon-balance Tool), developed by the Food and Agriculture Organization (FAO) and aimed at providing ex ante estimates of the impact of agriculture and forestry projects or policies on net GHG emissions (Bernoux et al. 2010). The mitigation potential of the low-carbon scenario is calculated as the difference in emissions resulting from the two scenarios (figure 1.2).

In consultation with government officials and other experts on Nigeria, the research team agreed to adopt a conservative assumption that the Vision 20: 2020 targets—including a sixfold increase in agricultural productivity—would be met by 2025 rather than 2020. Both scenarios therefore start in the year 2010 and span a 15-year implementation phase in which aggressive investments are

Figure 1.2 Mitigation Potential of Low-Carbon Practices on the Agriculture Sector



Source: World Bank data.

made to achieve sector development targets, and a 10-year capitalization phase, in which benefits of those investments continue to accrue.

A simple growth model was used to estimate the magnitude of crop expansion, consistent with the Vision 20: 2020 targets.[2] More detailed land use and technology change models were then constructed within the overall growth parameter in order to calculate emissions. The detailed assumptions used in the modeling drew from discussions among experts from the government, FAO, and World Bank staff to determine distributions of secondary forests, grasslands, degraded lands, and other lands, taking into account a spatial analysis of soil quality, slope, and other suitability factors for cultivation. Expert opinion was also used to select the most plausible low-carbon options suited to the Nigerian context.

The data sources on agronomic practices and land use are listed in tables 1.1 and 1.2.

Table 1.1 Sources for Nigerian Agronomic Practices

Practices	*Data sources*
Yield, irrigation	• Federal Government of Nigeria—National Implementation Plan (NIP) (FGN 2010a) • Getting Agriculture Going in Nigeria (World Bank 2006) • Nigerian Federal Ministry of Agriculture and Rural Development—National Agricultural Investment Plan (NAIP) (FGN 2010a) • The Nigerian Federal Ministry of Agriculture and Rural Development—Global Agriculture and Food Security Program (GAFSP) (FGN 2010b)
Fertilizer use	• FAOSTAT (faostat.fao.org) • National Bureau of Statistic of Nigeria (NBS) (NBS 2009)
Rice planning	• National Rice Development Strategy (NRDS) (NFRA—JICA 2009)
Livestock management, yield evolution, regional agriculture practices disparity	• New Nigerian Agricultural Policy (FGN 2010c)
SLM practices	• FADAMA study (Ike 2012) • Benefit Cost Analysis of SLMW in Nigeria (World Bank 2010a) • *NIGERIA Simulation of Sustainable Land Management Practices* (World Bank 2010b)

Source: World Bank data.

Table 1.2 Data Sources for Land Uses

Practices	*Data sources*
Rice	• National Rice Development Strategy (NRDS) (NFRA, JICA 2009)
Cropland and perennial crop	• FAOSTAT • National Bureau of Statistic of Nigeria (NBS 2009)
Forest management	• Forest Resources Assessment for Nigeria 2010 (FAO 2010) • UN Programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD) (FGN and UNDP 2010; Odigha and Dahiru 2011)
Cropland, grassland, forest, soil quality	• Global Administrative Areas Database (GADM 2010) • Global Land Cover Network (FAO 2009)
Climate and soil constraints for the cultivation of crops	• ASTER Global Digital Elevation Model (ASTER GDEM) (Japan Space Systems 2011) • The CGIAR Consortium for Spatial Information (CGIAR-CSI 2008) • IIASA Harmonized World Soil Database (IIASA 2008)

Source: World Bank data.

Table 1.3 Sources of Coefficients Used in the Analysis

Type of vegetation	*Type of coefficient*	*Tier 1 (IPCC 2006)*	*Tier 2 (data sources)*
Forests	Carbon content in above and below ground biomass for secondary forests		Henry 2010
	Emissions factors of forest biomass burning	×	
	Afforestation/reforestation: carbon pool content	×	
Annuals, perennials, grasslands, degraded lands, other	Nonforest land use changes (initial and final carbon pool in biomass and soil)	×	
Annuals	Carbon storage capacity of different agronomic practices	×	Chivenge et al. (2007); Leite et al. (2009)
Perennials	Above and below ground biomass growth rate	×	
	Emissions factors of biomass burning	×	
Rice	Methane emissions	×	
Grassland	Emissions factors of biomass burning	×	
Livestock	Methane emissions from enteric fermentation	×	
	Methane emissions from manure management	×	
	Nitrous oxide emissions from manure management	×	
	Mitigation potential of better feeding practices	×	
Inputs	Carbon dioxide emissions from urea application	×	
Other investments	CO_2 emissions of gasoil	×	
	CO_2 emissions of biodiesel		Guo and Hanaki (2010)
	CO_2 emissions of the installation of irrigation system	×	
	CO_2 emissions from the construction of buildings and roads	×	

Source: World Bank data.

Emissions factors and carbon storage coefficients are needed to convert land use changes and agronomic practices into GHG emissions. The EX-ACT tool includes default coefficients taken from the Intergovernmental Panel on Climate Change Guidelines 2006 (IPCC 2006), but where possible and appropriate, local data were used to drive values more suited to the Nigerian context. Table 1.3 summarizes the sources of the coefficients used in the analysis. More details are available in appendix A.

Notes

1. Please refer to the first national communication of Nigeria to the UNFCCC for older but more comprehensive estimates (FGN 2003).
2. Note that it is assumed that the sixfold increase in the value of agricultural output envisioned under Vision 20: 2020 is only partly met through increases in physical output, with the rest accounted for in terms of an increases in price per value of output, at least partly due to increased value-added among other factors. Hence, the growth in physical output to 2025 used as the basis of the growth model is less than a sixfold increase.

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CHAPTER 2

The Reference Scenario

Agricultural Growth Model

A simplified growth model was constructed representing a feasible pathway to achieving the increase in total agricultural production envisaged by Vision 20: 2020. The model, based on literature, consultation with stakeholders, and expert judgment, accounts for overall economic growth in agriculture using the following three factors:

- **Cropland expansion**. The annual rate of cropland expansion is assumed to decline from 2.33 percent to 0.79 percent linearly, resulting in a compounded mean annual growth rate of 1.56 percent for 2010–25. Thereafter, the rate of expansion remains at 0.79 percent per year.

- **Yield growth.** Average crop yields (per unit area of cropland) are estimated to grow by 3 percent per year for the first two years and then by 5 percent for the next three through investments in improved agronomic practices, such as adoption of improved seeds and fertilization, based on national yield responses to similar investments in Asian countries (Evenson and Gollin 2003). Thereafter, a 4 percent[1] annual growth rate was assumed for the rest of the modeling period, since shorter fallow periods will decrease soil organic content, thus limiting yield growth.

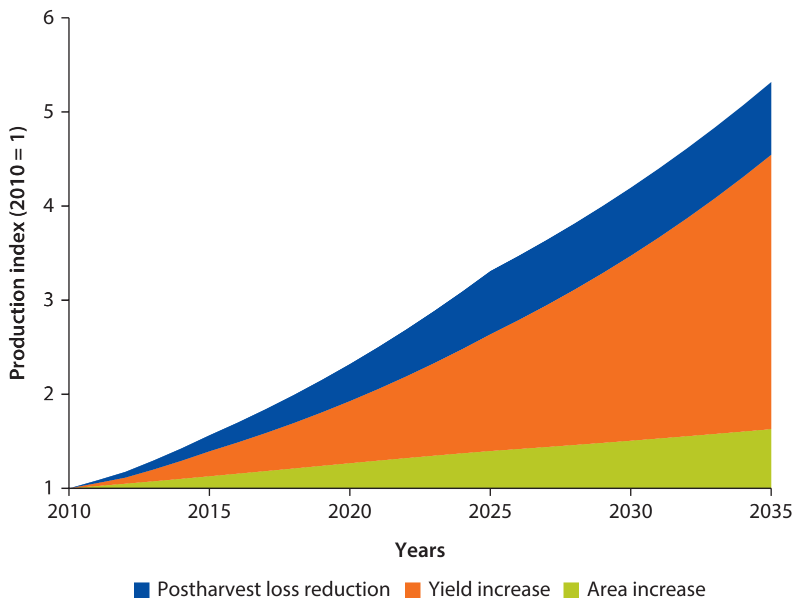
- **Annual growth due to the reduction of postharvest loss.** Postharvest loss is currently estimated at 33 percent of production. The Vision 20: 2020 strategy aims to reduce it by 50 percent by 2015 and 90 percent by 2020. The growth model assumes more conservatively that the 90 percent target will be reached by 2025 via a linear 6 percent decrease per year in the rate of postharvest loss. This is equivalent to an annualized compound growth rate of the volume of agricultural production reaching market of 2.48 percent during 2010–25. After 2025, reductions in postharvest losses are assumed to take place at a slower pace (less than 1 percent per year).

Table 2.1 Agricultural Growth Model Predicted Growth

Type of growth	*Average % growth*	
	2010–25	*2026–35*
Annual cropland expansion	1.56	0.79
Annual yield growth	4.07	4.00
Annual growth due to postharvest loss reduction	2.48	0.30

Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Figure 2.1 Agricultural Growth Model: Production Increase and Growth Sources



Source: World Bank data.

The assumptions and results of the growth model are illustrated, respectively, in table 2.1 and figure 2.1.

GHG Emissions Model

The growth model was then used as a basis for identifying a consistent set of land use and technological changes that could plausibly be expected to occur by 2025, and which would form the basis for estimating greenhouse gases (GHG) emissions from the agriculture sector and project an emissions model.

Land Use Changes

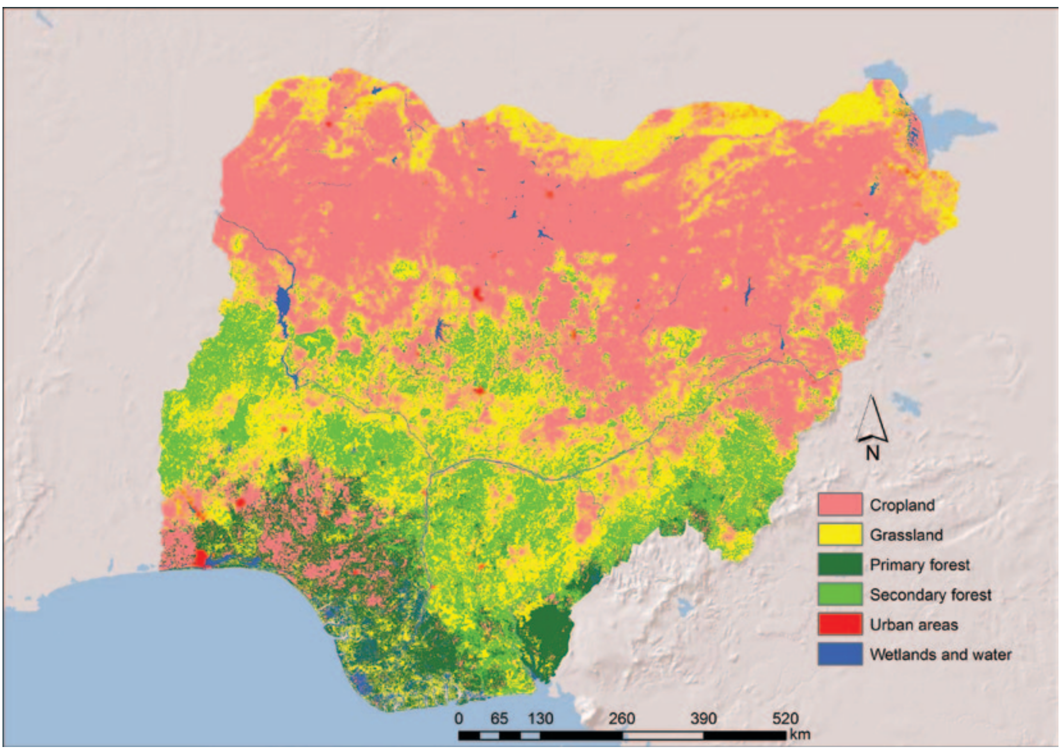
Land use changes are expected to contribute to greenhouse gas (GHG) emissions, albeit at a decreasing rate, particularly through conversion of forests, grassland (that is, pasturelands that also contribute to agriculture sector output), fallow acreage, and other lands to cropland. In accordance with government policies, land use changes are assumed to take place predominantly from 2010 to 2025. After 2025, land use patterns notionally follow the same trends as in the reference growth model, but only the land use changes until 2025 are counted in the calculation of emissions.

Conversion of forest to agricultural lands was assumed to affect only secondary forests. A GIS-based (geographic information services) evaluation of the suitability of secondary forests for agricultural conversion was undertaken based on current land use, slope, and soil quality (see map 2.1). Secondary forest areas were considered suitable for conversion if categorized as "partly with constraints" or as of "higher suitability." The results of the exercise are shown in map 2.2, which indicates that over 3 million hectares of existing secondary forest could be converted to agriculture under the two conditions given above.

The assumptions of the land use change model in the reference scenario, based on official policy, current trends, experts' opinion, and consistency with the growth model to 2025, are as follows:

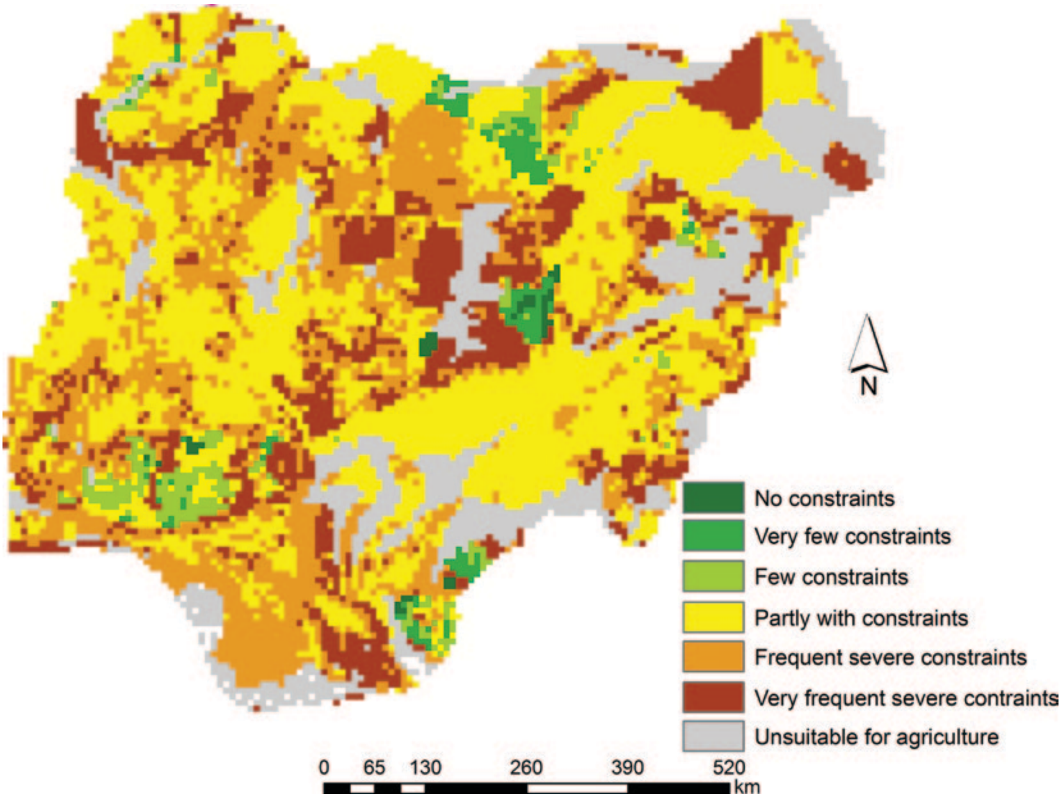
- Land conversions are based on linear processes, 2010–25.[2]
- The area of land under annual crops (cereals, tubers) increases by 1.56 percent/year, and the area under perennial crops (palm tree, rubber tree, cocoa) by 3.22 percent/year following the trend for 1990–2010.

Map 2.1 Land Use Map, 2011



Source: FAO GeoNetwork Database, World Bank Development Indicators 2011.

Map 2.2 Land Suitable for Agricultural Use, 2011



Source: FAO GeoNetwork Database, World Bank Development Indicators 2011.

- Ninety percent of secondary forest land suitable for agriculture is converted into annual crops, with the rest assigned to perennials and grasslands.
- Tropical secondary forest in the Southwest accounts for 75 percent of forest land converted to perennial crops, due to the wet preference of perennials. The remaining 25 percent of forest conversion to perennials takes place in moist secondary forest in the North.
- As the area of forest available for conversion is insufficient to meet the total increase in cropland, some grassland and fallow are also converted to cropland, since they offer a better soil quality for cultivation than degraded land or other land.
- The area of wet rice cultivation within annual cropland roughly doubles to 2.625 million ha by 2025, from 1.313 in 2010, meeting the Government's 2018 target from the National Rice Development Strategy (NFRA—JICA 2009).
- Based on consultation with the Department of Forestry, afforestation will take place over 600,000 hectares. Reforestation (dry and moist plantation forest) takes place on degraded land (50 percent), fallow (30 percent), and pasture-lands (20 percent).

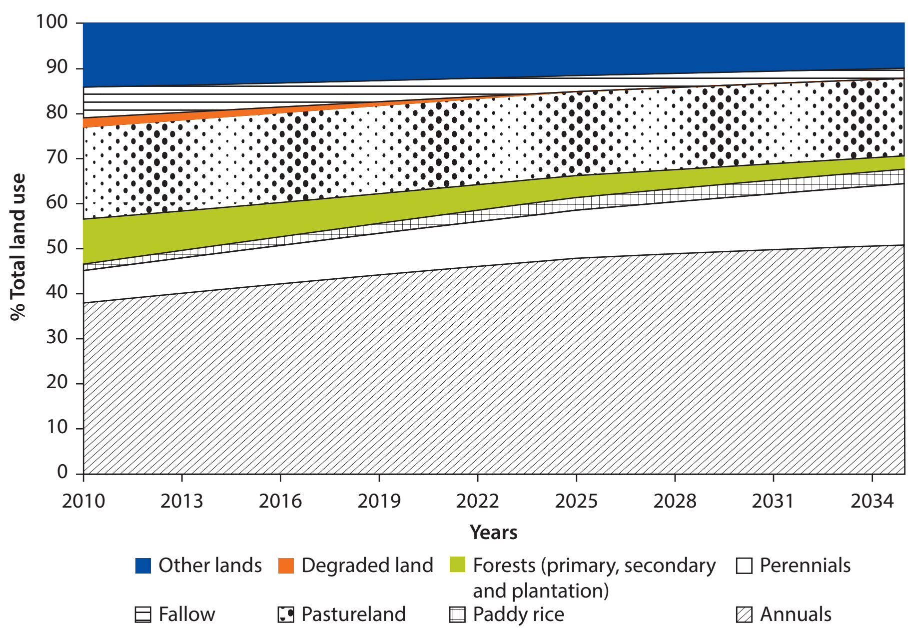
- Half of the degraded lands are restored into perennial plantation, while the rest is restored to pasturelands or forest.
- The conversion of other land uses (grassland, degraded land, fallow, other land[3]) is calculated in ways that ensure overall consistency of the land use matrix reported appendix B for 2025.

Figure 2.2 illustrates the change in land use over time. Overall, by 2025, forest land shrinks by more than 50 percent, and annuals and perennials increase by a factor of 1.3. Grassland and other lands remain stable or are slightly reduced. In 2010 crops (annual, perennial, rice) account for 46 percent of the total country area, forests for 10 percent, pasturelands for 20 percent, and the rest (degraded land, fallow, other) for 23 percent. In 2025 crops are projected to account for 61 percent of total land area. Forests have shrunk to 5 percent. Pasturelands remain stable at about 19 percent. After 2025, crop expansion slows down, and crops account in 2035 for 68 percent of the total country area, forest for 3 percent, pasturelands for 17 percent, and other lands for 12 percent. The land use change details can be found in appendix B; a concise overview is given in table 2.2.

Sector Investments and Technological Change

The reference scenario assumes that the Vision 20: 2020 goal for improved crop cultivars and fish and livestock breeds to constitute 50 percent of stocks will be met by 2025, via linear growth. It further assumes that where applied, these improved varieties will be accompanied by better management, namely use of

Figure 2.2 Land Use Evolution in the Reference Scenario



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Table 2.2 Land Use in 2010, 2025, and 2035 for the Reference Scenario
ha, thousands

Land use	*2010*	*2025*	*2035*
Annuals	34,437	43,437	46,155
Perennials	6,552	9,712	12,419
Paddy rice	1,313	2,625	2,919
Forest	9,101	4,438	2,700
Secondary forest	8,805	3,542	1,804
Plantation	296	896	896
Live fencing/agroforestry	0	0	0
Pastureland	18,629	16,974	15,669
Degraded land	1,849	0	0
Fallow	6,234	3,257	2,076
Other lands	12,941	10,602	9,116
Total	91,054	91,054	91,054

Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Table 2.3 Projected Expansion of Infrastructure for Agriculture in 2025

		Surface, 1000 m²		
Type of building	*Quantity*	*Office*	*Concrete*	*Metal*
Livestock breeding and multiplication centers	12	12	23.76	0
Export conditioning centers	12	12	23.76	0
Agric seeds centers	36	36	71.28	0
Slaughterhouse	36	36	71.28	0
Large-scale rice processing	181	36.20	0	325.80
Cassava processing factories	200, 000	0	0	2,000
Storage capacity (3–44 Mt)	41	2.05	40,795	

Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

suitable fertilizers and no residue burning for crops, and improved breeding and feeding practices for livestock. Livestock numbers increase continuously at the same rate as for 2000–10.

The government target to expand irrigation—from 1 percent of cultivated area in 2010 to 25 percent in 2020—is assumed to be reached only in 2035. Hence in 2025, 15.8 percent of the cropland will be irrigated. All the irrigated area will be managed with improved water efficiency. Degraded lands converted to pasturelands will be improved with organic and inorganic fertilizers and managed without fire, to allow recovery of soil fertility.

It is assumed that 6,000 kilometers of roads will be constructed to improve market access to remote areas. The proportion of tractor-ploughed arable land will rise from about 8.5 percent to 50 percent by 2025 (Oni 2004). Assumptions about the expansion of processing and storage infrastructure were derived from Vision 20: 2020 plans to strengthen agricultural export markets (summarized in table 2.3).

Climate and Soils

Moist tropical climate and low-active clay (LAC) soil classifications were used for the analysis, as these were considered closest to the typical conditions in Nigeria. Although there is local variation in soil and climate conditions, a sensitivity analysis (see appendix E) was conducted which indicated that these factors would have little effect on the final results in terms of the comparative emissions between the reference and low-carbon scenarios.

Emissions Baseline

GHG emissions were calculated from 2010 to 2035 for land use changes and other sector reforms that take place up to 2025—that is, the emissions consequences of agricultural development up to 2025 is being estimated—with allowance for a 10-year *capitalization* period thereafter, but further sectoral changes after 2025 are not represented in the calculation.

GHG emissions are expressed in CO_2e.[4] The different emissions sources have been grouped into four main categories:

- **Crops (including annuals, perennials, and paddy rice).** Crops provide a net carbon sink over time, due to an increase in soil carbon through the improved management practices introduced alongside new crop varieties in the reference model. Paddy cultivation, on the other hand, acts as a net source due to methane production from the flooded soil.
- **Land use changes.** These changes will emit or sequester CO_2 depending on whether the conversion is to a vegetation cover type with lower or higher carbon density. The greatest changes occur as a result of deforestation or afforestation. Land use change may result in GHG emissions/sequestration beyond the time at which it occurs, due to associated changes in soil carbon, which may some years to reach a new equilibrium.
- **Livestock and pasturelands.** Emissions from the livestock are essentially methane and nitrous oxide produced by the digestion processes of ruminants and from manure, while improved pastureland management can store carbon through an increase in the soil organic matter.
- **Agricultural inputs.** These involve GHG emissions associated with fertilizer consumption and production, infrastructure construction, and fuel consumption.

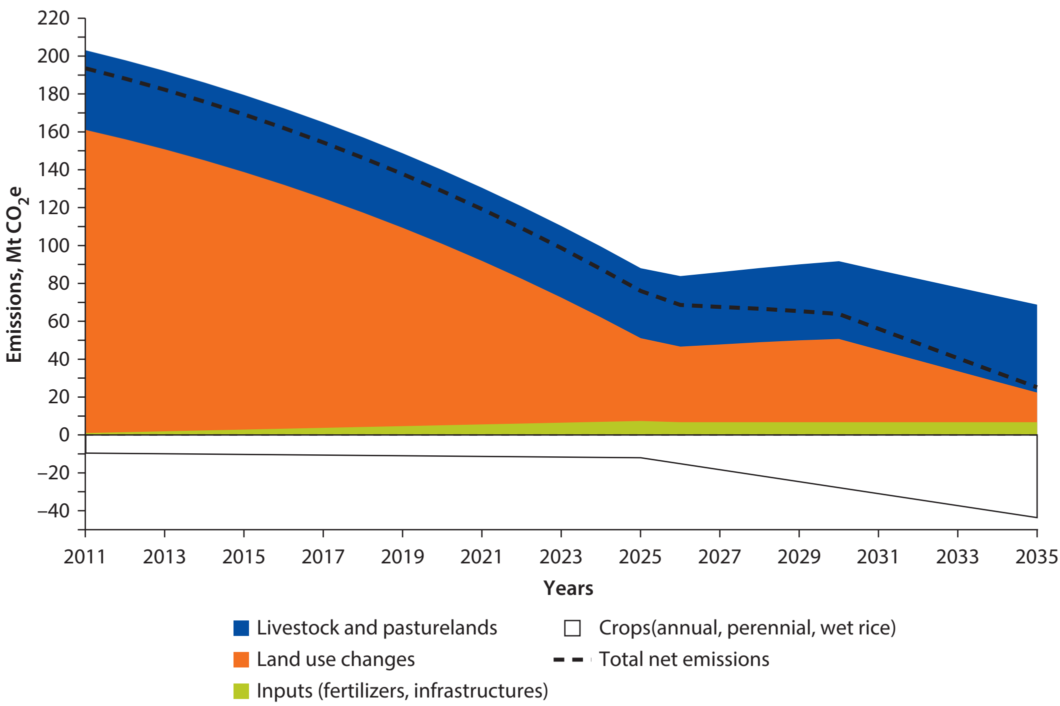
While emissions decrease over time, agriculture remains a net source of GHG in the reference scenario; it accounts for about 2.7 billion t CO_2e emissions during the whole period from 2010 to 2035 (that is, an average of 1.2 t CO_2e /ha/yr). Table 2.4 shows total annual emissions at the beginning (2010) and end (2035) of the simulation period. Figure 2.3 illustrates the evolution over time of the four main emissions categories, and the overall net emissions pathway.

Table 2.4 Annual Emissions of 2010 and 2035 in the Reference Scenario

	Emissions (Mt CO_2e/yr)		
Land use	*2010*	*2035*	*% Difference*
Land use changes	127.1	15.6	–88
Crops	–9.4	–43.6	–364
Livestock and grassland	42,4	46.4	+10
Inputs	0.6	6.7	+1068
Total	160.6	25.2	–84

Source: World Bank data.

Figure 2.3 Annual Emissions by Land Use Activity, in the Reference Scenario, 2010–35



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Annual emissions due to land use changes (representing 60 percent of cumulative emissions) decline by a factor of 8, as land use change (including net deforestation) is brought to a halt by 2025. Residual emissions from soil carbon changes related to land use change increase and then decrease after 2025 due to ongoing soil carbon loss from earlier occurring deforestation, with more gradual and increasing accumulation of soil carbon from afforestation.

Conversion of degraded land, fallow, and other lands into perennials accounts for 65 percent of gross sinks, followed by annual crops (22 percent) and afforestation (13 percent).

Emissions from livestock and grassland account for 30 percent of the cumulative total. They increase a little due to augmentation in the number of animals.

The net sink function of crops is enhanced over time as a result of both the increase in the area of perennials and improvements in agronomic practices for annual crops (for example, use of improved seeds and water management for the irrigated surfaces). Carbon storage increases after 2025 because residue burning in annual and perennial croplands is halted by that point. Wet rice remains a net GHG source, but its emissions are exceeded by the sink function of annuals and perennials.

Emissions from inputs and infrastructure increase, reflecting government plans to expand the use of fertilizers. However, they contribute to a limited part (4 percent) of total GHG emissions.

Notes

1. As no scientific data were available, this figure was estimated thanks to consultations with FAO experts.
2. Forest loss is actually a decelerating process, rather than being strictly linear, but the effect is too minor to be evident in figure 1.4.
3. Other lands include gullies, dominantly grasses, discontinuous grassland; shrub/sedge/graminoid; freshwater marsh/swamp; natural waterbodies; sand dunes; montane grassland; reservoirs; rock outcrop; saltmarsh/tidal flat; alluvial; mining areas; and canals.
4. Which standardizes the contribution of each GHG, according to its Global Warming Power (GWP): 1 for carbon dioxide, 21 for methane, and 310 for nitrous oxide.

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Oni, K. C. 2004. "Creating a Competitive Edge through Agricultural Mechanization." Invited paper presented at the 3rd Agricultural Summit of the Nigerian Economic Summit Group (NESG), Benin City, Edo State, December 8–10.

CHAPTER 3

The Low-Carbon Scenarios: Mitigation Options

The low-carbon scenarios pursue the same development goals as the reference scenario, that is, a roughly sixfold increase in the overall productivity of the agricultural sector by the end of the model period until 2035, but include additional investments aimed specifically at reducing the net greenhouse gases (GHG) emissions from the sector. These mitigation options are composed of available and proven sustainable land management (SLM) practices. According to TerrAfrica (World Bank 2011, 26), sustainable land management is the "adoption of land systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources."

Sustainable Land Management Options

SLM options occur in agricultural, livestock, and forestry land uses, and may be interlinked:

- **Conservation agriculture** aims at increasing yields environmental benefits through improved management of soil and water resources. The key agronomic practices included are crop rotation/intercropping, minimal turning of the soil (minimum or no tillage), and maintaining soil cover through cover cropping or mulching. However, the availability of mulch material (for example, crop residues, cut vegetation, manure, compost, and by-products of agro-industries) is typically lower in semi-arid regions (Kayombo and Lal 1993), which cover a significant part of Nigeria.

- **Avoiding deforestation** is another major mitigation benefit potentially achieved by conservation agriculture. Increased yields from well-established agricultural systems using conservation management practices can reduce the need to convert additional forest areas to cropland (for the same overall production targets[1]).

- **Agroforestry** refers to land use systems in which woody perennials are integrated with crops and/or animals on the same land management unit (Junge et al. 2008), including agro-silvicultural systems (intercropping, alley cropping), silvo-pastoral systems (fodder banks, live fences, trees and shrubs on pasture), and intermixtures. Agroforestry may also contribute to conservation agriculture by providing mulch.

- **Sustainable Rice Intensification (SRI)** practices can reduce methane emissions from rice paddies. SRI practices involve modifying the growing environment so that the rice plants can grow better with more economical use of inputs. For instance, instead of flooding the rice, the seedlings are planted in dry soils that are watered periodically. Seedlings are also spaced more widely, to allow for regular soil aeration and weeding as the plants develop.

- **Better feeding and breeding practices** help reduce livestock emissions from enteric fermentation and manure, which can even be offset by sequestering carbon in the biomass and soil of pasturelands. Improved rangeland management may involve rotational grazing, reduction of fire use, application of fertilizers or manure, irrigation, improved grass varieties, association with legumes, and other practices. Sustainable rangeland management should also result in lower stocking densities.

The public and private costs for the various SLM options vary. Public costs are incurred through provision of government support for each option; for example, provision of improved seed, fertilizers or feed, extension services, and administrative/management costs. Farmers or private landowners incur costs—for example, labor and producing/purchasing fertilizer, feed, and fuel—but also benefit from the incomes accruing from increased production.

Table 3.1 summarizes the different SLM technologies appropriate for Nigeria that have been used to formulate the low-carbon scenario, including information on public costs and private costs/benefits that will be used in the models. Appendix C, tables C.1 and C.2, present those technologies in more detail, and table C.3 provides information on the assumptions behind the calculation of costs for those SLM options.

Adjusted Agricultural Growth Model

The agricultural growth model was adjusted to assess whether it was feasible for crop expansion to decrease to 0 percent by 2025, while still reaching the same sector production targets, given the higher yields expected from the introduction of SLM technologies. Reduction of postharvest loss remains the same as in the reference scenario, as indicated in table 3.2 and figure 3.1. Annual yield growth is expected to be a little higher than in the reference scenario, but numerous studies indicate that the increase in yield from SLM may take a little time to become noticeable. Therefore the increase in annual growth yield is estimated to

Table 3.1 Mitigation Options Adopted in the Low-Carbon Scenario

Description	*Dynamic of adoption and year lag*	*Potential yield increase*	*Potential carbon benefits*	*Public costs $/ha/yr*	*Private costs and benefits $/ha/yr (negative = benefit)*	*Key constraints*
SLM practice: protection of existing forests—avoiding deforestation						
The forest is preserved	Gradual adoption rate (geometric) No year lag, because it is vital to take action immediately to preserve the remaining forest and biodiversity it shelters.		Depends on the type of forest, its density, and the use after conversion. From 0.75 to 4.25 t C/ha/yr for a Brazilian tropical forest	Year 1: 1481 Years 2–4: 600 Following years: 0 Cost to protect the forest (physical and policy/ management protection), plus an opportunity cost the first year (nonharvesting of timber)	During entire period: 588 Opportunity cost for nonconversion of the forest into a more profitable land use Benefits: Non-Timber Forest Product (NTPF), i.e., fauna and flora	Often the sole option to preserve forested area is to intensify agricultural production on other land. Need to find and provide more affordable fuel-efficient stoves or sustainable alternative fuels to decrease the pressure on wood resources. Timber for some countries can be important export revenue that they might not want to loose. Sustainable forest management is effective if designed on a participatory basis.

table continues next page

Table 3.1 Mitigation Options Adopted in the Low-Carbon Scenario (*continued*)

Description	*Dynamic of adoption and year lag*	*Potential yield increase*	*Potential carbon benefits*	*Public costs $/ha/yr*	*Private costs and benefits $/ha/yr (negative = benefit)*	*Key constraints*
SLM practice: conservation agriculture						
Minimum or no-tillage Mulching Crop rotation integrating leguminous and crop association	Gradual adoption rate (geometric) Conservation agriculture is one of the most important low-carbon (LC) options, therefore must be implemented rapidly. Research team suggests beginning 2 years after the actions on deforestation.	Yields can be more than 60% higher than under conventional tillage. Conservation agriculture with fertilization increases the yield from 1.2 to 2.0 t/ha for maize, and from 0.5–0.7 to 1.1 t/ha for tef in Ethiopia (an annual grass crop harvested for grain)	Conservation tillage can sequester 0.1–1.3 t C/ha/yr globally	Years 1–3: 71 Following years: 21 It includes the public subsidies for seeds and fertilizers, which stops after 3 years, as well as the cost of extension services and the transaction expenses.	Year 1: 71 Years 2–3: –234 Following years: –218 The cost for producing the manure and purchasing the fertilizers is compensated by the 80% increase in yield.	Farmers need training and access to skilled advisory services. Transition period (5–7 yr) before conservation agriculture reaches equilibrium. Reduced tillage means having recourse to herbicides (farmers must be educated in correct use) or adopt integrated pest management (crop rotation, cover crop, cultural practices) (Pieri et al. 2002, 30). Not successful in heavy clay soils, poorly drained sites, compacted soils, and arid areas.

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Table 3.1 Mitigation Options Adopted in the Low-Carbon Scenario *(continued)*

Description	*Dynamic of adoption and year lag*	*Potential yield increase*	*Potential carbon benefits*	*Public costs $/ha/yr*	*Private costs and benefits $/ha/yr (negative = benefit)*	*Key constraints*
SLM practice: agroforestry						
Establishing stands of trees on land not currently classified as forest (includes shelterbelts, windbreaks, and woodlots)	Gradual adoption rate (geometric) Agroforestry should begin at the same time as conservation agriculture, as they are linked and work in synergy. The year lag is therefore 2 years.	Growth rate depends on the type of plantation, as well as its density. The crop yield response is uncertain and variable due to competitive effects of the different cultures for light, water, and nutrients. Different studies show an increase by 50–200%; others no significant effect.	0.86–3.75 t C/ha/yr for a Brazilian tropical plantation	Year 1: 166 Years 2–5: 300 Following years: 0 Government pays 25% of the plantation (live fencing, hedges, etc.) cost, and the protection costs.	Year 1: 906 Year 2: 357 Year 3: 280 Following years: –318 The first years, the farmer bears 75% of the plantation cost. For entire period, the maintenance cost of the live fences and the opportunity cost (because trees are planted on cropland and grassland surfaces) are taken into account. But the NTPF from the hedges (fodder, wood) and the 50% increase in the yield of adjacent crops largely compensate for the expenses.	In dry lands, planting of trees is difficult due to lack of water for nurseries in the dry season and absence of labor for protecting the trees. Uncertain land tenure situations. Land availability is limited, due to high population density and competition for land between agriculture and forestry. Ongoing need for protection, as with natural forests. Long period to grow industrial tree crops to merchantable size. Risks of fungal or insect diseases

table continues next page

Table 3.1 Mitigation Options Adopted in the Low-Carbon Scenario (*continued*)

Description	*Dynamic of adoption and year lag*	*Potential yield increase*	*Potential carbon benefits*	*Public costs $/ha/yr*	*Private costs and benefits $/ha/yr (negative = benefit)*	*Key constraints*
SLM practice: Sustainable Rice Intensification (SRI) (flooded rice)						
Rotational and intermittent irrigation Use of genetically improved seeds that are transplanted instead of broadcasted Application of organic fertilizers Integrated Pest Management	Gradual adoption rate (geometric) SRI is another important mitigation option, but may be less important than conservation agriculture and avoiding deforestation, since less surface is concerned. The research team therefore recommends starting SRI just after the other techniques have been introduced, e.g., starting from year 3.	Average yield increase 10–25%	Emission rates ranged from less than 100 kg CH_4 ha^{-1} to more than 400 kg CH_4 ha^{-1} for intermittent irrigation and continuous flooding, respectively.	Years 1–5: 42 Following years: 16 Subsidies for improved seeds, plus transaction and extension services costs	Year 1: 296 Year 2: 36 Following years: –64 Takes into account time for coordination, manure production, and an increase by 25% in the yield.	Due to great diversity in rice production systems, SRI will not be applicable invariably everywhere. SRI requires excellent land preparation, timely availability of irrigation water during critical periods of growth, good irrigation infrastructure, and efficient weed control methods. SRI is mainly suitable for increasing rice yields in environments with acid, iron-rich soils, high labor availability, and a generally low level of crop intensification.

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Table 3.1 Mitigation Options Adopted in the Low-Carbon Scenario (*continued*)

Description	*Dynamic of adoption and year lag*	*Potential yield increase*	*Potential carbon benefits*	*Public costs $/ha/yr*	*Private costs and benefits $/ha/yr (negative = benefit)*	*Key constraints*
SLM practice: Sustainable grazing management (SGM) with inputs (gathered in the livestock and pastureland improvement category)						
Restoration of degraded pastures with inputs such as mineral fertilizers, manure application, and irrigation No use of fire	Gradual adoption rate (geometric) Livestock and grassland management are linked; these three options should be implemented at the same time, after leaving about 3 years between the start of conservation agriculture and grassland improvements (so the farmers have time to integrate conservation agriculture practices and start seeing increased revenues before implementing other measures).	Increase varies depending on the type and quantity of improvements. Herbage production can be increased 1- to 4-fold through timing and intensity of grazing.	Rates of carbon sequestration by type of improvement: 0.11–3.04 t $C{\cdot}ha^{-1}\ yr^{-1}$, with a mean of 0.54 t $C{\cdot}ha^{-1}{\cdot}yr^{-1}$ (highly influenced by biome type and climate)	Years 1–3: 35 Years 4–5: 15 Following years: 2 Subsidies for fertilizers (during 3 years), for seeds (during 5 years), and extension services and transaction costs.	Years 1–3: 80 Following years: 96 The small pastoralist gain does not cover costs of fertilizers.	Requires community organization for limiting overgrazing. Investments must be made the first years in fertilizers and irrigation systems.

table continues next page

Table 3.1 Mitigation Options Adopted in the Low-Carbon Scenario (*continued*)

Description	*Dynamic of adoption and year lag*	*Potential yield increase*	*Potential carbon benefits*	*Public costs $/ha/yr*	*Private costs and benefits $/ha/yr (negative = benefit)*	*Key constraints*
SLM practice: Sustainable grazing management (SGM) without inputs (gathered in the livestock and pastureland improvement category)						
Restoration of degraded pastures without inputs, through the use of improved grass variety and rotational grassing No use of fire	Gradual adoption rate (geometric) 5-year lag	Increase varies depending on the type and quantity of improvements.	0.2–0.4 t C/ha/yr (improved species, controlled grazing, fire management)	Whole period: 2 Transaction and extension service cost	Whole period: 0.1 Small increase in the yield by the reduction of fire use (in the reference scenario, pastures are also improved without inputs, but fire is heavily used).	Need to develop grazing plans tailored to specific local conditions to encourage participative approaches
SLM practice: Livestock management (cattle, sheep, goats) (gathered in the livestock and pastureland improvement category)						
Better feeding practices Breeding management to select improved and more efficient animals Limitation of the number of livestock	Gradual adoption rate (geometric) 5-year lag, as for sustainable grazing	Increase in meat and milk production per animal	Possible decreases in GHG production per unit of livestock product, about 1% per year Methane production can be reduced by 10–40%	Year 1–3: 21 Following years: 0.2 Subsidies for prophylaxis and feed during 3 years, plus transaction and extension services costs.	Year 1–3: 26 Following years: 10 The costs of feed and prophylaxis are covered by the 33% increase in animal yield.	Techniques are often out of reach for smallholder livestock producers who lack the capital and often the knowledge to implement such changes. Fewer animals reduce the amount of manure available to fertilize the crops, which may lead to the use of chemical fertilizers.

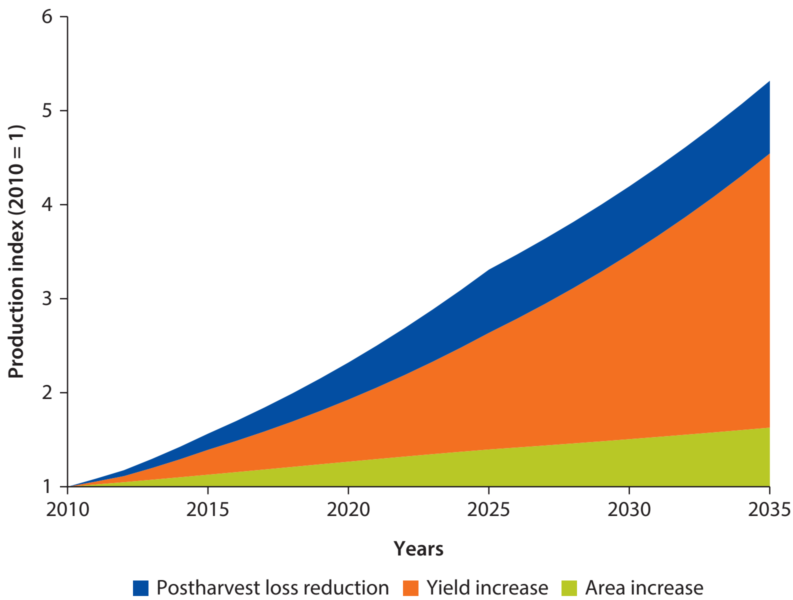
Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Table 3.2 Agricultural Growth Model of Low-Carbon vs. Reference Scenarios

	Percent of total growth			
	2010–25		*2026–35*	
Source of growth	*Reference*	*Low-carbon*	*Reference*	*Low-carbon*
Area increase	1.56	1.24	0.79	0.00
Postharvest loss reduction	2.48	2.48	0.03	0.03
Yield increase	4.07	5.07	4.00	6.00
Total Production Growth	8.30	9.00	4.86	6.04

Source: Calculations based on data sources listed in tables 1.1–1.3.
Note: The way in which the sources of growth interact in determining total production growth is nonlinear. So the last row in the table is not the result of adding the values reported in the three rows above it.

Figure 3.1 Total Production Increase and Growth Sources for Low-Carbon Scenario



Source: Calculations based on data sources listed in tables 1.1–1.3.

be the same as in the reference scenario for the first 5 years, then 1 point higher than the reference scenario for the following 5 years, and 2 points higher the next 5 years. This gives an annual compound growth rate close to 5.1 percent. After the implementation phase, 2025 and beyond, yield growth remains stable, at the same rate of 2025. This results in total production growth during the model period that is somewhat higher than that of the reference scenario.

Emissions Models under Two Low-Carbon Scenarios

Introduction of SLM technologies is assumed to be an accelerating process (due to some of the initial implementation lags discussed in table 3.1), but one that is also subject to a technical constraint—that is, no more than 800,000 hectare per year on average can be brought under new SLM technologies.[2] Subject to this constraint, the study team explored two scenarios:

- **Scenario A:** Resources available to support the introduction of SLM technologies are targeted to maximize the total mitigation potential.
- **Scenario B:** Resources available to support the introduction of SLM technologies are targeted to maximize profitability (for example, seeking to increase net present value (NPV) of private investment) for farmers, according to the cost/benefit estimates in table 3.1.

In order to provide for a minimally balanced mix of mitigation options, the team devised additional constraints on the minimum rate of adoption for each SLM technology, in line with their anticipated intrinsic appeal to farmers.[3] These minimum rates of uptake by 2025 are as follows:

- Conservation agriculture: 13 percent of annual cropland area
- SRI: 3 percent of total rice area
- Avoided deforestation: 5 percent of secondary degraded forest partly with constraints
- Agroforestry: 3 percent of annual cropland area[4]
- Improved pasture management: 2 percent of existing pasturelands
- Improved livestock management: 51 percent (that is, 1 percent more than the 50 percent already included under the reference scenario).

The two different scenarios impact choices between available mitigation measures, but not the total land area subject to introduction of SLM technologies.

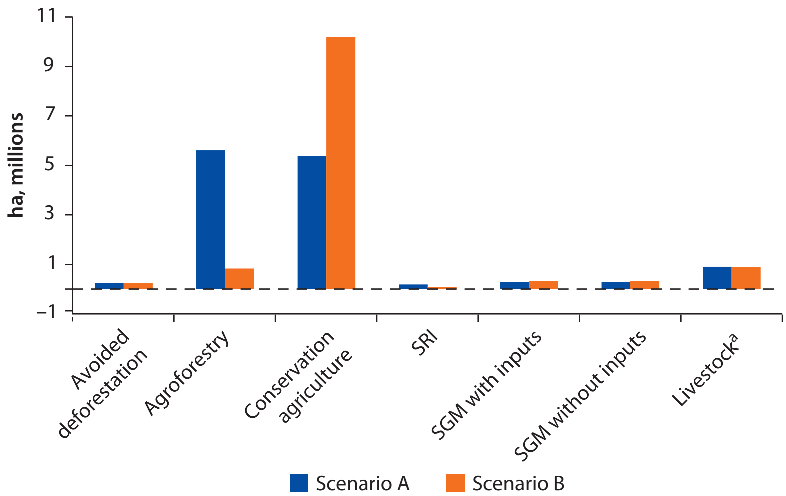
Land Use and Other Mitigation Factors

In accordance with the revised growth model, the expansion of agricultural land is reduced under both low-carbon scenarios, compared to the reference scenario, as an increased proportion of the least suitable secondary forest is not converted to agriculture.

Under scenario B, SLM options selected favor profitability to the farmer over maximum GHG abatement potential. As conservation agriculture provides the largest private returns, it accounts for 82 percent of the 800,000 hectare per year area subject to new SLM technologies, resulting in 24 percent of the annual cropland being managed under conservation agriculture practices, compared to only 13 percent under scenario A (figure 3.2). Other SLM technologies are only adopted at their minimum rates under scenario B.

Scenario A favors high mitigation land uses, but the available area of avoided deforestation is limited to no more than that also involved in scenario B. Hence SLM investments under scenario A focus on agroforestry, with a little SRI. Other SLM technologies are introduced according to their assumed minima, although that still involves a considerable area of conservation agriculture.

Figure 3.2 Adoption Rate of SLM Practices



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.
Notes: SRI = Sustainable rice intensification; SGM = Sustainable grazing management.
a. Livestock = number of heads, thousands.

Table 3.3 Land Use for Low-Carbon Scenarios (2025/2035) vs. Reference Scenario

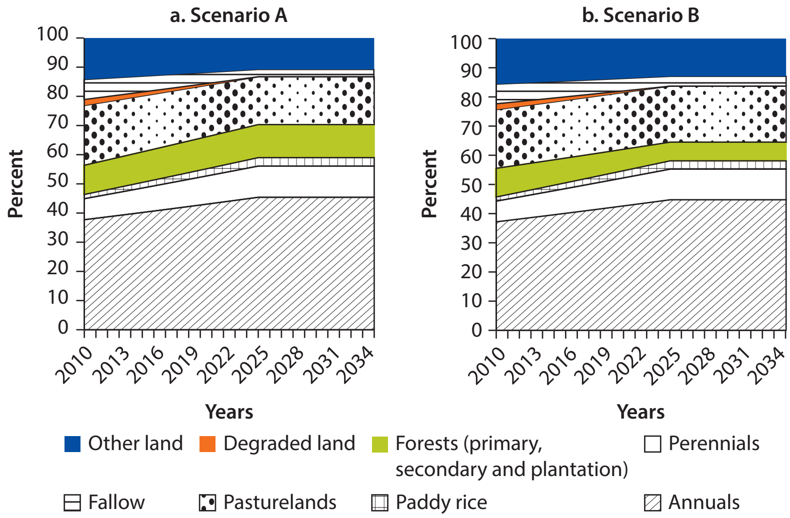
		2025/2035		
Land use	*2010*	*Reference*	*Low-carbon scenario A*	*Low-carbon scenario B*
Annuals	34,437	46,155	41,432	41,432
Perennials	6,552	12,419	9,721	9,721
Wet rice	1,313	2,919	2,625	2,625
Forests	9,101	2,700	10,301	5,929
Secondary forests	8,805	1,804	3,790	3,790
Plantations	296	896	896	896
Live fencing/agroforestry	0	0	5,615	1,243
Pasturelands	18,629	15,669	14,882	17,779
Degraded lands	1,849	0	0	0
Fallows	6,234	2,076	2,290	3,110
Other lands	12,941	9,116	9,803	10,459
Total	91,054	91,054	91,054	91,054

Source: Calculations based on data sources listed in tables 1.1–1.3.

The greater emphasis on agroforestry under scenario A results in changes to the final ratio of agroforestry-to-grassland area in comparison with scenario B. Largely due to the investment in agroforestry, scenario A ends up with over 4 times the area of secondary forest and live fences than the reference scenario and almost 2 times that of scenario B. Table 3.3 and Source: Calculations based on data sources listed in tables 1.1–1.3.

Figure 3.3 show the evolution of land use 2010–35, for the reference scenario and the two low-carbon simulations. The cropland area remains the same under

Figure 3.3 Land Use Evolution in Low-Carbon Scenarios, 2010–35



Source: Calculations based on data sources listed in tables 1.1–1.3.

both scenarios. (Appendix B, table B.1 presents the land use matrix for the reference scenario. Appendix D, tables D.1 and D.2 present the land use change matrixes for low-carbon A and B, respectively.)

Other land use changes (such as expansion of perennial crops and paddy and restoration of degraded land) remain the same as the reference scenario, as do other emissions model parameters (such as soil and climate characteristics, construction of new infrastructure, and introduction of technologies and improvements already included under the reference scenario). However, it is assumed that 75 percent of the existing perennial cropland will stop burning practices by 2025, as opposed to 50 percent in the reference scenario. Also there are some differences in the amounts of inputs and energy used in line with changes in cropland areas and extent of application of improved agronomic techniques.

Low-Carbon Scenarios: Results

Mitigation Potential

Total emissions accumulated over the model period remain positive under both low-carbon scenarios (tables D.3 and D.4 in appendix D present the gross GHG emissions for the different low-carbon simulations). Total mitigation potentials compared to the reference scenario are summarized in table 3.4.

Both low-carbon scenarios present a significant mitigation potential, of 1.0 and 0.6 billion t CO_2e, respectively, during the 25 years of the study.

In scenario A, various land use changes, including reduced net deforestation, agroforestry, and nonforest land use change, account for 77 percent of emissions reduction. In scenario B, the total mitigation potential is a little over half that of A, and contributions are more evenly spread across emissions classes, particularly from a much greater contribution from croplands to carbon sinks as conservation

Table 3.4 Results for the Two Low-Carbon Simulations

Scenario	*A*	*B*
Emissions for entire 25-year period of model (Mt CO_2e)	1,687	2,017
Total mitigation potential (t CO_2e)	976	646
Average mitigation potential (t CO_2e/ha/year)	0.4	0.3
Public expenses during 20 years (gross/NPV in $, millions)	10,211/3,207	6,983/2,228
Private revenues during 25 years (gross/NPV), in M$	41,024/5 699	44,278/7,277

Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Table 3.5 Mitigation Potential of Various Activities

	Scenario A mitigation			*Scenario B mitigation*		
Activities	*in Mt CO_2e*	*in Mt CO_2e/ha*		*in Mt CO_2e*	*in Mt CO_2e/ha*	
Avoided deforestation	207	833[a]	18%	207	830	30%
Afforestation and agroforestry (live fences)	712	126[b]	61%	158	126	22%
Nonforest land use change	–142	–11[c]	n.a.	–13	–1	n.a.
Annual crops	124	3[d]	11%	222	5	32%
Perennial crops	46	6	4%	46	6	7%
Wet rice	7	3	1%	3	1	0%
Grassland	34	2	3%	34	2	5%
Livestock	28	0[e]	2%	28	0	4%
Inputs	–39	–1[f]	n.a.	–39	–1	n.a.
Other investment	2	0[g]	0%	2	0	0%
Total	**976**	**6.8**[h]		**646**	**4.6**	

Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.
Notes: Calculations based on the following: (a) surface, nondeforested; (b) ha planted; (c) ha changing land use; (d) total annual/perennial/rice/grassland surface; (e) number of heads; (f) surface area fertilized. (g) Calculated based on the tilled surface; even if there are more areas under conservation agriculture (no-tillage), the assumption is that 50% of the total annuals surfaces will be tilled, as in the reference scenario. n.a. = not applicable.

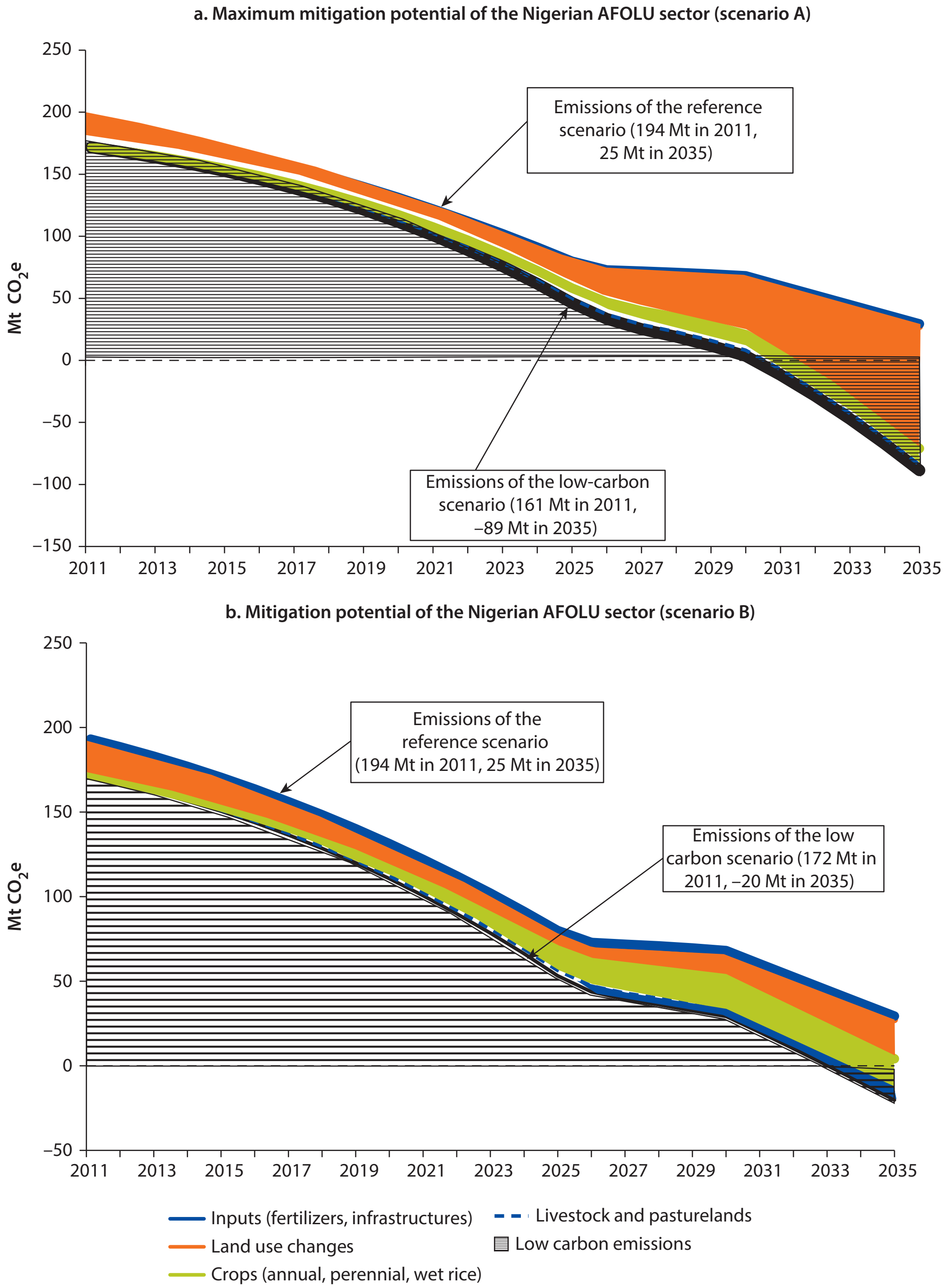
agriculture techniques increase soil and above-ground carbon level. In both low-carbon (LC) scenarios, the increased use of fertilizers emits more GHG than in the reference scenario, but it is really negligible compare to the reduction of other emissions. Energy and fuel consumption decrease a little compared to the reference scenario since less land area is tilled and more agricultural land is under conservation agriculture instead.

Table 3.5 and figure 3.4 illustrate the contribution of each subsector to the mitigation potential of the different LC scenarios. A negative figure indicates higher emissions compare to the reference scenario.

On a per hectare basis, mitigation potential differs among the different activities between the two scenarios:

- Annual crops sequester more C per hectare under scenario B, because a higher proportion is subject to conservation agriculture.
- Grasslands sequester more C per hectare under scenario A because the total extent of grasslands is lower, and therefore a higher proportion is subject to sustainable rangeland management.

Figure 3.4 Agricultural Mitigation Potential by Subsector for Low-Carbon Scenarios



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.
Note: AFOLU = agriculture, forestry, and other land use.

Marginal Abatement Costs

The marginal abatement cost (MAC) is the NPV (calculated at a 10 percent discount rate) of cost of each mitigation option per unit of emissions reduction.[6] These were calculated separately for public and private costs in order to construct marginal abatement cost (mac) curves to visualize the cost-effectiveness of various mitigation options for government and for farmers. A MAC curve is a histogram that displays both the MAC (height of each bar) and the total mitigation potential (width of the bar) for each mitigation option. The bars are arranged in order of increasing unit cost along the x axis, so that the cheapest mitigation options intuitively considered first, and the total emissions abatement cost increase with the area under the curve as additional mitigation activities are undertaken.

However, the following should be taken into account:

- Only monetary costs and revenues were included in the analysis—no account was taken of externalities, such as positive or negative environmental or social effects.
- Negative costs imply that a mitigation option is profitable in its own right—that is, it would make financial sense to adopt it, even if there were no interest in reducing GHG emissions.
- The MACC should not be used to compare mitigation costs directly to current or projected carbon prices. For a valid comparison to be made, expected future carbon finance income would have to be discounted to its net present value.

The unit public costs to the FGN for the various mitigation options are always positive and do not vary between the two low-carbon scenarios, since government does not receive any direct revenue from agricultural production and there are no economies of scale included in the cost models for SLM support. However, the total mitigation available from each option varies with the adoption rate. The results are shown in table 3.6 and figure 3.5.

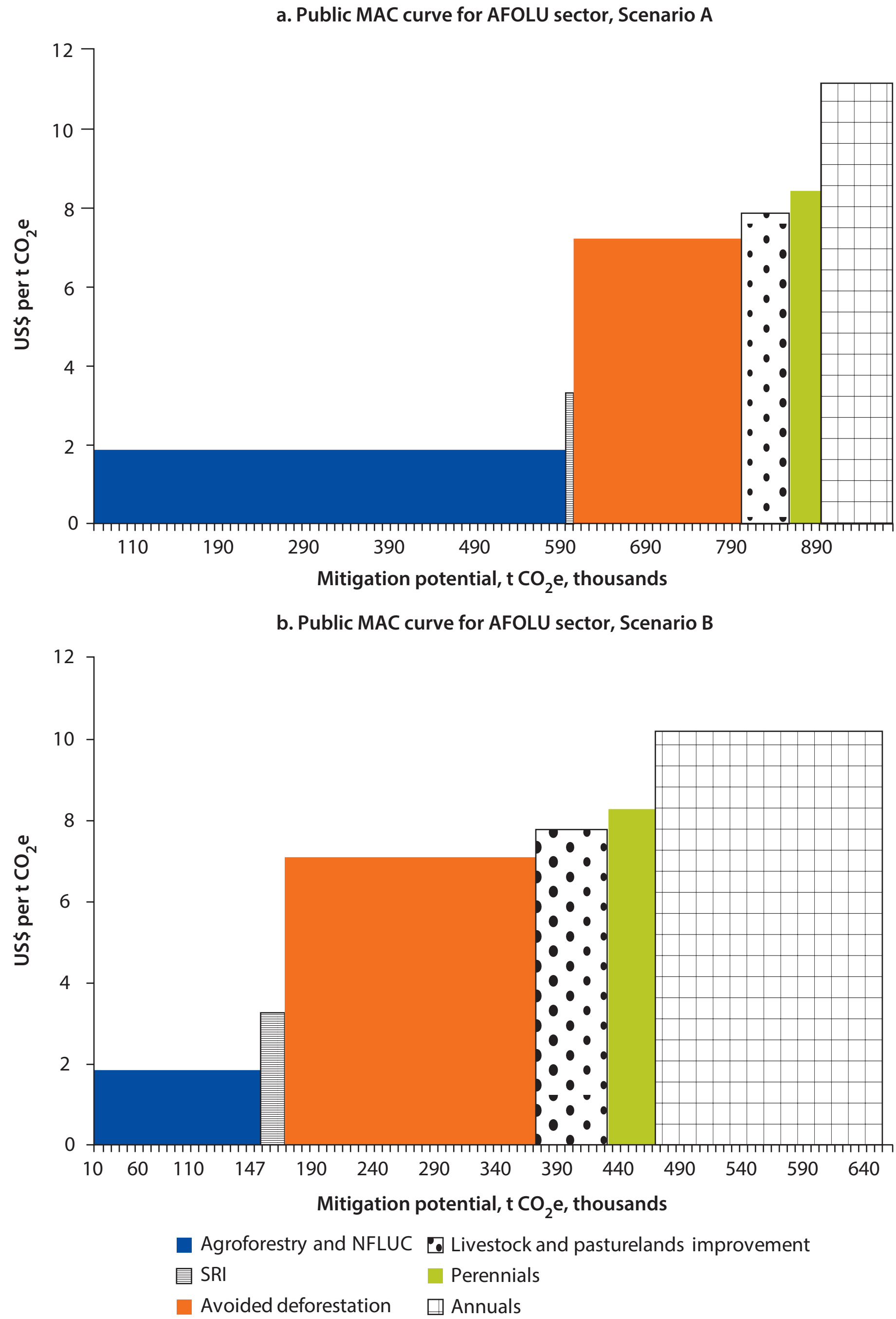
Some specific SLM measure, for example, conservation agriculture or agroforestry, have been included into a broader category to take into account the whole

Table 3.6 Public Cost of Emissions and Mitigation Potential of SLM Measures, 2011–35

	Mitigation potential, Mt CO_2eCO_2		*MAC, \$/t CO_2eCO_2*	
Mitigation option	*Scenario A*	*Scenario B*	*Scenario A*	*Scenario B*
Agroforestry and NFLUC	569.4	144.7	1.86	1.86
SRI	6.7	2.8	3.31	3.31
Avoided deforestation	206.6	206.6	7.10	7.10
Livestock and pasturelands improvement	61.6	61.5	7.87	7.91
Perennials	38.5	38.5	8.42	8.42
Annuals	93.2	191.7	11.15	10.38
Total	975.9	645.8		

Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Figure 3.5 Marginal Abatement Cost of SLM Practices for FGN



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

mitigation potential of the subcategory. Therefore, the following categories include the following:

- **Annuals:** conservation agriculture, no residue burning, higher fertilization on annual crops (in total, not per ha), reduced fuel consumption (in total, not per ha).
- **Perennials:** no residue burning, higher fertilization on perennial crops (in total, not per ha).
- **Livestock and pasturelands improvement:** pastures improved with and without inputs, reduced fire, livestock improvements.
- **Avoided deforestation:** only the surfaces of forest not converted into another land use
- **SRI**: only rice.
- **Agroforestry and NFLUC:** agroforestry and nonforest land use changes, since the plantation of trees on grass and crops will have an impact on other lands (for example, fallows have to be converted into crop to satisfy cropland expansion).

Between scenarios A and B, the average hectare of perennial, rice, agroforestry, pastureland, and protected forest is the same (or very slightly different), so the MAC curves are also identical. However, for annuals, the composition of an average hectare of annual differs: in scenario B, there is a higher proportion of conservation agriculture than in scenario A.

Agroforestry and sustainable rice intensification (SRI) are the most cost-effective mitigation options for the government, while livestock/pasturelands improvement, perennials, as well as annuals are more expensive to support. If FGN were to support all mitigation options, the total cost (in cash flow terms) would be about US$10 billion in scenario A and US$7 billion in scenario B, at an average cost of $10/t CO_2e (in cash flow terms).

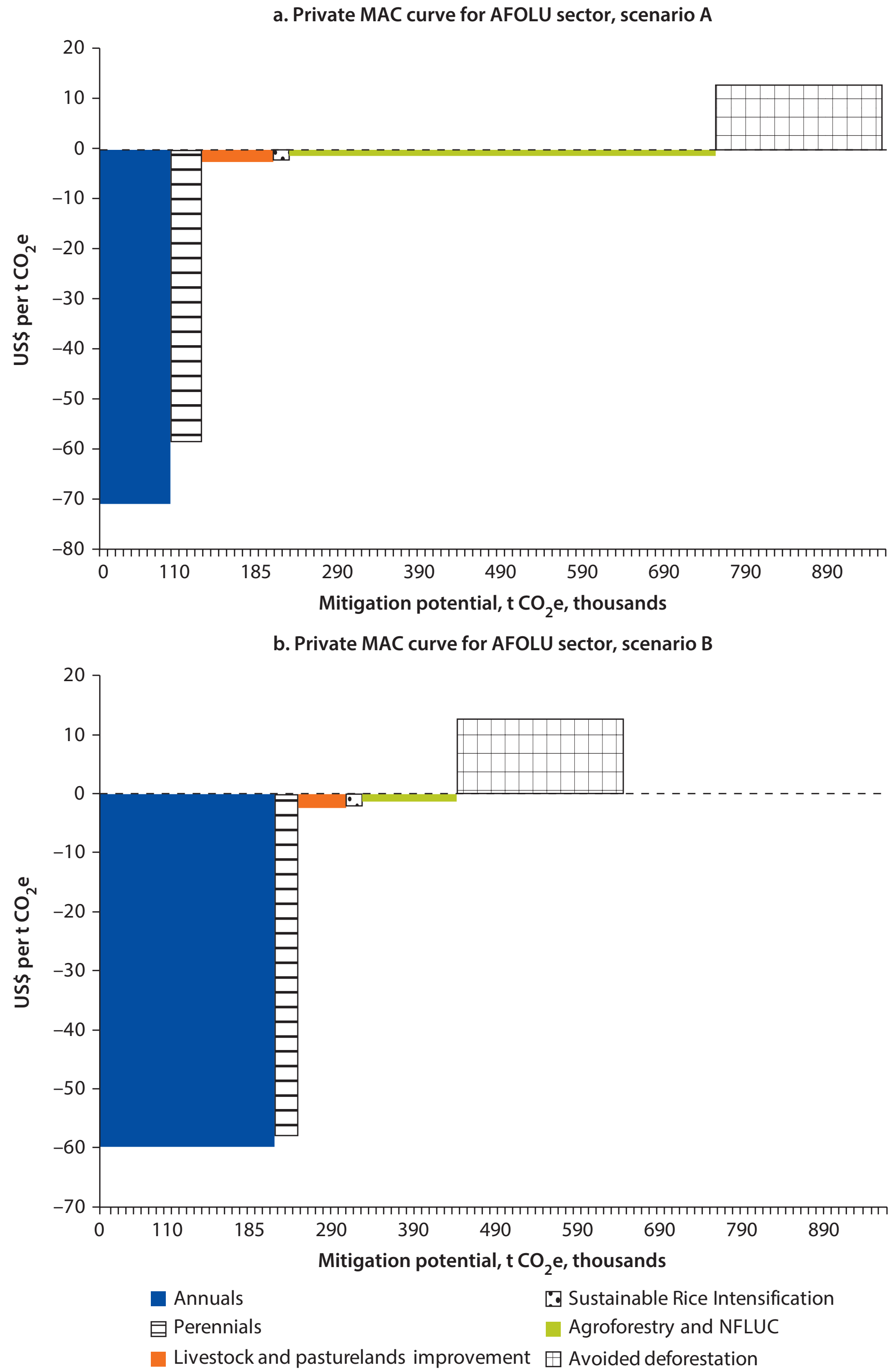
Net costs to farmers depend on the expenses for additional inputs (fertilizer, feed, fuel, labor, etc.) compared to the gain from higher yields. Negative costs shown in table 3.7 and figure 3.6 indicate that several mitigation options are

Table 3.7 Private Cost of Emissions and Mitigation Potential of SLM Measures

	Mitigation potential (Mt CO_2e)		*MAC (\$/t CO_2e)*	
Mitigation option	*Scenario A*	*Scenario B*	*Scenario A*	*Scenario B*
Annuals	93.2	191.7	−70.33	−56.76
Perennials	38.5	38.5	−58.18	−58.18
Livestock and pasturelands improvement	61.6	61.5	−2.49	−2.50
SRI	6.7	2.8	−2.04	−2.04
Agroforestry and Nonforest land use changes (NFLUC)	569.4	144.7	−1.32	−1.32
Avoided deforestation	206.6	206.6	12.82	12.82
Total	975.9	645.8		

Source: World Bank data.

Figure 3.6 Marginal Abatement Cost to Farmers of SLM practices



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

intrinsically beneficial to farmers. There are significant differences in the likely attractiveness of the various options to FGN and farmers. Avoiding deforestation is not financially rewarding for farmers because they would benefit from converting the forest into more productive lands. And agroforestry is only marginally profitable, due to high implementation costs, which offset the significant downstream yield increases, despite these options offering the greatest mitigation potential per hectare and being most cost-effective for FGN. Conservation agriculture (part of the annuals category) is highly attractive to farmers, while it offers relatively little mitigation potential per hectare and is comparatively costly for FGN to support. The same observation can be made for perennial crops.

When public and private costs are combined, only two SLM measures, annuals (that is, mainly conservation agriculture) and perennials (no residue burning), are profitable without any additional carbon revenues. Agroforestry presents a small cost of 0.5 \$/t CO_2e, while avoiding deforestation is the most expensive option for the whole nation (20 \$/t CO_2e).

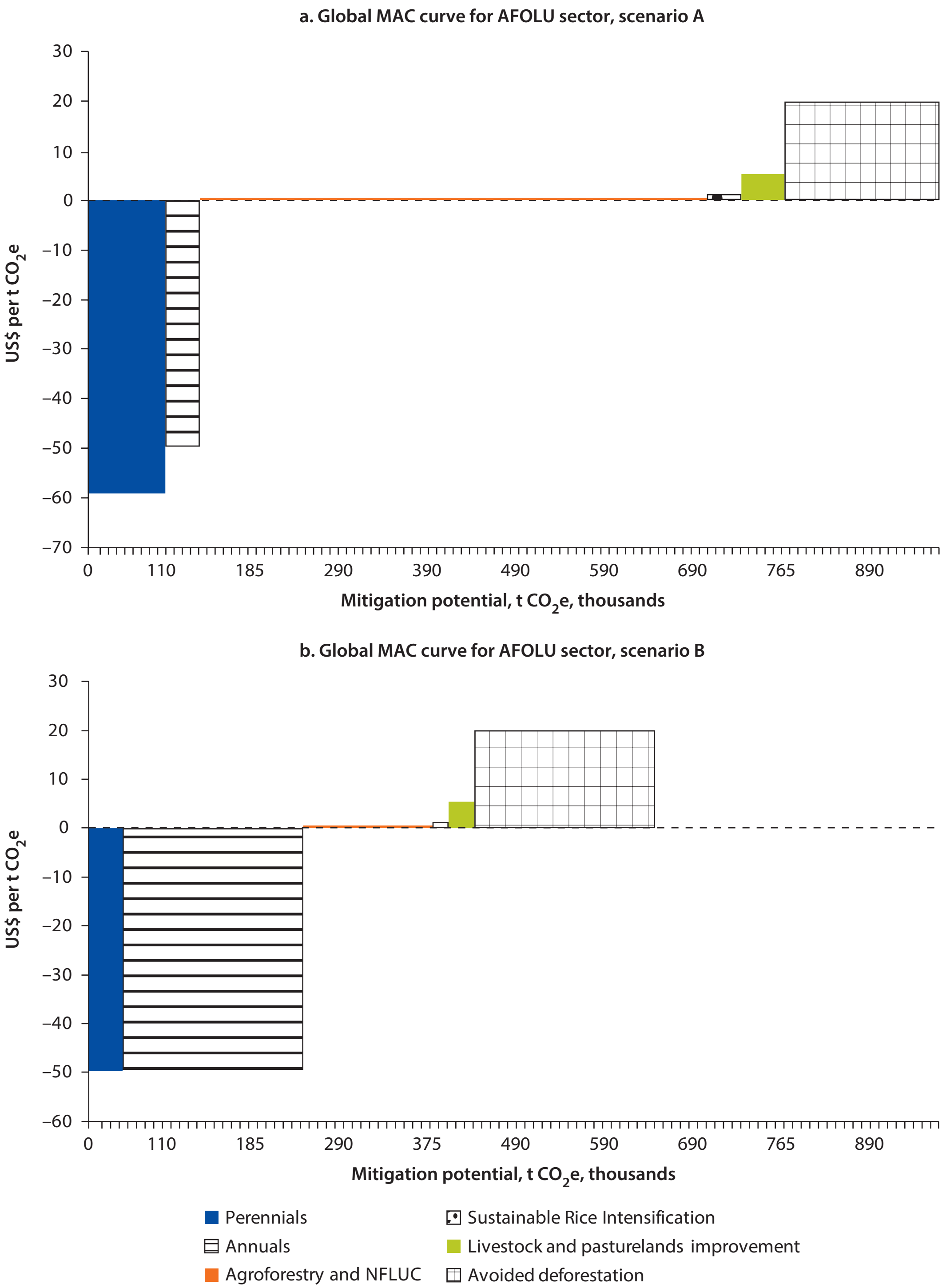
Incentivizing High Mitigation through Carbon Payments

The NPV of the financial benefit to farmers from all the SLM measures introduced in scenario A is just over US\$5 billion (see figure 3.7). Under scenario B, where private benefits are maximized, this increases totals to almost \$7 billion. However, the additional GHG emissions reductions generated under scenario A make it possible to use carbon payments to incentivize landowners/farmers to adopt more carbon-intensive land uses. In fact, a minimum carbon price of \$6.1/t CO_2e paid to farmers[7] would be sufficient to increase the private financial benefit of the land use choices under scenario A to the same level as those enjoyed under scenario B, effectively compensating farmers for adopting SLM options with higher mitigation potential.

Figure 3.8 represents in the following the private and global MACs for scenario A with carbon payments to farmers of \$6.1/t CO_2e (the public MAC is the same as for the standard scenario A shown in figure 3.7). With carbon payments, conservation agriculture is still the most profitable option, but introducing a system of rice intensification (SRI) and livestock/pasturelands improvement are significantly more attractive, and avoided deforestation is relatively more attractive, although still not financially rewarding in isolation. Hence carbon payments at this level are not sufficient to incentivize private decisions to take up all SLM options in accordance with scenario A, but could be used to compensate to the foregone income at the macro level. Therefore, if governments were able to control the distribution of carbon incomes, then these incomes could potentially be used to selectively incentivize the most carbon-intensive options, such as avoided deforestation and agroforestry, as a strategy to provide for a more balanced mix of SLM technologies that would exploit the synergies between them,[8] as well as the additional positive environmental externalities from maintaining increased forest cover.[9]

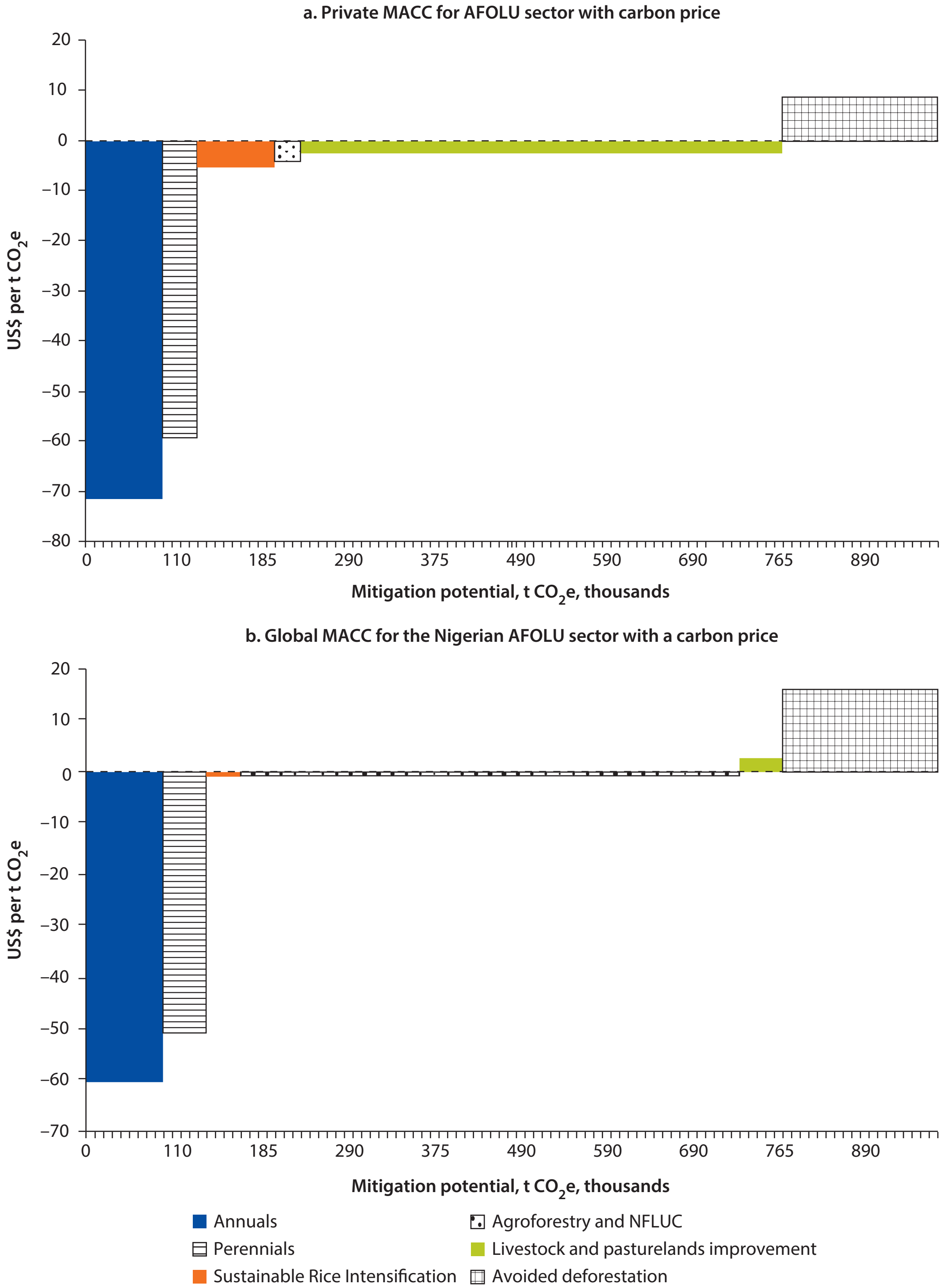
It is worth noting that at a global level—that is, from a public and private point of view—only two options result in a positive MAC: namely,

Figure 3.7 MAC Curves of SLM Practices for All of Nigeria (public + private costs and benefits)



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Figure 3.8 MAC of SLM practices (scenario A), with Carbon Revenue Added for Farmers



Source: Calculations based on sources in chapter 1 "Data Sources for the Agriculture and Land Use Sector" and tables 1.1–1.3.

Table 3.8 MAC of SLM Measures, Depending on the Low-Carbon Scenarios

	Public MAC	*Private MAC*	
MAC, in \$/t CO_2e	*Public*	*Private*	*Private with carbon payment*
Annuals	For scenario A: 11.2 For scenario B: 10.4	For scenario A: –70.3 For scenario B: –56.8	–71.5
Perennials	8.4	–58.2	–59.2
Livestock and pasturelands improvement	7.9	–2.5	–5.3
SRI	3.3	–2.0	–4.2
Agroforestry and NFLUC	1.9	–1.3	–2.6
Avoided deforestation	7.2	12.8	8.7

livestock/pasturelands and avoided deforestation, compared to four options without the addition of a carbon price.

Table 3.8 summarizes the public and private MACs for each SLM option under various conditions.

Notes

1. Conservation agriculture also tends to be more labor intensive for a given area of cropping.
2. At an average farm size of 2 hectares, this is equivalent to roughly 400,000 rural families adopting SLM options annually. This is ambitious, but not compared to the scale of sector reforms already needed to address the Vision 20: 2020 productivity goals.
3. Another scenario was also explored in which a realistic budget constraint was applied, but the technical constraint was still found to be more limiting.
4. A 3:1 ratio is also assumed for the introduction of live fences on annual cropland and pasturelands, respectively.
5. Note also that agroforestry investments provide for significant increases in productivity of the surrounding agricultural land. This largely compensates for the foregone yield increases that could otherwise have been achieved through additional investment in conservation agriculture, such that the sectorwide agricultural yield increase for both scenarios A and B are roughly equivalent and in line with the modified growth model for the low-carbon options.
6. That is,

$$MAC^i = \frac{NPV^i_{LC} - NPV^i_{ref}}{E^i_{ref} - E^i_{LC}}$$

where

- MAC_i is the marginal abatement cost of the option i, expressed in \$/t CO_2e
- NPV_{LC} is the Net Present Value of the technology i in the low-carbon scenario, expressed in \$
- NPV_{ref} is the Net Present Value of the technology in the reference scenario, expressed in \$
- E_{ref} is the total GHG emissions with the technology in the reference scenario, expressed in t CO_2e

- E_{LC} is the total GHG emissions with the technology in the low-carbon scenario, expressed in t CO_2e.

7. That is, public goods such as maintenance of hydrological functions, which benefit local farmers and downstream water users, and provision of forest products.
8. The high number of small farmers and their scattering in rural areas are a main constraint to reach small farmers with both incentives and adequate extension support within manageable transaction costs. A key issue is to find an entry point that allows outreach to a wide number of small farmers. It can be farmer unions, cooperatives, value chains, or an existing project or program that covers a whole region or district with adequate services. The role of the aggregator is to deliver the whole range of services and support to a wide number of small farmers, including the possibility of channeling of payment of environment services.
9. EX-ACT (Ex Ante Carbon-balance Tool) http://www.fao.org/tc/exact/en/.

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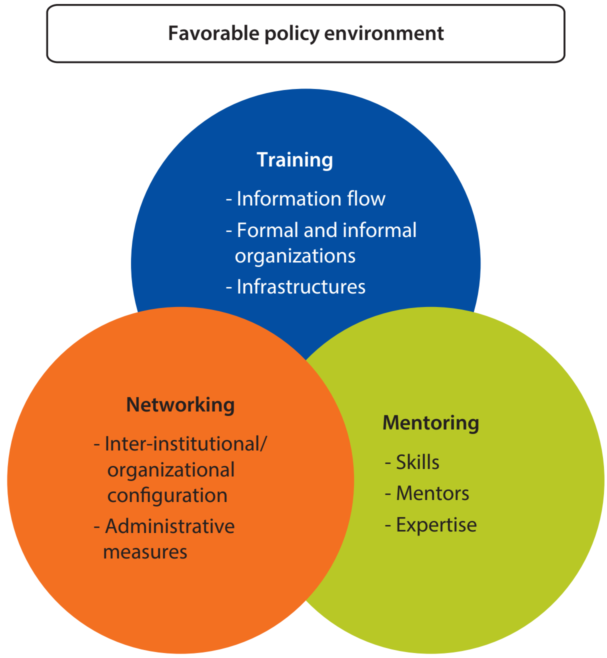
CHAPTER 4

Recommendations for an Effective Low-Carbon Strategy in the AFOLU Sector

Despite the demonstrated benefits of sustainable land management (SLM) technologies, uptake for reforms in the AFOLU (agriculture, forestry, and land use) sector is still often slow, even for those options that involve significant private financial returns. According to the Fadama Project (Ike 2012), only 30 percent of farmers currently use manure, 4.6 percent compost, and 3.4 percent mulching practices. Several practical obstacles hinder rapid adoption, including the need to convince and train risk-averse farmers in new methods, and the frequent need for up-front investment that pay off over a number of years. Financial support, training, and demonstrations are all necessary to encourage farmers to radically changes in working and thinking needed to adopt new SLM techniques. A further practical issue for low-carbon scenarios is that they assume that higher productivity will offset expansion of cropland, whereas in reality increasing yields may increase the private incentives to convert more land to agriculture—with the risk that overexploitation of land may eventually lead to declining output. Hence, agricultural intensification is unlikely to result in avoided deforestation unless it occurs within a strong policy framework. This section discusses some of the policy and institutional steps needed to realize the potential of SLM.

Building the capacities and the political framework to mainstream climate change in agriculture and forestry strategies is a complex and dynamic process that involves numerous stakeholders, from national to field level. Figure 4.1 is a schematic of the minimum necessary elements (1) mentoring, that is, research institutions identifying problems and solutions; (2) training, which will bring to the field scientific knowledge; and (3) networking, that is, creating a conductive policy environment with interactions between experts and actors.

Figure 4.1 Capacity Building Model



Source: Design based on Sanni et al. 2010.

Building a Network of Climate Smart Agriculture Partners

Implementation of a low-carbon policy within the agriculture and forestry sector will require mobilization of major public institutions, development partners, and federal, state, and local level stakeholders, including banks, the private sector, legislators, nongovernmental organizations and other actors. Specific recommended steps include the following:

- **Key institutions** to be mobilized include (1) Federal Ministry of Environment as the National designated Authority for Climate Change and Sustainable Development; (2) Federal Ministry of Agriculture and Water Resources (FMAWR) as the main coordinator; (3) River Basin Development Authorities (watershed management–reforestation); (4) Nigerian Agricultural Insurance Corporation (NAIC) on risk managements–weather based insurance; and (5) Nigeria Agricultural Cooperative and Rural Development Bank (NACRDB) for items such as fertilizer and other input-investment credits.

- **Farmer organizations** are one of the most important pillars of policy and institutional capability for agricultural development because they engage in dialogue with the government and can widely mobilize farmers. The participation of farmer associations in policy formulation, monitoring, and evaluation increases ownership and sustainability of policy measures. The All Farmers Association of Nigeria (AFAN), an umbrella body for Nigerian farmers, is the national platform for corporate and professional bodies, cooperatives, and commodity associations. Currently, 43 major farmers' associations in Nigeria have been formed along commodity lines (FGN 2011). The AFAN could act as a field support platform to promote climate smart agriculture practices and gather smallholders to channel carbon funding and payment of environment services.

Effective Implementation Mechanisms

Supporting Agricultural Research

Agricultural research has been shown to be one of the most effective forms of public investment (Fan and Rao 2003; Hazell and Haddad 2001). Compared to the popular recommendation that agricultural research spending should not be less than 2 percent of agricultural GDP, FGN's funding of agricultural research has been well below the average for Africa as a whole (0.85 percent of GDP (Enete and Amusa 2010). Moreover, private sector agricultural research in Nigeria is also negligible, as is the case throughout most of Sub-Saharan Africa (Mogues et al. 2008).

The Department of Agricultural Sciences (DAS) of the Federal Ministry of Agriculture is responsible for all aspects of agricultural research in Nigeria. DAS oversees the funding and management of 15 national agricultural research institutes located throughout the country. These institutes are tasked with generating improved agricultural technologies for use by farmers and agro-industries. However, DAS funding of agricultural science research and technology has been generally stagnant and has even decreased since the collapse of oil prices in the early 1980s.

The agricultural research capacity in Nigeria is highly dispersed and the country does not have a well-defined national strategy. Nonetheless, research is necessary to develop crop and livestock management practices aimed at enhancing the resilience and mitigation potential of smallholder farming systems, through adapting SLM approaches to local circumstances, as well as by meeting the overall growth targets under Vision 20: 2020.

Another key challenge involves extending the existing capacity in agro-meteorological disciplines to include agro-climatic competency. Local climate change adaptation platforms have been proposed by a number of development agencies, as a means of promoting collaboration between scientists and practitioners and enhancing local adaptation capacity. Such platforms enable collaborative action, mutual learning, and the exchange of a range of material, for example, from mailing lists, e-conferences, academic papers, policy briefs, or information sheets. It is essential that these institutions design their activities around local needs and not the funding or reporting requirements of the international climate change community (SEI 2008).

IFPRI (2010) assessed the level of innovation capacity of Nigerian agricultural research system and made the following recommendations to strengthen it:

- **Improve collaboration between researchers and promote communication on innovations.** Although research productivity seems high, the overall level of collaboration is low and there is a lack of monitoring and evaluating the use, influence, and impact of technologies and publications produced by organizations and individual researchers.
- **Increase interactions with farmers, the private sector, extension agents, and other actors within the innovation system.** Greater awareness and sensitization, as well as exposure to practical knowledge, good practices, and experiences on innovation systems in other countries, are urgently needed. The Agricultural Research Council of Nigeria can play a role in facilitating a platform or forum for greater interaction and collaboration.
- **Strengthen the abilities for fundraising and diversifying fund sources.** Current agricultural research organizations have substantive capacity and incentive gaps. Among research institutes, the timely release of funds is the top motivating factor identified by researchers in order for them to produce more and be more innovative.
- **Improve governance of research organization.** Good performance and innovation capacity are associated with the presence of fair and transparent hiring procedures; effective performance evaluation and reward systems; systems of career development and job security; systems of information sharing and knowledge management; clearly defined and communicated division of roles and responsibilities; systems of feedback from stakeholders; and provision of flexibility, freedom to do work, and mobility among researchers.
- **Establish a mechanism of continuous training and skill development.**

Capacity Building and Technology Transfer Platforms

Diffusion of scientific and technical knowledge to farmers is a prerequisite to the adoption of SLM and climate-smart agriculture (CSA) practices. Agriculture needs to become professionalized, with better incentives for training and development of technical capacity in crop and livestock production.

Agricultural Development Projects (ADPs) are the main vehicle for the delivery of public extension services in Nigeria. Despite their name, ADPs are not "projects" in the conventional sense, but state-level parastatals working in the agricultural sector. The first generation ADPs were created during the mid-1970s and supported largely with donor funds. Their extension activities include establishing demonstration farms, identifying lead farmers, providing them with information about good farming practices, facilitating access to improved technology and inputs (for example, seeds of improved varieties, fertilizer, machinery services), and helping leading farmers teach other farmers.

ADPs could serve as platforms for capacity-building, to promote the adoption of climate-smart agriculture (CSA) techniques. They can network with local-level training institutions to serve both extension officers and regional/local planners for promoting CSA both at the planning and project design levels.

Field Support Platforms as Small Farmer Aggregators

A key issue in exploiting carbon finance potentials in the agriculture sector is that, while the overall GHG emissions potential may be highly significant, the contribution of each individual farm is often small. Therefore a highly efficient approach to aggregating the contributions of individual farmers is required in order to avoid excessive transaction costs. Farmer federations with support from ADPs could be strengthened to become field platforms and potentially to channel carbon funds and payment of environment services. Their value chain–based structure and their capacity to gather small farmers give them a comparative advantage as a farmer's aggregator.[1] From this perspective, it is therefore important to accomplish the following goals:

- Build the capacity of these organizations to effectively and sustainably play a role in the promotion of improved practices and in the control and monitoring of applications programs and projects.
- Provide technical assistance to farmer organizations to enable the trade of carbon credits on the voluntary markets (and possibly on the compliance market as well). These carbon assets (including soil carbon) would result from the implementation of CSA activities.
- Develop effective and scalable tools to support partnerships and alliances between governments, private sector operators, and leading local farmer organizations and trade associations in order to broaden the access of smallholder farmers to commercial and technical services.
- Provide a platform to scale out participatory farmer-to-farmer learning and farmer champions. It is often difficult to identify well-connected and credible farmer champions that will hold on-farm demonstrations and learning events that are critical for scaling out, but this is typically an important part of any strategy to scale-up specific technologies.

Systematic Review and Carbon Appraisal of Sector Project and Program Proposals

A reform with the potential to provide rapid results would be to request a systematic review of any new investment project or program, in terms of its impact on climate mitigation and its ability to foster resilience. It automatically raises these criteria within the choice of technical options by project designers.

The UN Food and Agriculture Organization's *FAO Guidance to Best Practices* (FAO 2007, 2009a, 2009b) and its guidance on carbon balance appraisal of projects and policies[2] could be used by the country to develop its climate change response and adaptation strategies down to project and strategy design and appraisal.

The development of country-specific planning tools (for example, a CSA Atlas) to identify and prioritize opportunities for adopting a triple-win agriculture management options (higher yields, higher climate resilience, reduced carbon emissions) should also be considered.

Building a Strong and Coherent Policy Environment

Stability of the Policy Framework

A stable policy environment is a key requirement for the effective development of the agriculture sector and its contribution to mitigating climate change. Unfortunately, this stability has generally been lacking in Nigeria, as successive governments have often reversed policies put in place by predecessors. Inconsistent agricultural policies have resulted in apathy on the part of the farmers regarding anything from government because they never know how long an incentive may last; import policies have been erratic, characterized by frequent changes in both import tariffs and quantitative import restrictions, creating much uncertainty for producers; and the government has failed to set up a satisfactory credit system for farming.

However, in the way of improvement, Nigeria has recently developed an Agricultural Transformation Agenda (ATA), which could be a key long-term vehicle to champion sustainable and climate-smart sector policies. The 2012 ATA is a comprehensive plan that aims to restore Nigeria's old glory as an agriculture powerhouse. To this effect, the ATA seeks to achieve dramatic increases in agricultural productivity, massive job creation in the agriculture sector, significant expansion of value-addition in processing, drastic reductions in agricultural imports, and improved penetration of international markets.

The ATA is an important point of departure for transforming Nigeria's agriculture sector by providing the following: (1) an in-depth analysis of root causes of poor performance of the agriculture sector along with quantification of lost opportunities caused by this poor performance; (2) a clear vision for transformation of the sector as a process, including import substitution, export orientation, value-addition through processing, and backward integration linkages; (3) an explicit focus on agriculture as a business, putting the private sector in the driver's seat and recognizing the critical role of women; (4) a comprehensive approach to change by focusing on value-chains; (5) a concrete and specific program of sector policy reforms, including reform of the fertilizer subsidy program that has been a major drain on sector expenditures; and (6) specific and quantified targets for expected outcomes in terms of jobs, income, food security, and productivity improvements.

Strengthening Capacity of Decentralized Institutions

With its federal system of government, Nigeria faces a challenge to define the roles and responsibilities of each tier of government. All the agricultural research institutes are owned and managed by the Federal Government, while state and local governments, which provide extension services, have no research institutes. This means that all decisions on the funding, direction, and implementation of research activities are taken from FGN–Abuja (Agbamu 2000), resulting in a discrepancy between local needs and current R&D programs. The FGN should make an effort to decentralize research funding and activities to reduce concentration at the federal level and strengthen the linkage to extension services and farmer organizations.

Strengthening CSA Policy and Project Planning

Policies and institutions also need coordination with initiatives in other sectors that could help to strength the climate resilience in agriculture. The FGN could undertake the following actions to achieve this:

- Technical assistance is required to consolidate and harmonize policies and legislation related to water resources management, as a prerequisite for organic and effective integration of climate change considerations into sector planning and development.
- Guidelines should be prepared to enhance climate resilience of water resource development projects in the irrigation and hydropower subsectors, including design criteria to enhance the reliability of water storage infrastructure under wider precipitation swings.
- Further attention should be paid to developing small-scale finance provisions such as micro insurance, savings and transfer of money building on the innovation practices introduced by IT development.
- If safety nets are to be part of the risk-reduction strategy in Nigeria, they need to be elaborated and carefully designed to ensure they contribute to growth, rather than competing for resources. Many elements of the NAIP and NFSP can provide social protection elements, for example, public works programs on building dams, food for work programs, food for school programs, conditional transfers of farm inputs for stimulating agriculture, asset transfers through livestock or vouchers, among others.

Notes

1. See http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/NIGERIAEXTN/0,,menuPK:368922~pagePK:141132~piPK:141109~theSitePK:368896,00.html.
2. Please refer to Batjes 2010, p. 9 and the European Soil Portal http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/for soil maps of Nigeria.

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APPENDIX A

Emissions Coefficients and Other Parameters Used in the Model

Table A.1 Coefficients Used in the Model

Type of vegetation concerned	*Type of coefficient*	*Data sources*	*Value of the coefficients*	
Forests	Carbon content in above and below ground biomass for secondary forests	Henry 2010	Secondary moist forest	AGB = 32.2 t C/ha/yr BGB = 7.7 t C/ha/yr
			----------------	------------------
			Secondary rain forest	AGB = 89.3 t C/ha/yr BGB = 33.0 t C/ha/yr
	Emissions factors of forest biomass burning	IPCC 2006	Secondary moist forest	% of biomass burned = 36% GHG emissions: 6.8 g CH_4/kg dry matter (DM) burned 0.2 g N_2O/kg DM burned
			---------------	---------------
			Secondary rain forest	% of biomass burned = 32% GHG emissions: 6.8 g CH_4/kg DM burned 0.2 g N_2O/kg DM burned
	Aforestation/ reforestation: carbon pool content	IPCC 2006	Plantation of 2sd moist forest	AGB = 4.70 t C/ha/yr BGB = 0.94 t C/ha/yr
			---------------	---------------
			Plantation of 2sd dry forest	AGB = 3.76 t C/ha/yr BGB = 2.11 t C/ha/yr

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Table A.1 Coefficients Used in the Model *(continued)*

Type of vegetation concerned	*Type of coefficient*	*Data sources*	*Value of the coefficients*	
Annuals, perennials, grasslands, degraded lands, other	Non-forest land use changes (initial and final carbon pool in biomass and soil)	IPCC 2006	Annual	Biomass = 5 t C/ha Soil = 22.6 t C/ha
			Perennial	Biomass = 2.6 t C/ha Soil = 47 t C/ha
			Wet rice	Biomass = 5 t C/ha Soil = 51.7 t C/ha
			Grassland	Biomass = 6.4 t C/ha Soil = 47 t C/ha
			Degraded land	Biomass = 1 t C/ha Soil = 15.5 t C/ha
			Other	Biomass = 0 t C/ha Soil = 47 t C/ha
			Fallow	Biomass = 5 t C/ha Soil = 38.5 t C/ha
Annuals	Carbon storage capacity of different agronomic practices	IPCC 2006; Lal (2004b)	Moist tropical climate, improved varieties	0.24 t C/ha/year
			Moist tropical climate, water management	0.31 t C/ha/year
		Chivenge et al. 2007; Leite et al. 2009	Moist tropical climate, conservation agriculture	1.27–1.32 t CO_2e/ha/year Model uses the average (1.3 t CO_2e/ha/year), which is equivalent to 0.35 t C/ha/year

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Table A.1 Coefficients Used in the Model *(continued)*

Type of vegetation concerned	*Type of coefficient*	*Data sources*	*Value of the coefficients*	
Perennials	Above and below ground biomass growth rate (biomass accumulation rate)	IPCC 2006	Tropical moist climate	AGB: 2.6 t C/ha/year BGB: 0 t C/ha/year
	Emissions factors of biomass burning	IPCC 2006		% of biomass burned = 80% GHG emissions: 2.3 g CH_4/kg DM burned 0.21 g N_2O/kg DM burned
Rice	Methane emissions	IPCC 2006	Continuously flooded, non-flooded preseason <180 days --------------- Intermittently flooded, non-flooded preseason >180 days	1.3 kg CH_4/ha/day --------------- 0.69 kg CH_4/ha/day
Grassland	Soil carbon content after 20 years (in 02–30cm depth)	IPCC 2006	Non-degraded --------------- Severely degraded --------------- Moderately degraded --------------- Improved without inputs --------------- Improved with inputs	47.0 t C/ha --------------- 32.9 t C/ha --------------- 45.1 t C/ha --------------- 54.5 t C/ha --------------- 60.5 t C/ha
	Above ground biomass (AGB)	IPCC 2006	Tropical moist, LAC soil	AGB = 6.2 t DM/ha
	Emissions factors of biomass burning	IPCC 2006		% of biomass burned = 77% GHG emissions: 2.3 g CH_4/kg DM burned 0.21 g N_2O/kg DM burned

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Table A.1 Coefficients Used in the Model *(continued)*

Type of vegetation concerned	*Type of coefficient*	*Data sources*	*Value of the coefficients*	
Livestock	Methane emissions from enteric fermentation	IPCC 2006	Cattle	31 kg CH_4/head/year
			Sheep	8
			Swine	1
			Goat	5
			Camel	46
			Horse	18
			Donkey	10
			Poultry	0
Livestock	Methane emissions from manure management	IPCC 2006	Cattle	1 kg CH_4/head/year
			Sheep	0.37
			Swine	2
			Goat	0.26
			Camel	3.17
			Horse	3.13
			Donkey	0.9
			Poultry	0.02

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Table A.1 Coefficients Used in the Model *(continued)*

Type of vegetation concerned	*Type of coefficient*	*Data sources*	*Value of the coefficients*	
	Nitrous oxide emissions from manure management	IPCC 2006	Cattle	39.8 kg N_2O/head/year
			Sheep	20.7
			Swine	16.8
			Goat	19.3
			Camel	36.4
			Horse	63.3
			Donkey	21.8
			Poultry	0.6
	Mitigation potential of better feeding practices	IPCC 2006	Reduction in enteric fermentation from feeding practices (for cattle and sheep/goat)	−1%
			Reduction in enteric fermentation from breeding practices (for cattle and sheep/goat)	−0.6%
Inputs	Carbon dioxide emissions from urea application	IPCC 2006		0.2 kg CO_2e/t urea
	Nitrous oxide emissions from N application	IPCC 2006		0.01 kg N_2O/t N

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Table A.1 Coefficients Used in the Model *(continued)*

Type of vegetation concerned	*Type of coefficient*	*Data sources*	*Value of the coefficients*	
Other investments	CO_2 emissions of gasoil	IPCC 2006		2.63 t CO_2e/m^3
	CO_2 emissions of the installation of irrigation system	IPCC 2006	Hand moved sprinkle	60 kg CO_2e/ha
	CO_2 emissions from the construction of buildings and roads	IPCC 2006	Office (concrete)	0.469 kg CO_2e/m^2
			Industrial building (concrete)	0.825
			Industrial building (metal)	0.275
			Agricultural building (concrete)	0.656
			Agricultural building (metal)	0.220
			Road	0.073

Source: World Bank data.

APPENDIX B

Land Use Changes in the Reference Scenario

Table B.1 Land Use Change Matrix for Reference Scenario (ha, thousands)

	Initial 2010								
Final 2025	*Annuals*	*Wet rice*	*Perennials*	*Forests*	*Grasslands*	*Degraded lands*	*Fallow*	*Other lands*	*Total final*
Annuals	33,124			4,641	2,063		2,063	1,547	**43,437**
Wet rice	1,312	1,313							**2,625**
Perennials			6,552	475	317	951	634	792	**9,721**
Forests				3,838	120	300	180		**4,438**
Grasslands				147	16,129	598	100		**16,974**
Degraded lands						0			**0**
Fallow							3,257		**3,257**
Other lands								10,602	**10,602**
Total initial	**34,437**	**1,313**	**6,552**	**9,101**	**18,629**	**1,849**	**6,234**	**12,941**	**91,054**

Source: World Bank data.

APPENDIX C

Mitigation Options in the Low-Carbon Scenario

Table C.1 Mitigation Options in the Low-Carbon Scenario: SLM Measures and Limits of Implementation

SLM practice	*Justification*	*Description*	*Impacts*	*Main constraints of implementation*
Conservation agriculture	Reference scenario already contained some improved agronomic practices, such as using improved varieties, but Nigeria needs to go further if it wants to reduce crop expansion (and thus deforestation) while in the meantime increasing productivity to achieve food security and limit food imports.	Land use concerned: **Cropland** • Minimum or no-tillage • Mulching (30% minimum of the crops residue remains on the soil surface after planting) • Crop rotation integrating leguminous and crop association	• The "no-tillage" increases the soil organic content and soil properties (physical, chemical, and biological), thus leading to a more efficient use of precipitation, soil moisture, and plant nutrients, limiting erosion and storing carbon in soils. • The surface mulch that develops protects the soil surface from the impact of heavy raindrops, reducing the erosive power of the water (Derpsch et al., 1991) and wind while protecting the surface from excessive heat. • Increase yield within a single year and reduce inter-year variation in yields (FAO 2008).	• Farmers need extensive training and access to skilled advisory services. Compared to conventional farming, a fundamental change in approach is required. • Typically there is a transition period of 5–7 years before a conservation agriculture system reaches equilibrium. Yields may be lower in the early years. • One of the biggest issues with no-tillage is weed control: reduced tillage means having recourse to herbicides. Farmers must be educated in the correct use of these herbicides, to avoid the harmful effects to the environment of improper use, or they have to adopt integrated pest management (crop rotation, cover crop, cultural practices) (Pieri et al. 2002, 30). • Farmers need to make an initial investment in specialized machinery, with initially increased labor (weeding); for example, Laikipia District in Kenya maintenance = $93/ha/yr; Morocco maintenance = $600/ha/yr. • Conservation agriculture has not been successful in heavy clay soils, poorly drained sites, compacted soils, and arid areas due to insufficient carbon.

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Table C.1 Mitigation Options in the Low-Carbon Scenario: SLM Measures and Limits of Implementation *(continued)*

SLM practice	*Justification*	*Description*	*Impacts*	*Main constraints of implementation*
Sustainable Rice Intensification (SRI) (Styger et al. 2011)	Rice is an important crop for Nigeria whose growers seek to increase its production (in yield and in surface), but it also contributes highly to climate change through methane emissions; therefore, adopting better water management practices is vital.	Land use concerned: **Irrigated rice** • Rotational and intermittent irrigation (keeping a saturated condition, non-flooded) • Use of genetically improved seeds that are transplanted instead of broadcasted • Application of organic fertilizers • Integrated pest management (use less pesticide)	• Transplantation reduces the number of plants and therefore of seeds (economical benefit). • Organic fertilizers improve soil structure, organic matter content, and fertility. • Reduce health hazards due to the use of pesticides. • Increase in yields. • Irrigation management reduces methane emissions.	• In view of the great diversity in rice production systems that operate under varied local biophysical and socioeconomic conditions, SRI methods will not be applicable invariably everywhere. Each situation will require research and validation of the various SRI components (Dobermann 2003). • Higher labor requirements, especially for weed control, initial investments in machinery for direct seeding, and weeding operations. SRI requires excellent land preparation, timely availability of irrigation water during critical periods of growth, good irrigation infrastructure, and efficient methods of weed control. If land leveling and water management are poor, the risk for yield reduction due to temporary drought stress, weeds, or nutrient losses increases (Dobermann 2003). • Other potential uncertainties include increases in soil greenhouse gas emissions (N_2O) in systems with alternate wet–dry conditions (Bronson et al. 1997). • It appears that SRI is mainly suitable for increasing rice yields in environments with acid, iron-rich soils, high labor availability, and a generally low level of crop intensification. Benefits of SRI over conventional rice management are likely to be small on fertile rice soils with no constraints such as potential iron toxicity, provided that management follows known best practices (Dobermann 2003).

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Table C.1 Mitigation Options in the Low-Carbon Scenario: SLM Measures and Limits of Implementation *(continued)*

SLM practice	*Justification*	*Description*	*Impacts*	*Main constraints of implementation*
Livestock management	One Vision 20: 2020 target is to expand dairy production and milk yield from less than 2 t to 5 t per cow per lactation by 2015 (FGN 2010, 58). It will require a switch to more productive animals but also better livestock management in feeding and breeding.	• Better feeding practices (less forage, more concentrates and additives) • Breeding management to select improved and more efficient animals	• Improving animal nutrition will increase the productivity of the livestock. • Selecting more productive animals enables limitation of livestock numbers, therefore reducing the emissions from enteric fermentation (ruminants) and manure management. • Dietary improvements reduce methane emission due to enteric fermentation and, through increased production efficiency, lead to a reduction of methane emitted per unit of production.	• Such techniques are often out of reach for smallholder livestock producers who lack the capital and often knowledge to implement such changes (Steinfeld et al. 2006). • Limiting the number of animals also reduces the amount of manure available to fertilize the crops, which may lead to the use of chemical fertilizers. • Regular extension services are not easily accessible for mobile pastoralists.
Sustainable grazing management *with* inputs	In line with the increase in livestock productivity targeted by Vision 20: 2020, improving grassland management and restoring degraded grassland will support livestock productivity.	Land use concerned: **Grassland** • Restoration of degraded pastures with inputs such as mineral fertilizers, manure application, irrigation • Less or no use of fire	• Maximize the capture, infiltration, and storage of rainwater into soils, thus promoting conditions that increase vegetation cover, improve soil organic content, and conserve above and below ground biodiversity. • Improved grazing conditions will increase livestock productivity in rangelands, in turn increasing food security. • Fires reduce soil organic content (SOC) (thus releasing carbon) and nutrients level, lead to erosion, and kill surface micro-organisms, limiting the soil capacity to reform. Limiting the use of fire limits all these drawbacks.	• Requires community organization for limiting overgrazing. • Requires large investments the first years in fertilizers and irrigation systems.

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Table C.1 Mitigation Options in the Low-Carbon Scenario: SLM Measures and Limits of Implementation *(continued)*

SLM practice	*Justification*	*Description*	*Impacts*	*Main constraints of implementation*
Sustainable grazing management *without* inputs	FGN wants to establish at least 50 gazetted grazing reserves, (FGN 2010) thus a sustainable grazing management is needed to support this goal.	Land use concerned: **Grassland** • Restoration of degraded pastures without inputs through the use of improved grass variety and rotational grassing • Less or no use of fire	• Maximize the capture, infiltration, and storage of rainwater into soils, thus promoting conditions that increase vegetation cover and soil organic content and conserve above and below ground biodiversity. • Improved grazing conditions will increase livestock productivity in rangelands, in turn increasing food security. • Fires reduce SOC (thus releasing carbon) and nutrients level, lead to erosion, and kill surface micro-organisms, limiting the soil capacity to reform. Limiting the use of fire limits all these drawbacks.	• Need to develop grazing plans tailored to specific local conditions (inter alia the pattern of local rainfall, area of land available, location of water supplies, numbers, and types of livestock) by using participative approaches with entire communities developing, for example, new systems and regulations involving communities gathering their livestock into a group, then moving from one portion of their grazing lands to another during the year. • Costs in Ethiopia in improved grazing land management = $1,035/yr establishment, and $126/yr maintenance; range closure for rehabilitation = $390/ha establishment, and $90/yr maintenance (TerrAfrica 2009).
Avoided deforestation	Deforestation is the biggest GHG emissions source in the reference scenario; therefore, it is an important improvement point.	Land use concerned: **Forest** The forest is preserved	• Avoiding deforestation prevents the important release of CO_2 in the atmosphere (from clearing and burning). • Preserving the forest will preserve biodiversity. • Deforestation can affect the flux of moisture to the atmosphere, regional convection, and regional rainfall.	• In many instances, the sole option to preserve forested area is to intensify agricultural production on other land. This raises complexities; for example, when intensification involves increased fertilizer inputs, there will be increased emissions related to the fertilizer (TerrAfrica 2009). • Need to find and provide more affordable fuel-efficient stoves or sustainable alternative fuels to decrease the pressure on wood resources. • For some countries timber can be an important export revenue that they might not want to lose.

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Table C.1 Mitigation Options in the Low-Carbon Scenario: SLM Measures and Limits of Implementation *(continued)*

SLM practice	*Justification*	*Description*	*Impacts*	*Main constraints of implementation*
Reforestation/ Afforestation and Agroforestry (live fences, alley cropping)	FGN objective is a proactive policy of afforestation, reforestation, and erosion control programs (FGN 2010, 62).	Land use concerned: **Forest** • Reforestation is planting new trees in previously forested areas (where old tress have been recently cut or burned). • Afforestation involves planting stands of trees on land that is not currently classified as forest. • Both reforestation and afforestation can include shelterbelts, windbreaks, and woodlots. • The alley-cropping technique involves growing annual crops in spaces (4- to 6-meter-wide "alleys") between rows of leguminous trees or shrubs maintained as hedges.	• Tree planting sequesters carbon in the biomass and the soil, while conserving soil and water quality and quantity. • Increased tree cover will improve the functioning of the hydrological system and protect wild biodiversity. • Reforestation and afforestation will increase the amount of sustainably sourced wood for fuel and timber and non-woody forest products (medicinal plants, wild food, fodder, and so on), which would bring economic benefits to local people. • The hedges are heavily pruned throughout the crop season to prevent them from shading the crops. The prunings and crop residues are used as mulch to conserve moisture and enrich the soil in the cultivated alleys. Soil nutrients and nitrogen fixed by the tree roots similarly enrich the soil in the alleys. The technique allows for continuous cultivation of food crops because soil productivity is restored throughout the cropping cycle, thus eliminating the need for a fallow period. (USAID 1989). • For agroforestry, benefits are numerous: erosion control, runoff barrier, improvement of soil fertility and moisture content, and control of drought and desertification.	• In dryland areas, purposeful planting of trees is difficult due to lack of water for nurseries in the dry season and absence of labor for protecting the trees (TerrAfrica 2009). • Uncertain land tenure situations certainly had an adverse impact on farmers' attitudes toward tree planting in several countries (Spears 1983). • A common constraint is land availability, particularly where there is high population density and competition for land between agriculture and forestry, and especially in those countries where a high proportion of the land suitable for forest is under fragmented private ownership (Spears 1983). • Given the fact that it takes 20–25 years in many countries to grow industrial tree crops to merchantable size, this long time period before any income is obtained can act a disincentive to small farmers participating in industrial forestry (Spears 1983). • The risks of fungal or insect diseases associated with large-scale plantation monocultures have created problems in some countries (for example, *Dothistroma pinii* in Kenya and the ravages of the Pine Shoot moth in the Philippines) (Spears 1983). • Regarding agroforestry, the demand for labor is high (pruning).

Source: World Bank data.

Table C.2 Impact of SLM Measures on GHG Emissions and Yield

SLM practice	*Potential yield augmentation*	*Potential impact on GHG emissions and carbon sequestration*
Conservation agriculture	• Regarding the carbon storage in soil, changes in yield due to conservation agriculture will vary depending on the site characteristics. Researches shows that yields often decreased in the first years, before increasing. • Yields can be more than 60% higher than under conventional tillage (FAO 2007). • Studies in East and Southern Africa show that conservation agriculture with fertilization increases the yield from 1.2 to 2 t/ha for maize and from 0.5–0.7 to 1.1 t/ha for *tef* (grass crop) in Ethiopia (Rockström 2008).	• It is difficult to make definitive quantitative statements on the effects of reducing tillage on SOC, because the effects are highly dependent on the individual site (*inter alia* soil type, climate, crops grown, previous intensity of tillage, new regime). • A change from conventional tillage to no-till can sequester 0.57 ± 0.14 t C/ha/yr (West and Post, 2002). The IPCC (2006) estimated that conservation tillage can sequester 0.1–1.3 t C/ha/yr globally. • A field monitoring site in western Nigeria recorded that no-tillage combined with mulch application increased SOC from 15 to 32.3 t/ha in four years (Ringius 2002). • Levels can be expected to peak after 5–10 years, with SOC reaching a new equilibrium in 15–20 years. Overall, rates of SOC are lower in hotter climates.
Sustainable rice intensification	Average yield increase by 10–25% (Ramasamy 1997): • From 2.5t/h to 5–7.5t/ha in Gambia and Sierra Leone Ceesay et al. 2006. • up to 15 t/ha in Madagascar (Stoop, Ubhoff, and Kasam 2002). • Maximum SRI yields in the range of about 8–12 t/ha appear to be more common in other studies (Dobermann 2003).	• Emission rates ranged from < 100 kg CH_4 ha^{-1} to > 400 kg CH_4 ha^{-1} for intermittent irrigation and continuous flooding respectively (Wassmann et al. 2000). • Yue et al. (2005) compared continuous flooding with intermittent flooding and their role on CH_4 and N_2O emissions in Southern China and found that intermittent flooding showed a 17% lower Global Warming Potential (GWP) compared to continuous flooding, while there was no significant differences between yields. • The soil carbon pool can be enriched with 401 kg C ha^{-1} annually, with a rice yield of 3.96 t ha^{-1} and input of crop residues amounting to 2.67 t ha^{-1} (Jarecki and Lal 2003).
Livestock management	Increase in meat and milk production; Example: in Kenya, genetic improvement program: the average lactation milk yield in the stud has gone up from 1,042 kg in 1965 to 1,527 kg in 1971. With the present selection procedure, annual genetic gain is projected to be 0.12 genetic standard deviations, or 43.4 kg (Meyen and Wilkins 1973).	• Recent modeling studies in the United Kingdom by Genesis-Faraday (Genesis-Faraday Partnership 2008; Jones et al. 2008) have indicated that past selection for production traits, such as growth rate, milk production, fertility, and efficiency of feed conversion, has resulted in decreases in GHG production per unit of livestock product of about 1% per year. • Depending on the nature of the intervention, methane production can be reduced 10–40%. Increasing DMI (dry matter intake) and the proportion of concentrate in the diet reduced methane production (–7 and –40%, respectively). Methane production was also decreased with the replacement of fibrous concentrate with starchy concentrate (–22%) and with the utilization of less ruminally degradable starch (–17%). The use of more digestible forage (less mature and processed forage) resulted in a reduction of methane production (–15 and –21%, respectively). Methane production was lower with legume than with grass forage (–28%), and with silage compared to hay (–20%). • Supplementation or ammoniation of straw did not reduce methane losses, but had a positive impact on the efficiency of rumen metabolism (Benchaar, Pomar, and Chiquette 2001).

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Table C.2 Impact of SLM Measures on GHG Emissions and Yield *(continued)*

SLM practice	*Potential yield augmentation*	*Potential impact on GHG emissions and carbon sequestration*
Sustainable grazing management *with* inputs	• Increase in yield will vary, depending on the type and quantity of improvements (level of fertilization, amount of water, presence of leguminous, species, level of plants diversity, and so on). • Herbage production can be increased one- to four-fold through timing and intensity of grazing (Bryant 1985).	• Rates of C sequestration by type of improvement ranged from 0.11 to 3.04 t $C{\cdot}ha^{-1}\ yr^{-1}$, with a mean of 0.54 t $C{\cdot}ha^{-1}{\cdot}yr^{-1}$, and were highly influenced by biome type and climate (Conant, Paustian, and Elliott 2001). • Stocking rates increased by 50% (from 0,8 to 1,2 AU/ha/year) in Brazil, mainly due to the better grazing efficiency associated with rotational grazing (Corsi. Do Nascimento, and Balsalobre 2001).
Sustainable grazing management *without* inputs	Increase in yield will vary depending on the type and quantity of improvements (level of fertilization, amount of water, presence of leguminous, species, level of plants diversity, and so on).	From 0.2 to 0.4 t C/ha/yr (improved species, controlled grazing, fire management) (Lal 2004).
Avoided deforestation		• It depends on the type of forest, its density, and the use after conversion (emissions will be higher if the forest is converted into annual crops versus perennial crops or grassland). • From 0.75 to 4.25 t C/ha/yr (Masera 1995) for a Brazilian tropical forest.
Reforestation/ afforestation and agroforestry (live fences, alley cropping)	Growth rate depends on the type of plantation, as well as its density: • Broad leaves plantation: 1 t DM/ha/yr (Koch, Dayan, and Mey-Marom 2000) • Conifer plantation: 4 t DM/ha/yr • Eucalyptus plantation: 7 t DM/ha/yr • Fodder (tree + shrubland): up to 6.9 t DM/ha/yr in Tanzania (Mbwambo 2004). Agroforestry (alley cropping, contour hedge-row farming) increases the yield of millet, maize, and other grains by 45–200%, according to some studies (Kang et al. 1999; ILCA and IITA l986). Other researchers suggest that alley cropping has no significant effect on crop yields in most cases (Junge 2008). The crop yield response is uncertain and variable due to competitive effects of the different cultures for light, water, and nutrients.	• From 0.86 to 3.75 t C/ha/yr (Masera 1995) for a Brazilian tropical plantation. • The C sequestration potential of agroforestry systems is estimated at 12–228 Mg/ha with a median value of 95 Mg/ha (Albrecht and Kandji 2003).

Source: World Bank data.

Table C.3 Sources of Data And Assumptions to Calculate Costs for Each SLM Option

Required investment	*Mitigation option concerned*	*Assumptions*	*References*
Fertilizer need	• Conservation agriculture and annuals • Sustainable grazing management with inputs • Perennials	FGN supports farmers in using fertilizers with subsidies. Subsidies represent 17% of the total cost of buying fertilizers. Farmers pay 83% of the total cost to buy these fertilizers.	• Federal Fertilizer Department, FGN 2006 • Federal Ministry of Agriculture and Rural Development • University of Calabar 2002 • International Food Policy Research Institute (IFPRI) Nigeria Agriculture Public Expenditure Review (World Bank 2008)
Organic fertilizer	• Conservation agriculture • Sustainable rice intensification	Prices (US$23/bag) and quantities obtained from records of the Soil Science Department, Organic Fertilizer Unit, University of Calabar Cost born 100% by farmers	Bisong 2010
Agric. extension agent	• Conservation agriculture and annuals • Perennials • Sustainable Rice Intensification • Sustainable grazing management with and without inputs • Livestock management	• Number of visits/production rotation = 20 • Cost born at 100% by FGN	University of Calabar 2002
Seed development cost	• Conservation agriculture • Sustainable Rice Intensification • Sustainable grazing management with and without inputs	• Cost based on market prices for matured seedlings • Cost born at 100% by FGN	• University of Calabar 2002 • National Programme for Food Security: Federal Ministry of Agriculture and Water Resources
Administrative cost	• For all measures	Assumed to be 20% of all other costs, based on qualitative feedback from the Fadama project, born 100% by FGN	Ike, 2012.
Higher yield	• Sustainable grazing management with and without inputs • Livestock management • SRI • Conservation agriculture and annuals • Perennials • Agroforestry	Assumed to be 80% of the traditional yield for conservation agriculture, 50% for agroforestry, 25% for SRI, 33% for livestock,10–66% for grassland	University of Calabar 2002 Junge et al. 2008; Kang et al. 1999;Ramasamy 1997; Infonet/Biodivision http://www.infonet-biovision.org/default/ct/268/livestockSpecies; Federal Fertilizer Department, FGN 2006.

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Table C.3 Sources of Data And Assumptions to Calculate Costs for Each SLM Option *(continued)*

Required investment	*Mitigation option concerned*	*Assumptions*	*References*
Feed and management (prophylaxis and breeding)	• Livestock management	FGN gives subsidies to farmers to help them improve feeding and breeding practices. Subsidies represent 17% of the total cost, therefore farmers still have to pay 83%.	No specific data was found in the scientific literature, so the figures used are based on the scheme for fertilizers subsidies.
Planting cost	• Reforestation/afforestation and agroforestry	Cost born at 100% by FGN for afforestation, and at 25% for agroforestry. Thus farmers need to pay 75% of the cost of planting live fences and hedges.	Federal Department of Forestry, Nigeria Tewari 2008
Protection cost (against animals, during growing time, and forest management and enforcement)	• Reforestation/afforestation	Cost born at 100% by FGN	Federal Department of Forestry, Nigeria
Opportunity cost	• Reforestation/afforestation and agroforestry • Avoided deforestation	• The cost of nonconverting the forested area into a more productive crop is born by the farmers, while the cost of non-harvesting is supported by the Government. • It is the value of the next-highest-valued alternative use of that resource—the benefits that could have been received by taking an alternative action, for example, deforestation.	International Institute for Environment and Development (IIED 2008)
Non-Forest Timber Product (NFTP)	• Reforestation/afforestation and agroforestry • Avoided deforestation	NFTP to benefit the farmers, includes the economical value of flora and fauna (picking, hunt), for the forest plantation, and the value of grass, fodder, and wood for the agroforestry/live fencing.	Yaron 2001 (Data are for Cameroon); Tewari 2008
Fuel costs	• Annuals	0.77$/liter in 2010	WB country data Trading Economics http://www.tradingeconomics.com/nigeria/pump-price-for-diesel-fuel-us-dollar-per-liter-wb-data.html

Source: World Bank data.

APPENDIX D

Further Details on Low-Carbon Scenarios A and B

GHG Emissions in Scenario A

The total emissions of scenarios A and B for the whole 25-year period go up to 1,687 Mt CO_2e, that is, 0.74 t CO_2e/ha/yr—or 1.6 times less than the reference scenario. However, from 2030, the agriculture, forestry, land use (AFOLU) sector begins to be a net sink, thanks to greenhouse gases (GHG) abatement and carbon storage from the land use change component. Indeed, emissions from deforestation and other land use changes (LUCs) are offset by the sequestration of carbon in tree plantations.

Gross emissions come from LUC until 2029 (56 percent of total), from livestock and pasturelands (37 percent), and from inputs (7 percent). Gross sinks are divided between crops and LUC with a ratio of almost 4:1 (73 percent and 27 percent, from 2030 for LUC). Perennials and agroforestry/afforestation especially account for the carbon sequestration, respectively, 33 percent and 47 percent. Even if reduced, deforestation still contributes strongly to gross emissions (53 percent), followed by livestock (29 percent). For further details of scenario A see table D.3 and figure D.1.

GHG Emissions for Scenario B

Total emissions for the whole period reach 2,017 Mt CO_2e, which is equivalent to an average of 0.89 t CO_2e/ha/yr. Net emissions are positive until 2033, after which 2034 and 2035 are the first years where the agricultural and forestry sector becomes a sink. The main sources of gross emissions are LUC with 59 percent, followed by livestock and grass (35 percent). This is essentially due to deforestation and enteric/manure management emissions. Crops provide the great majority of abatement through annuals and conservation agriculture (31 percent) as well as perennials (45 percent). Since in this low-carbon scenario agroforestry is not as important as in the previous ones, the contribution of this mitigation option is more limited (21 percent instead of 47 percent).

Table D.1 Land Use Change Matrix for Scenario A
Hectares, thousands

	Initial 2010								
Final 2025	*Annuals*	*Wet rice*	*Perennials*	*Forests*	*Grasslands*	*Degraded lands*	*Fallow*	*Other lands*	*Total final*
Annuals	28,913			4,381	2,504		3,130	2,504	**41,432**
Wet rice	1,312	1,313							**2,625**
Perennials			6,552	634	475	792	634	634	**9,721**
Forests + live fences/ agroforestry	4,211			4,086	1,524	300	180		**10,301**
Grasslands					14,126	757			**14,882**
Degraded lands						0			**0**
Fallow							2,290		**2,290**
Other lands								9,803	**9,803**
Total initial	**34,437**	**1,313**	**6,552**	**9,101**	**18,629**	**1,849**	**6,234**	**12,941**	**91,054**

Source: World Bank data.

Table D.2 Land Use Change Matrix for Scenario B
Hectares, thousands

	Initial 2010								
Final 2025	*Annuals*	*Wet rice*	*Perennials*	*Forests*	*Grasslands*	*Degraded lands*	*Fallow*	*Other lands*	*Total final*
Annuals	32,192			3,234	1,848		2,310	1,848	**41,432**
Wet rice	1,312	1,313							**2,625**
Perennials			6,552	634	475	792	634	634	**9,721**
Forests + live fences/ agroforestry	932			4,086	431	300	180		**5,929**
Grasslands				1,148	15,875	757			**17,779**
Degraded lands						0			**0**
Fallow							3,110		**3,110**
Other lands								10,459	**10,459**
Total initial	**34,437**	**1,313**	**6,552**	**9,101**	**18,629**	**1,849**	**6,234**	**12,941**	**91,054**

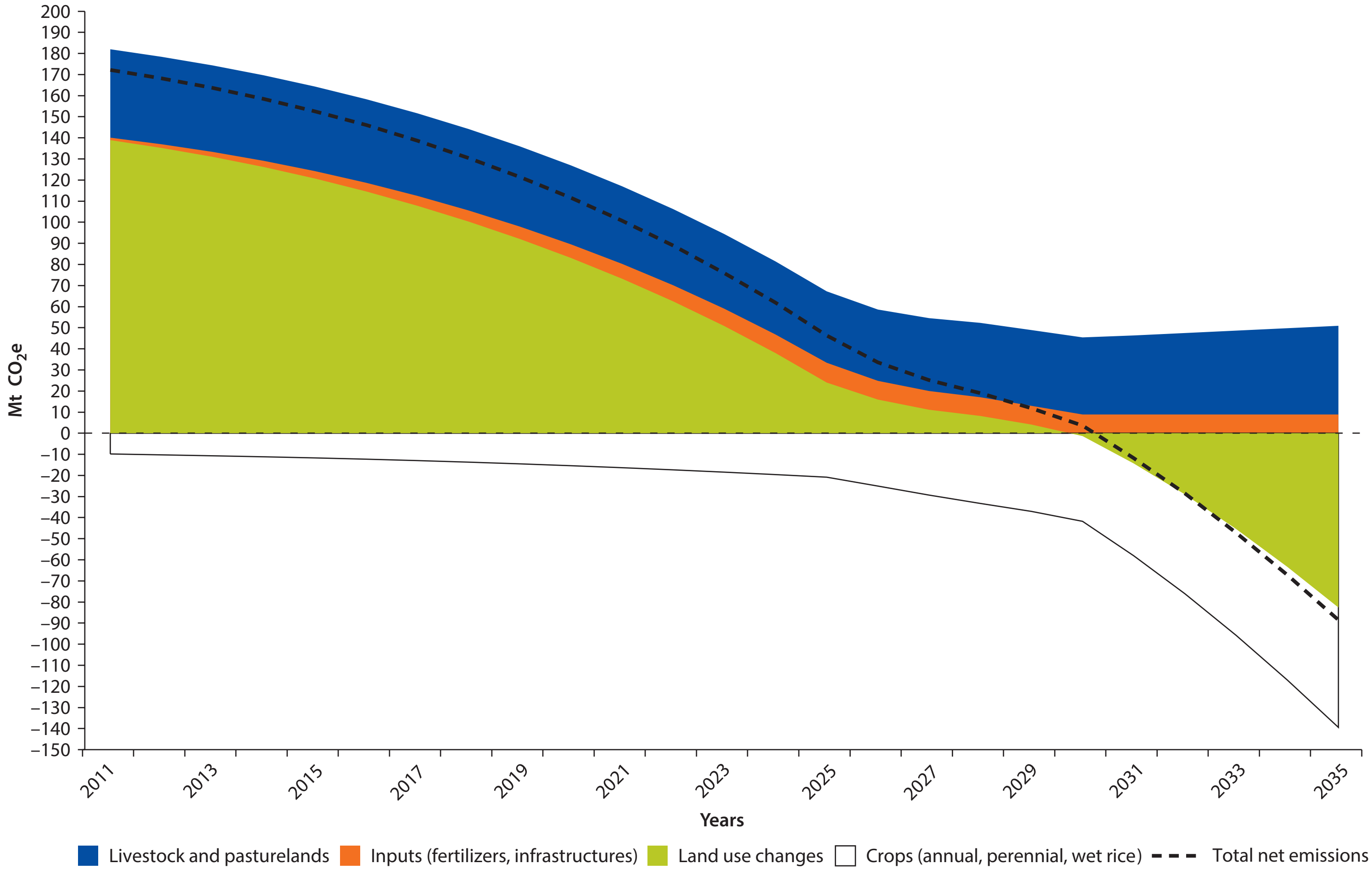
Source: World Bank data.

Table D.3 Annual Emissions of 2010 vs. 2035 in Scenario A (Mt CO_2e/yr)

		2035		Percent difference	
Activities	*2010*	*Baseline*	*Low carbon*	*Baseline*	*Low carbon*
Land use changes	127.1	15.6	–82.6	–88	–165
Crops	–9.4	–43.6	–56.8	–364	–504
Livestock and grassland	42.4	46.4	42.0	+10	–1
Other	0.6	6.7	8.9	+1,068	+1,439
Total	**160.6**	**25.2**	**–88.5**	**–84**	**–155**

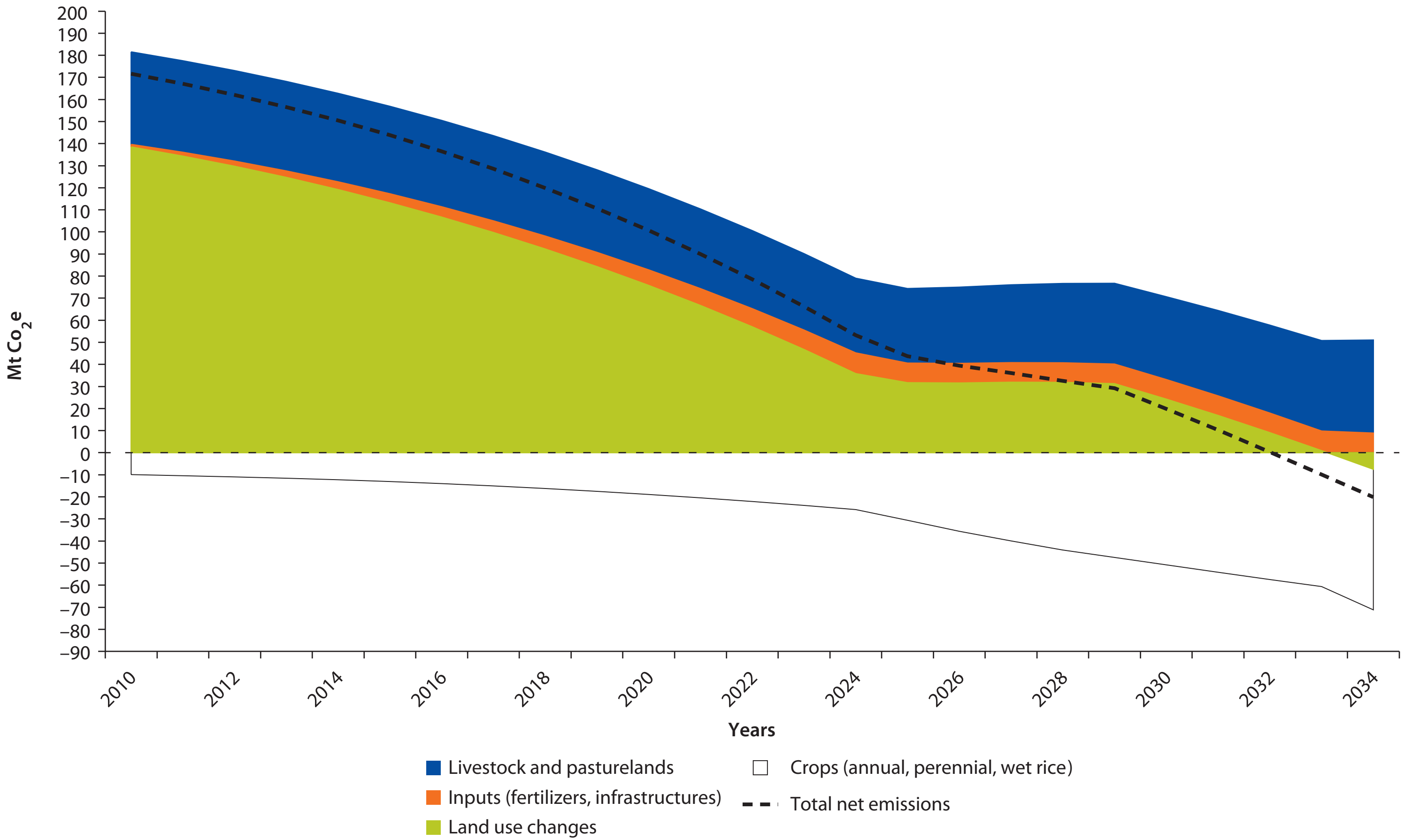
Source: World Bank data.

Figure D.1 Evolution of Annual Emissions, by Activity, in Scenario A, 2010–35



Source: World Bank data.

Figure D.2 Evolution of Annual Emissions, by Activity, in Scenario B, 2010–35



Source: World Bank data.

Total emissions for the whole period reach 2,017 Mt CO_2e, equivalent to an average of 0.89 t CO_2e/ha/yr. Net emissions are positive until 2033, after which 2034 and 2035 are the first years where the agricultural and forestry sector becomes a sink. The main sources of gross emissions are LUC (59 percent of total), followed by livestock and grass (35 percent), due to deforestation and enteric/manure management emissions. Crops provide the great majority of sequestration, through annuals and conservation agriculture (31 percent) as well as perennials (45 percent). Since in this low-carbon scenario, agroforestry is not as important as in the previous ones, the contribution of this mitigation option is more limited (21 percent instead of 47 percent).

Table D.4 Annual Emissions of 2010 vs. 2035 in Scenario B
Mt CO_2e/yr

		2035		*Percent difference*	
Activities	*2010*	*Baseline*	*Low carbon*	*Baseline*	*Low carbon*
Land use changes	127.1	15.6	–7.5	–88	–106
Crops	–9.4	–43.6	–63.7	–364	–577
Livestock and grassland	42.4	46.4	42.1	+10	0
Other	0.6	6.7	8.9	+1068	+1439
Total	**160.6**	**25.2**	**–20.2**	**–84**	**–113**

Source: World Bank data.

APPENDIX E

Sensitivity Analysis of the Model Results

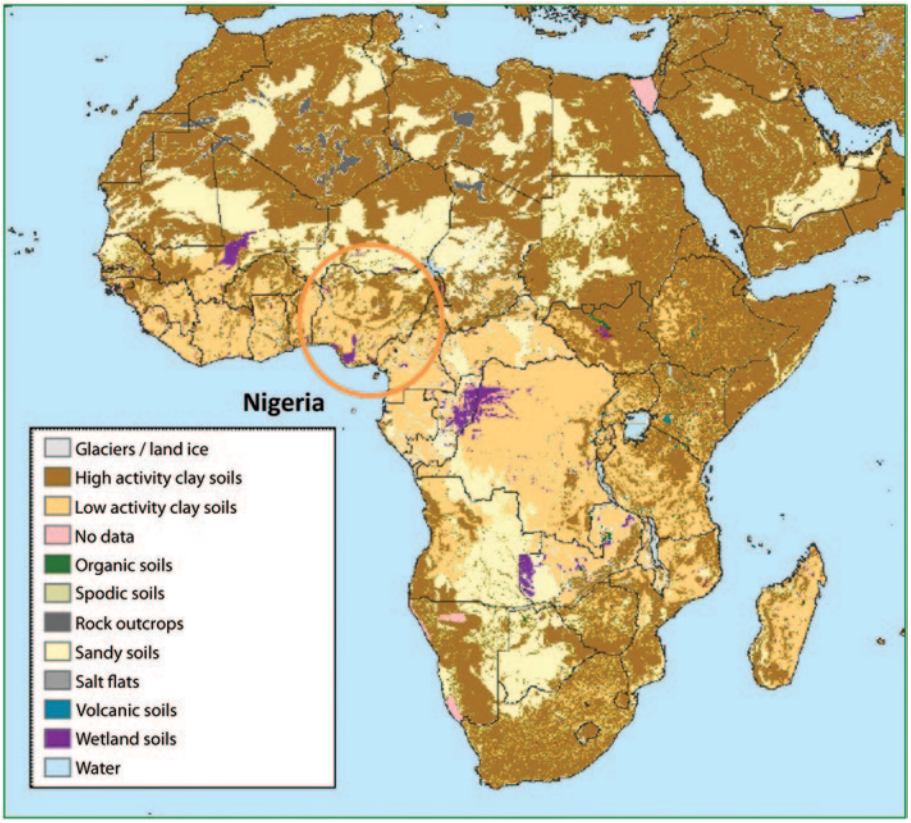
The results presented in this study depend, among others, on assumptions made about climate and soils. Given the study's limited timeframe, climate and soil variables have been selected at a coarse scale of aggregation, selecting a single value for the country as a whole from the options defined by the IPCC (2006) (maps E.1 and E.2)[1] at the global scale. Specifically, a tropical moist climate and LAC soil have been chosen because they best represent the bulk, but not all, of Nigeria's territory. To gauge the bias due to selection of single values for these parameters, the research team undertook a sensitivity analysis using different combinations of climate and soil parameters (tropical wet/moist climate, and low activity clay/high activity clay (LAC/HAC) soil).

Tables E.1 and E.2 display the detailed changes in overall emission results as following from different assumptions of climate and soil.

Changing only the type of soil (from LAC in the initial analysis to HAC) does not significantly affect the emission estimates; the difference is only 0 to 1 percent. However, the type of climate has an important impact on the emissions: the tropical wet climate gives figures that are 2 to 12 times lower than the tropical moist climate.

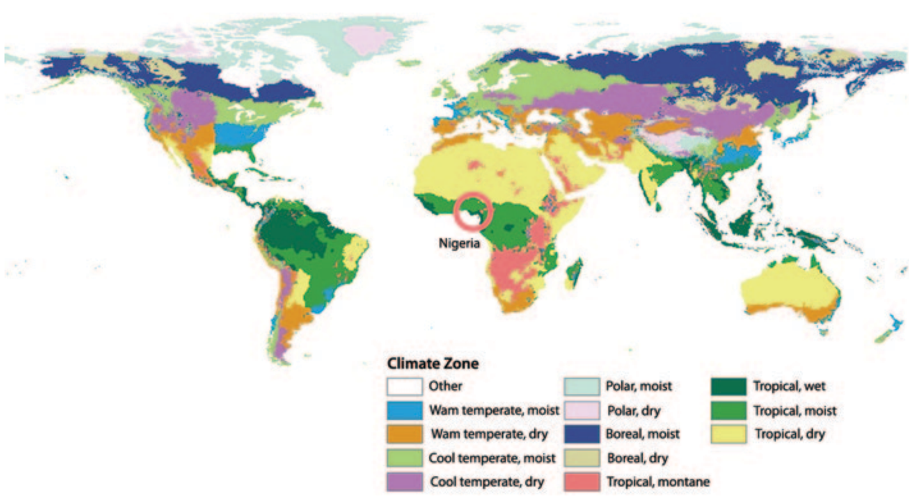
Differences in mitigation potential, however, are low (less than 3 percent). This is not considered significant compared to the uncertainty surrounding emissions factors for a single set of soil and climatic conditions (generally at least 30 percent). Therefore, the selection of soil and climate parameters is not considered to have significantly affected the results in terms of the sector mitigation potentials.

Map E.1 Distribution of Spatially Dominant IPCC Soil Class for Africa



Source: Batjes 2010.

Map E.2 IPCC (2006) World Climatic Zones



Source: Joint Research Center, European Soil Portal, http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/.

Table E.1 Discrepancy in GHG Emissions Depending on Climate and Soil Types
(Thereby case 1 stands for the climate and soil parameters of the main analysis presented in this study, while case 2–4 are variations as part of the sensitivity analysis)

Case	Climate	Soil
1	Tropical moist	LAC (low activity clay)
2	Tropical moist	HAC (high activity clay)
3	Tropical wet	HAC
4	Tropical wet	LAC

	Reference scenario		Low-carbon scenario A		Low-carbon scenario B	
Case	GHG emissions for the whole 25 year-period in Mt CO_2e	Percent difference (relative to case 1)	GHG emissions for the whole 25 year-period in Mt CO_2e	Percent difference (relative to case 1)	GHG emissions for the whole 25 year-period in Mt CO_2e	Percent difference (relative to case 1)
1	2,663		1,687		2,017	
2	2,682	0.7	1,696	0.5	2,019	0.1
3	1,112	–58.3	138	–91.8	469	–76.8
4	1,128	–57.6	146	–91.3	471	–76.7

Source: World Bank data.

Table E.2 Discrepancy in Mitigation Potential Depending on Climate and Soil Types

	Scenario A		Scenario B	
Case	GHG avoided for the whole 25 year-period in Mt CO_2e	Percent difference (relative to case 1)	GHG avoided for the whole 25 year-period in Mt CO_2e	Percent difference (relative to case 1)
1	976		646	
2	986	1.07	662	2.5
3	973	–0.3	643	–0.5
4	982	0.6	657	1.8

Source: World Bank data.

Note

1. Available at: http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/NIGERIAEXTN/0,,menuPK:368922~pagePK:141132~piPK:141109~theSitePK:368896,00.html.

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