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DIRECTIONS IN DEVELOPMENT
Countries and Regions

Low-Carbon Development

Opportunities for Nigeria

Raffaello Cervigni, John Allen Rogers, and Max Henrion, Editors

THE WORLD BANK

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Cover image: A member of a women's farming cooperative stands before solar panels that power her community's drip irrigation farms. Solar market gardens provide a cost-effective, labor-saving, and clean way of delivering much-needed irrigation water, particularly during the long, dry season. © Jennifer Burney, Center on Food Security and the Environment, Stanford University. Used with the permission of Jennifer Burney / Center on Food Security and the Environment, Stanford University. Further permission required for reuse.
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Foreword by Nigeria's Coordinating Minister for the Economy

Over the past decade Nigeria has experienced steady growth, averaging more than 7 percent per annum in the last five years. Our country has the potential to make further strides toward rapid, more inclusive growth, which would reduce poverty further and create more opportunities for shared prosperity. We need to do this in a way that is sustainable over the longer term, in economic, social, and environmental terms; we need to develop innovative ways to diversify our economy, still too dependent on petroleum products; and we all need to work together to make this an enduring reality.

"Green growth" is emerging as a new paradigm to reconcile developing countries' urgent need for rapid growth and poverty reduction with the conservation of the natural resources capital on which lasting development depends. Green growth promises to provide people with both jobs and a healthier environment—for today and tomorrow.

However, there is no single blueprint defining how this new paradigm could be implemented in different countries. What is essential is a solid knowledge base to assess costs and benefits of different avenues to pursue green growth, which are inherently country-specific.

This book provides an important foundation of such a knowledge platform, as it assesses how "low carbon" (a key ingredient of green growth) could be mainstreamed into Nigeria's development path over the next 25 years. Its main insight—that Nigeria can stabilize carbon emissions while at the same time reaping significant national benefits—is an important one. The book points, in a practical way, to areas where low-carbon technologies and management options could contribute to domestic development. These include tapping into renewable energy and energy efficiency, accelerating the reduction of gas flaring and exploiting opportunities for commercial use of natural gas thereby saved, scaling up sustainable land management for higher yields in agriculture, and enhancing the fuel efficiency of vehicles to make road transport cheaper and cleaner.

These are important elements that can help the design and implementation of sector policies. In addition, the book also provides insights for broader, crosscutting policy planning, and in particular the observation that low-carbon development might have significant net benefits for the economy as a whole, which the book quantifies on the order of 2 percent of GDP. As we look to the next wave of investment to move Nigeria closer to the objectives of Vision 20: 2020, this book will assist us in making choices that could reconcile economic and environmental objectives.

Ngozi Okonjo-Iweala
Coordinating Minister for the Economy and
Federal Minister of Finance

Foreword by the World Bank

Nigeria has the ambition, as enshrined in the "Vision 20: 2020" strategy document, to become one of the world's 20 largest economies by the year 2020. Some observers believe that this objective cannot be met without damage to the national or global environment. However, experience has shown that this is not inevitable. The development community is looking with increasing interest, particularly in the aftermath of the Rio+20 Summit, at concepts such as "green growth" and "low-carbon development" and how these principles can be translated into concrete policies and investments.

The Federal Government of Nigeria and the World Bank have agreed to carry out a comprehensive analysis of the opportunities to reconcile economic growth with concerns for climate change. Over the course of two years, we at the World Bank have worked closely with the government, as well as with representatives of academia, the private sector, civil society, and the community of development partners, to produce the first comprehensive low-carbon development study for Nigeria (and, with the exception of South Africa, first for the Sub-Saharan Africa region as a whole).

This book presents the final results of that analysis. Focusing on four key sectors—agriculture and land use, oil and gas, power, and transport—the analysis shows that low-carbon development can be an attractive proposition for Nigeria, not just because it would position the country as a leader in the fight against climate change, but, perhaps more importantly, because it would generate significant domestic benefits. These include a more productive and climate-resilient agriculture sector, cheaper and more geographically balanced power generation, more efficient use of the country's endowment of oil and gas resources, and better provision of transport services, resulting in improved air quality and lower congestion.

This book identifies a number of specific actions that Nigeria can undertake to move toward a model of development that reduces carbon emissions while at the same time spurring growth. We believe that with the right combination of better knowledge, more evidence-based environmental policies, better governance, and adequate funding, Nigeria could rapidly seize many of the win-win opportunities the book discusses; the World Bank stands ready to assist the country in all of these areas.

Marie Francoise Marie-Nelly
Country Director for Nigeria
The World Bank

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Preface

The analysis of low-carbon development options in Nigeria was undertaken during a period of more than two years and involved the preparation of a number of sector-specific background reports. This book presents a synthesis of the key findings and conclusions for the sectors of inquiry—agriculture and land use, oil and gas, power, and transport—as well as cross-cutting findings and recommendations for the country as a whole.

A separate companion volume, *Assessing Low-Carbon Development in Nigeria: An Analysis of Four Sectors*, to be published as part of the World Bank Studies series, provides a more detailed description of the study methodology and the results obtained in each of the four economic sectors.

The analysis is based on data and information collected up to June 2012; changes in government policies, national or international markets, and other developments that have occurred since then are not reflected in the book.

Acknowledgments

This book is the result of a collaboration of a large number of individuals and organizations that have provided many different inputs throughout the process of its preparation.

The contributors to the drafting of the text are as follows.

Introduction, country and sector background, research approach and methods, and summary of findings and recommendations: Raffaello Cervigni and John A. Rogers.

Agriculture and land use sector: Louis Bockel, Pierre Luc Sutter, and Ophélie Touchemoulin (Food and Agriculture Organization, FAO); with Francis Bisong (consultant).

Oil and gas sector: Huw Martyn Howells (World Bank), Max Henrion (Lumina Decision Systems) and Gary Howorth (consultant); with Felix Dayo and Wumi Iledare (Triple E Systems).

Power sector: Max Henrion and Surya Swamy (Lumina Decision Systems); with Felix Dayo and Asmerom Gilau (Triple E Systems), and Anthony Adegbulugbe (consultant).

Transport sector: Robin Kaenzig (Integrated Transport Planning Ltd.) and John A. Rogers; with S. B. Akintayo (consultant).

The following World Bank staff contributed to the writing: Ademola Braimoh, Stephen Danyo, Erik Magnus Fernstrom, Roger Gorham, Anushika Karunaratne, Stephen Ling, Manuel Luengo, Brice Quesnel, and Venkata Ramana Putti. The peer reviewers for the original report were Sameer Akbar, Christophe de Gouvello, and Todd Johnson. The extended World Bank team included Amos Abu, Abimbola Adubi, Joseph E. Akpokodje, Irina Dvorak, Jane Ebinger, Oluwafemi Faleye, Francesca Fusaro, Julie Godin, Ella Omomene Iklaga, Beula Selvadurai, Shobha Shetty, and Govinda R. Timilsina.

The work was undertaken under the supervision of World Bank managers, Idah Z. Pswarayi-Riddihough (Sector Manager, Environment, Natural Resources and Climate Change in Africa); Jamal Saghir (Director, Africa Sustainable Development Department); and Marie Francoise Marie-Nelly and Onno Ruhl (respectively, current and former Country Director for Nigeria).

The book was edited by Valerie Ziobro (consultant) based on a previous draft edited by Max Henrion and Kristin Abkemeier (Lumina Decision Systems). Irina Dvorak coordinated the inputs from the various authors to the final version of the book. In the World Bank's Office of the Publisher, Stephen Pazdan oversaw the book production process and Patricia Katayama handled acquisition duties.

From the Federal Government of Nigeria, policy guidance was provided by Hon. Mrs. Hadiza Ibrahim Mailafa (Minister of Environment), and Hon. Dr. Akinwunmi Ayo Adesina (Minister of Agriculture). The following senior officials from the Federal Government of Nigeria provided important contributions: Abubakar Sambo (Director General, Energy Commission of Nigeria, ECN), Dere Awoshika (Permanent Secretary, Federal Ministry of Power, FMP), Adera Adejuwon (Director, Department of Climate Change, Federal Ministry of the Environment, FME), Tim Okon (Group General Manager, Nigerian National Petroleum Corporation, NNPC), Sam Amadi (Chairman, Nigeria Energy Regulation Commission), Bahijjahtu Abubakar (National Coordinator Renewable Energy, FME), and Johnson O. Ojosu (Director, ECN).

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About the Editors

Raffaello Cervigni is a lead environmental economist with the Africa Region of the World Bank. He holds a master's in economics from Oxford University and a PhD in economics from University College London. He has more than 18 years of professional experience in programs, projects, and research financed by the World Bank, the Global Environment Facility, the European Union, and the Italian Government in many sectors. He is currently the World Bank's regional coordinator for climate change in the Africa Region, after having served for about three years in a similar role for the Middle East and North Africa Region. He is the author or coauthor of over 40 technical papers and publications, including books, book chapters, and articles in learned journals.

John Allen Rogers is an engineer specializing in low-carbon development modeling. As Senior Climate Change Specialist at the World Bank, he has developed EFFECT, a Visual Basic, Excel-based, bottom-up model of climate-changing greenhouse gas emissions with associated costs and benefits, that can be applied to on-road transport as well as to the power sector, industry, nonresidential, and household electricity consumption. EFFECT is currently used by the World Bank, the Asian Development Bank, and others in approximately 18 countries. Before joining the World Bank, Rogers worked for over 20 years as an international consultant after a long career in engineering, quality control, and marketing with heavy-duty vehicle and diesel engine manufacturers.

Max Henrion is the chief executive officer of Lumina Decision Systems in Los Gatos, California. He has 30 years of experience as a professor, decision consultant, software designer, and entrepreneur. He has led teams to develop decision and policy models for clients in government and industry in energy and environment, aerospace, analytics, and consumer choice. He is the originator of Lumina's flagship software product, Analytica. Before founding Lumina, he was an associate professor at Carnegie Mellon University and vice president of decision technology at the search engine company, Ask Jeeves. He has a BA in natural sciences from Cambridge University, a master of design from the Royal College of Art, and a PhD in operations research from Carnegie Mellon. He is the author or coauthor of three books, including *Uncertainty: A Guide to Dealing with Uncertainty in Policy and Risk Analysis* (Cambridge University Press, 1990), and more than 60 peer-reviewed articles.

Abbreviations

ADPs	Agricultural Development Projects
A/F	afforestation and reforestation
AFOLU	agriculture, forestry, and other land use
AG	associated gas (gas produced in association with oil)
ATA	Agricultural Transformation Agenda
BAU	business-as-usual
bbl	barrels of oil
BoI	Nigerian Bank of Industry
BRT	bus rapid transit
CAIT	Climate Analysis Indicators Tool
CBN	Central Bank of Nigeria
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CER	certified emissions reduction
CFL	compact fluorescent lamp
CGE	computable general equilibrium
CNG	compressed natural gas
COP	Conference of the Parties
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPS	Country Partnership Strategy
CSA	climate-smart agriculture
CSIRO	Commonwealth Scientific and Industrial Organization
CSP	concentrated solar power
CTF	Clean Technology Fund
DAS	Department of Agricultural Sciences
DNI	direct normal irradiation
DPR	Department for Petroleum Resources

ECN	Energy Commission of Nigeria
EE	energy efficiency
EFFECT	Energy Forecasting Framework and Emissions Consensus Tool
EIA	Energy Information Agency
EMT	Economic Management Team
ESMAP	Energy Sector Management Assistance Program (of the World Bank)
ETS	EU Emissions Trading System
EU	European Union
EX-ACT	Ex Ante Appraisal Carbon-Balance Tool
FAO	Food and Agriculture Organization of the United Nations
FGN	Federal Government of Nigeria
FIT	feed-in tariff
FMARD	Federal Ministry of Agriculture and Rural Development
FME	Federal Ministry of the Environment
FMP	Federal Ministry of Power
FMST	Federal Ministry of Science and Technology
FNC	First National Communication
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas(es)
GIS	geographic information system
GOR	gas-to-oil ratio
GPP	gross primary productivity
Gt	gigaton(s)
GTL	gas to liquid
GW	gigawatt(s)
GWh	gigawatt-hour(s)
GWP	global warming potential
IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
IP	investment plan
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
ISCC	integrated solar combined cycle
JV	joint venture
kt	kiloton(s)
kW	kilowatt(s)
kWh	kilowatt-hour(s)
LCOE	levelized cost of electricity

LNG	liquefied natural gas
LPG	liquefied petroleum gas
LUC	land use change
LULUCF	land use, land use change, and forestry
m	meter(s)
MAC	marginal abatement cost
MDAs	ministries, departments, and agencies
MDGs	Millennium Development Goals
mln bbl	million barrels
MMBtu	million British thermal units
MMscf	million standard cubic feet
MRV	monitoring, reporting, and verification
MSMEs	micro, small, and medium enterprises
Mt	million metric ton(s)
MW	megawatt(s)
MYTO	Multi-Year Tariff Order
NAEC	Nigerian Atomic Energy Agency
NAG	nonassociated gas (gas not produced in association with oil)
NAIP	National Agriculture Investment Plan
NAMA	Nationally Appropriate Mitigation Action
NBS	National Bureau of Statistics (Nigeria)
NERC	National Electric Regulatory Commission
NEWMAP	Nigeria Erosion and Watershed Management Project
NGC	Nigeria Gas Company
NGO	nongovernmental organization
NIPCO	Nigerian Independent Petroleum Company
NNPC	Nigerian National Petroleum Corporation
NPV	net present value
O&M	operation and maintenance
OCGT	open cycle gas turbine
PoAs	programs of activities
PPP	purchasing power parity
PSCs	production sharing contracts
PV	photovoltaic
R&D	research and development
RE	renewable energy
REA	Rural Electrification Agency of Nigeria
REC	Renewable Energy Certificate
RPS	renewable portfolio standards

SAM	social accounting matrix
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCGT	single cycle gas turbine
SLM	sustainable land management
SRI	system of rice intensification
SSA	Sub-Saharan Africa
T&D	transmission and distribution
TCF	trillion cubic feet
t CO_2e	ton of carbon dioxide equivalent
TWh	terawatt-hour(s)
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollars
WAGP	West Africa Gas Pipeline
WRI	World Resources Institute

Overview

Main Message: A Low-Carbon Way to Achieve Vision 20: 2020

The Federal Government of Nigeria (FGN) has formulated an ambitious strategy, known as Vision 20: 2020, which aims to make Nigeria the world's 20th largest economy by 2020. Sustaining such a pace of growth over a longer term implies that by 2035 Nigeria would increase electricity generation by a factor of 9, road freight transport by a factor of 18, and private car ownership by a factor of 3.5. Domestic agricultural production would need to increase six-fold to meet the food requirements of a growing population while decreasing dependency on food imports—an important FGN priority.

Assuming conventional approaches to oil and gas production, electricity generation and use, transportation, and agriculture, the achievement of these goals could imply a doubling of greenhouse gas (GHG) emissions by 2035. Cumulative emissions over this period (2010–35) might add up to 11.6 billion tons of CO_2 to the atmosphere—five times the estimated historical emissions between 1900 and 2005.

This book argues that there are many ways that Nigeria can achieve the Vision 20: 2020 development objectives for 2020 and beyond, but with up to 32 percent lower carbon emissions. A lower carbon path offers not only the global benefits of reducing contributions to climate change, but also net economic benefits to Nigeria, estimated at about 2 percent of GDP. These national benefits include cheaper and more diversified electricity sources, with savings of the order of 7 percent or US$12 billion; more efficient operation of the oil and gas industry, with discounted net benefits of US$7.5 billion, more productive and climate-resilient agriculture; and better transport services, resulting in fuel savings, better air quality, and reduced congestion. These domestic benefits would be accompanied by a global benefit of avoiding some 2.3 billion tons of CO_2e (carbon dioxide equivalent) emissions over 25 years. An additional 1.4 billion tons of emission reductions are technically viable, but would require extra financial incentives to be economically viable for Nigeria.

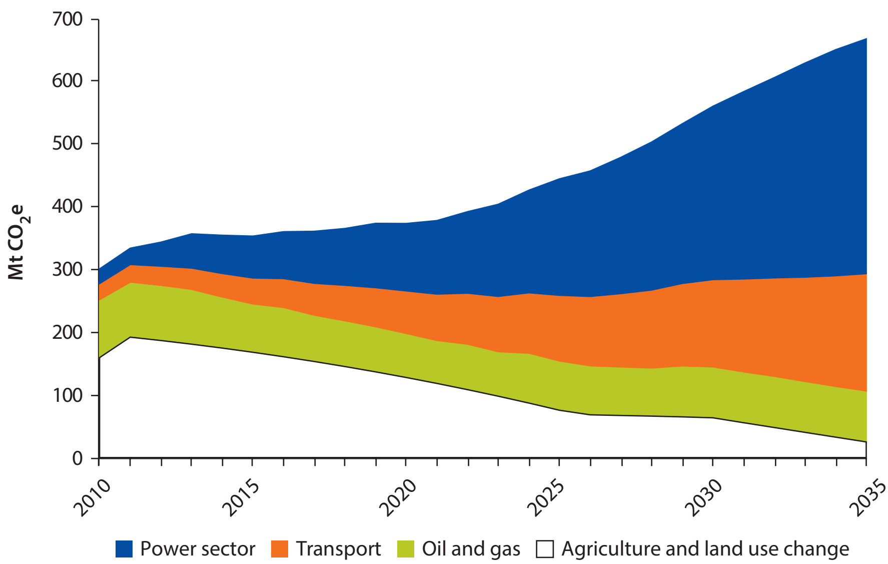
While possible and economically attractive, low-carbon development is by no means easy in Nigeria or anywhere in the world. A combination of better knowledge, expanded human capacity, reformed policies, and suitable financing is needed to overcome the barriers that stand in the way of adopting low-carbon development options. The FGN can play a catalytic role in getting the transition under way, but there is little time to waste: once locked into the country's economic fabric, higher carbon technologies are costly and impractical to reverse.

The Reference Scenario: Double Carbon Emissions

The *reference scenario* of growth for Nigeria assumes that no specific effort is made to adopt low-carbon technologies or management options. It depicts a plausible path of evolution to 2035 of the four sectors analyzed in this book (agriculture and land use, oil and gas, power, and road transport), consistent with overall growth targets defined in Vision 20: 2020 and with relevant sector development strategies. Under this scenario, by 2035, the study projects a doubling of total carbon emissions (figure O.1), with a radical change in contributions by sector: agriculture and land use are expected to shrink from over 50 percent to 4 percent of the total; energy-based emissions are projected to grow from 47 to 96 percent, with little change in emissions from oil and gas, but most of the increase due to the power and transport sectors.

Such a dramatic change in carbon emissions would be a result of the following: the slower pace of conversion of forests to cropland, as much of the forested area has already been cleared in the last couple of decades; rapid expansion of electricity generation (largely from thermal power technologies); and increased demand for passenger and freight transport needed to support planned GDP growth.

Figure O.1 Reference Scenario: Annual CO_2e Emissions to 2035



Source: Calculations based on data sources listed in the chapter 3 references.

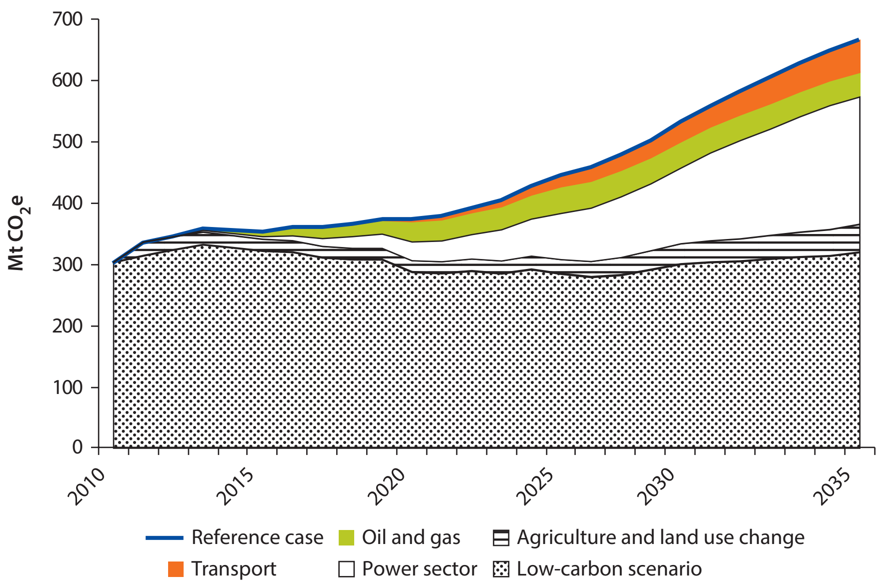
Emissions from oil and gas are expected to remain stable in absolute terms: a decrease from dwindling legacy gas flaring and slightly declining oil production are expected to balance an increase due to expanding extraction of gas for power generation and export.

Stabilizing Carbon Emissions

However, a wide range of technologies, practices, and management options could enable Nigeria to achieve its growth objectives with lower carbon emissions than in the reference scenario. This book identifies a subset of over 30 such options that are likely to be particularly attractive in terms of technical, economic, and institutional feasibility. Gradual adoption over time of all the low-carbon options analyzed would stabilize emissions at around 300 million metric tons of CO_2 equivalent (Mt CO_2e) per year, slightly above the estimated current level (figure O.2). It would avoid incurring a total of 3.8 billion Mt CO_2 over 25 years. About 50 percent of the carbon abatement potential is estimated to lie in the power sector, 20 percent in oil and gas, and the remaining 30 percent split between agriculture and transport. Key low-carbon options include the following:

- Agriculture and land use: agro-forestry, avoided deforestation, and conservation agriculture.
- Oil and gas sector: reduction of gas flaring, better management of oil storage, and enhanced energy efficiency in oil and gas facilities.

Figure O.2 Low-Carbon Scenario: Mitigation Potential and Residual Emissions by Sector



Source: Calculations based on data sources listed in the chapter 3 references.

- Electricity sector: energy efficiency (EE) for lighting, renewables (both off-grid and grid-based) such as photovoltaic (PV), concentrated solar power (CSP), wind, and hydropower, as well as wider use of combined cycle in gas power plants.
- Transport: fuel efficiency, improved freight management, modal shift of freight to rail, and use of alternative fuels such as compressed natural gas (CNG).

Economic Benefits of Low-Carbon Strategy

A low-carbon strategy along the lines proposed in this book would position Nigeria as a regional and international leader on climate action. Yet, the main reason why low-carbon development makes sense for the country is that it could generate significant national economic benefits in addition to the global benefit of avoiding some 3.7 billion tons of CO_2e emissions over 25 years. Expressed as a percentage of cumulative GDP over the study period (2010–35), net domestic benefits are estimated to be on the order of 2 percent of GDP, compared to costs on the order of 0.85 percent (table O.1).

In agriculture, adoption of sustainable land management (SLM) practices such as agroforestry and conservation agriculture is expected to significantly increase yields with net benefits to farmers in the short and medium term exceeding the public costs (such as extension) required to encourage their adoption. These technologies would also enhance farmers' resilience to climate variability and change.

In oil and gas, the low-carbon strategy includes interventions that would enable the industry to reduce the cost of operations or reduce the waste of associated gas (AG), or both, which is a proposition likely to become increasingly attractive, as new commercially viable opportunities for selling the recouped gas open up. The capital cost of implementing those interventions is estimated to be US$17 billion, but with the revenues generated by sale of the gas and associated liquefied petroleum gas (LPG) saved, the low-carbon scenario is estimated to generate a positive net present value (NPV) of over US$7.5 billion.

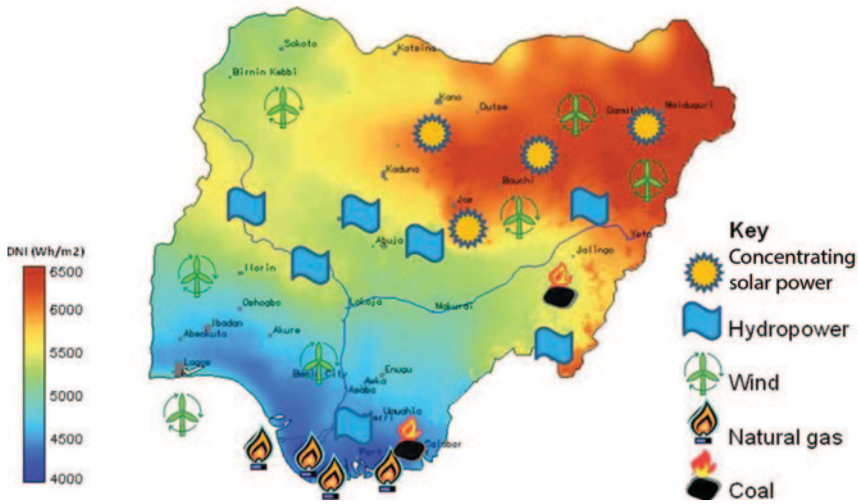
In the power sector, the low-carbon strategy enables Nigeria to achieve growth objectives consistent with Vision 20: 2020, but with a 15 percent reduction in power demand, thanks to more efficient use of electricity in the residential sector, and with lower overall costs of generation. While the capital cost of a greener energy mix is some 37 percent higher than in the reference scenario, lower operation and maintenance and, in particular, lower fuel costs result in the total

Table O.1 Low-Carbon Scenario: National Costs and Benefits by Sector (2010–35)

Sector	*National costs, % of GDP (2010–35)*	*Net national benefits, % of GDP (2010–35)*	*Cumulative GHG abatement, billion tons CO_2e*
Agriculture	0.04	0.23	0.65
Oil and gas	0.11	0.26	0.75
Power	0.70	1.40	1.92
Transport[a]	—	—	0.45
Total	0.85	1.89	3.77

Source: Calculations based on data sources listed in the chapter 3 references.
Note: — = not available.
a. For the transport sector, data and time limitations prevented a full quantification of national costs and benefits.

Map O.1 Diversification of Energy Sources in the Low-Carbon Scenario



Source: PVGIS © European Communities, 2001–2012, HelioClim-1 © MINES ParisTech, Centre Energetique et Procedes, 2001–2008, amended and reproduced by the World Bank study team with permission.
Note: Map colors represent Direct Normal Irradiation (DNI), a measure of solar intensity relevant to concentrated solar power (CSP). The map provides a stylized illustration of the distribution across Nigeria of sources of energy. Oil and gas are concentrated in the South and offshore; hydropower in central and southern Nigeria; coal deposits in the South and East; direct solar radiance for CSP in the Northeast (orange areas); good photovoltaic (PV) potential is found in most areas; and promising wind sites in the North and offshore.

costs for the low-carbon strategy being 7 percent lower than in the reference case. This finding is robust to a plausible range of different assumptions on the future evolution of the costs of renewables relative to fossil fuel generation technologies. In addition, the low-carbon scenario helps reduce the current spatial concentration of energy production sources (map O.1).

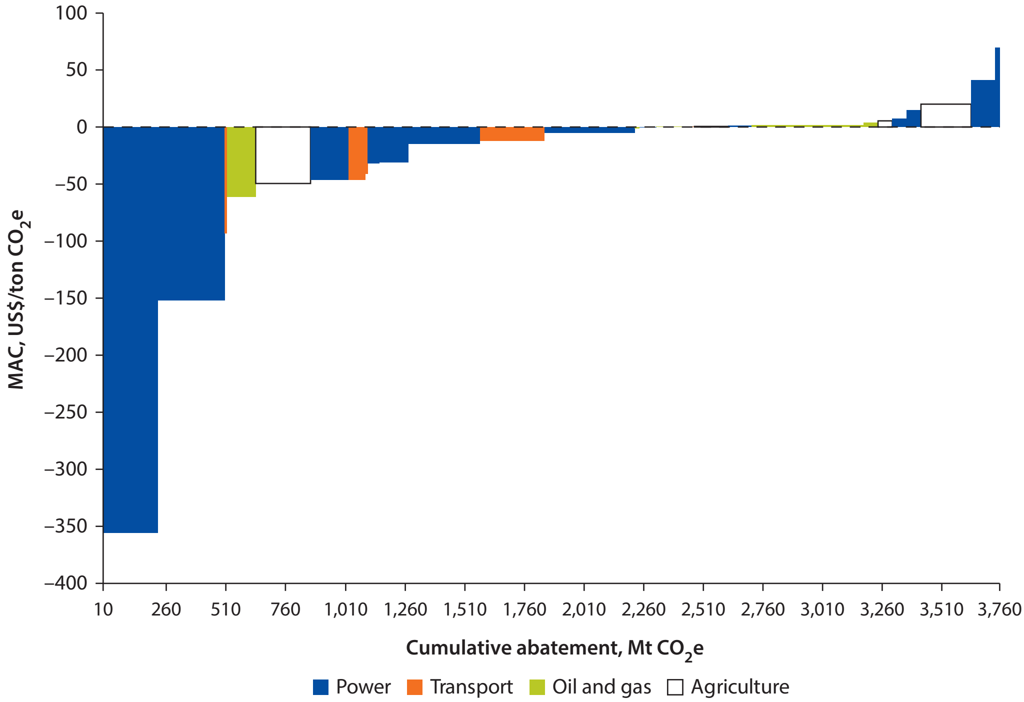
More evenly distributed power generation is an important consideration for the sector's development, in terms of energy security and geo-political balance between the North, the Central belt, and the South of the country.

Although not quantified in this book, the low-carbon strategy is likely to bring about important monetary and non-monetary benefits in the transport sector as well. These include reduced health risks resulting from the reduction in vehicular emissions, particularly in urban areas, lower traffic congestion leading to time savings in travel and improvement in quality of life, and increased productivity and competitiveness in the manufacturing and service sectors.

Setting Sector-Specific Priorities

While low-carbon development is an attractive proposition for the country as a whole, how much of the technical mitigation potential can actually be achieved at a net gain varies considerably by sector (figure O.3). While in the power and transport sectors, some 80 percent of total carbon emission reductions have a negative cost (that is, a benefit), in agriculture and oil and gas the win-win

Figure O.3 Marginal Abatement Cost Curve for Nigeria, 2010–35



Source: Calculations based on data sources listed in the chapter 3 references.

options account for 35 percent and 20 percent, respectively, of their total abatement potential. At the same time, in agriculture, a moderate carbon price of US$7 per ton CO_2e would create sufficient incentives for seizing the sector's full mitigation potential. Therefore, sector-specific low-carbon development strategies are needed to adequately focus efforts on activities with the best combination of carbon abatement and national economic benefits.

A number of challenges and barriers stand in the way of making low-carbon development a reality. These challenges include information needs, technologies, institutions/regulations, and financing. But in many cases, barriers to low carbon are the same as those that prevent conventional development. Regarding data, for example, while measuring and monitoring carbon emissions is limited at best, inadequate information problems also plague the monitoring of many of the sectors' "core business indicators," making it difficult to evaluate complementarities or trade-offs between mitigation and development objectives. In the power sector, for example, data on off-grid generation is very scant. In transport, information on the volume, composition, age, and technology mix of the vehicular fleet is largely inadequate.

Financing is a particularly significant barrier, because many low-carbon technologies tend to feature higher upfront costs and delayed benefits compared to the higher-carbon technology they can displace. This is the case for renewable energy and for several practices of conservation agriculture. Although their net benefits are typically larger in the long term than the reference technology, they are penalized by financial markets biased in favor of short-term returns.

Recommendations

The FGN, in partnership with the states as appropriate, might consider a number of actions that could help remove the barriers to low-carbon development. Table O.2 summarizes the main recommendations made here by sector and time

Table O.2 Indicative Targets and Recommendations by Sector and Time Horizon

		Recommended actions	
Sector	*Indicative targets (2020–22)*	*Short term*	*Medium term*
Cross-sector		1. Assign to the EMT overall policy coordination on low-carbon, climate-resilient development. 2. Finalize the NAMA document and submit it to the EMT for endorsement.	1. Define an action plan for the collection of data on carbon emissions and data to inform the design of low-carbon policies. 2. Formulate Nigeria's position on the reform of carbon markets.
Agriculture	By 2020 bring up to 1 million hectares under triple-win, SLM practices.	3. Include in the Agricultural Transformation Agenda (ATA) support to climate-smart agriculture demonstration projects. 4. Launch a dedicated research and extension program on climate-smart agriculture (CSA).	3. Define procedure and screening tools for integrating climate considerations into project evaluation.
Oil and gas	Reduce the AG flared in joint venture (JV) operations by 80% compared to current levels.	5. Launch a program to facilitate the cluster-based collection of gas from flare sites.	4. Create an inventory of emissions from the sector, and develop a low-carbon strategy for the oil and gas industry, as well as an action plan to address emissions at oil and gas facilities.
Power	Up to 20% of grid-based power generated by renewable energy sources (including hydro-power); 50% of total gas-powered generation coming from combined cycle gas turbines (CCGT); and 20% of all off-grid supply generated by renewables and hybrid systems.	6. Actively develop large-scale renewables (in particular hydropower plants) with the goal of three major projects ready for construction with full feasibility studies within the next 18–24 months. 7. Promote demonstration projects on low-carbon off-grid technologies. 8. Promote investment in CCGT including through tariffs and tax/duties exemption.	5. Launch an EE initiative on lighting, metering, and appliance standards.
Transport	Reach the goal of 40% of urban mass transit in 10–15 large cities supplied by formal bus services using large urban buses and BRT.	9. Define an action plan to improve fuel efficiency and the effectiveness of the vehicle inspection system. 10. Define an action plan to improve the efficiency of freight handling and transport.	6. Undertake a feasibility study for adopting CNG as a transport fuel in selected urban areas.

Note: BRT = bus rapid transit; EMT = Economic Management Team; NAMA = Nationally Appropriate Mitigation Action; triple win = higher yields, higher climate resilience, reduced carbon emissions.

horizon, as well as specific targets (for a time horizon of 8–10 years), that might help provide impetus and direction for action on low carbon in the sectors of analysis.

Cross-Sector Recommendations

Elevate Decision Making on Low-Carbon Strategies to the Economic Management Team level

An entity with a cross-sector policy mandate should be charged with the task of defining climate action policies that will require the concurrence of several line agencies. Pending a final decision on the proposed National Climate Change Commission, the FGN might consider assigning to the Economic Management Team (EMT) the role of overall coordination on policies for low-carbon, climate-resilient development. Such action would make the technical leadership exerted so far by the Federal Ministry of the Environment (FME) more effective; the FME would continue exerting a role of stimulus and liaison with international climate negotiations.

Complete Nigeria's Nationally Appropriate Mitigation Actions

It is also recommended that, using the findings of this book as inputs, the FME (in consultation with other relevant ministries, departments, and agencies, or MDAs) expeditiously finalizes Nigeria's Nationally Appropriate Mitigation Actions (NAMAs), and, prior to transmission to the UNFCCC, submits the NAMA document to the EMT for endorsement, in order to ensure high-level policy relevance and concrete follow-up. It is necessary to articulate Nigeria's overall vision and strategy on low-carbon development, both to define an internal consensus among stakeholders on priority policies and investment for climate action, and to better position the country within international discussions on climate agreements and climate finance. The document defining Nigeria's NAMAs could be a natural vehicle for this strategy. Once endorsed by the EMT, the NAMAs could become a key reference document to orient the design and monitoring of low-carbon policies across sectors.

Improve Data Collection and Analysis

Relevant MDAs in collaboration with the National Bureau of Statistics (NBS) could define action plans (with specific targets and milestones) to improve the quantity and quality of data required to design, monitor, and evaluate low-carbon sector development policies. In many cases, data required for the ordinary development of the power, agriculture, transport, and oil and gas sectors will also be useful for evaluating synergies or trade-offs with low-carbon development. In addition, the action plans should also contain provisions for measuring and monitoring emissions of GHGs, as these data will most likely be instrumental in accessing international climate finance.

Increase Awareness on the Benefits of Low-Carbon Development

Improved awareness of the potential benefits accruing from adoption at scale of low-carbon solutions is essential for ensuring public support for the formulation and enactment of the necessary policies. Relevant line ministries could identify priority topics for public awareness campaigns in their areas of institutional jurisdiction and earmark resources for supporting them. In addition, effective communication campaigns should accompany the introduction and roll-out of specific low-carbon measures (for example, feed-in tariffs), to ensure adequate uptake by potential beneficiaries.

Formulate Nigeria's Position on the Reform of Carbon Markets

The study found that Nigeria has the potential to prevent carbon emission for as much as 3.7 billion tons over 25 years. Even if just a fraction of that potential could be turned into assets tradable in the carbon markets of the future, the revenue-generating potential could be significant. This should be a sufficient argument to induce Nigeria to closely monitor the evolution of international discussions on future carbon markets. In recognition of this, the FME, in partnership with the Ministry of Finance, and in consultation with relevant MDAs, could formulate a carbon market position paper to be presented to the United Nations Framework Convention on Climate Change (UNFCCC) negotiations and other relevant international forums. Such a paper would discuss how the Clean Development Mechanism (CDM), and carbon markets more generally, should be reformed to enable Nigeria to maximize carbon revenues from the mitigation interventions identified in this book. The paper could also identify a few priorities for setting up Programs of Activities (PoAs) that could promote the sale of carbon assets on a programmatic, or sector-wide basis, rather than project by project.

Recommendations for the Agriculture Sector

Promote Research and Extension on Climate-Smart Agriculture (CSA)

The Federal Ministry of Agriculture and Rural Development (FMARD) could launch a dedicated program on CSA, with individual research lines to be awarded competitively to institutions included in the National Agricultural Research System. The program could focus on both development of planning tools (for example, a CSA atlas) to define and prioritize opportunities for adopting "triple-win" agricultural options (higher yields, higher climate resilience, reduced carbon emissions), as well as on the definition of solutions on the ground that farmers can adopt. Strengthening of research should be accompanied by suitable measures to improve the effectiveness of extension services, including through a larger involvement of state governments.

Support Demonstration Projects on CSA Technologies

The government could include in the Agricultural Transformation Agenda (ATA) a dedicated program to support projects aimed at demonstrating and scaling up climate-smart production and land management technologies. The proposed program should focus on a range of areas wide enough to represent Nigeria's different agro-climatic conditions, including regions particularly vulnerable (in the North, but also in the Southwest), and on strategic crops and supply chains.

Define Procedure and Screening Tools for Integrating Climate Considerations into Project Evaluation

The FMARD could introduce, initially on a pilot basis, screening tools to improve the ability of investment projects in agriculture to increase climate resilience and reduce emissions. Eventually such tools could be used to determine preferential access to technical and financial support.

Recommendations for the Oil and Gas Sector

Launch a Program to Facilitate the Cluster-Based Collection of Gas from Flare Sites

Because of the high cost of installing gas gathering and processing facilities at small flare sites, it is recommended that consideration be given to collecting the small volumes of AG in clusters for processing and export of the dry gas and LPGs. Opportunities for financing the initiative through a carbon-finance program of activities should be explored.

Develop a Low-Carbon Strategy and Action Plan for the Industry

The Ministry of Petroleum Resources and Nigerian National Petroleum Corporation (NNPC) could consider setting up a joint government-industry group to develop a low-carbon strategy and action plan for the oil and gas industry, with particular emphasis on actions to seize the potentially large benefits identified in this book in terms of cost savings and incremental revenues.

Set Up a Sector-Wide Inventory of Emission Sources

The Ministry of Petroleum Resources in collaboration with NNPC could establish an inventory of GHG emissions to better inform sector plans for low-carbon development. The inventory would include the status of each GHG source (age, condition, emission reduction actions already undertaken) and would prioritize potential emission reduction options.

Recommendations for the Power Sector

Support Grid and Off-Grid Renewable Energy Technologies

The Federal Ministry of Power (FMP) could actively develop large-scale renewable energy projects. Hydropower could be an immediate priority, with a possible goal of having three major hydro projects ready for construction within 18–24 months, with completed feasibility studies (including resettlement, environmental, and social impact assessments). Feasibility studies for large-scale wind and CSP plants should also be considered.

Promote Demonstration Projects for Grid and Off-Grid Low-Carbon Technologies

The FMP could launch a series of demonstration projects to test in different geographic contexts the viability of both small-scale, off-grid, low-carbon power systems (including PV, small hydro, wind, and hybrid systems–fossil fuel generator set/renewables) and larger scale renewable energy plants, such as wind and CSP.

Both the feasibility studies for large-scale renewable energy projects, as well as the financing for the demonstration off-grid projects, could be supported by seed resources already earmarked for this purpose under the World Bank NEWMAP project (Nigeria Erosion and Watershed Management Project) as well as through mobilization of additional resources.

Design Incentives Systems for Wider Uptake of Low-Carbon Power Generation

The FGN could provide incentives for investments in combined cycle gas turbine (CCGT), including both conversions of existing plants and new builds. This could be done by amendments to the tariffs (Multi-Year Tariff Order, or MYTO) for CCGT generators so as to offset the higher capital costs as well as provide tax and duties exemptions. Some of these incentives could be self-financed through a small levy on incremental liquefied natural gas (LNG) exports made available due to the CCGT efficiency savings.

Promote Demand-Side Energy Efficiency

To achieve the large energy (and emission) savings that can accrue from enhanced efficiency in the residential use of energy, the FMP could consider the following measures:

- National roll-out of a compact fluorescent and LED light bulbs program;
- Acceleration of consumer metering program; and
- Establishment of efficiency standards for common appliances, including refrigerators, air conditioners, and so on, with phase-out of sales of less efficient appliances. Because most appliances in Nigeria are imported, a “top runner” program like that of Japan, in which the most efficient model on the market is used to set future efficiency standards, would also make sense.

Recommendations for the Transport Sector

Define an Action Plan to Improve Fuel Efficiency and the Effectiveness of the Vehicle Inspection System

The FGN could develop an action plan to gradually close the gap between Nigerian and European standards on vehicle efficiency and emissions. In parallel, the application of an effective vehicle inspection and maintenance system in major cities could be considered to improve vehicle maintenance and reduce tailpipe and GHG emissions.

Define an Action Plan to Improve the Efficiency of Freight Handling and Transport

The FGN could define an action plan for improving freight handling and transport. Such a plan could involve an effective expansion of rail services, road infrastructure, vehicle technology, logistical planning, and fleet management. Significant savings (and a reduction in GHG emissions) can be achieved by leapfrogging into solutions that have proven effective in higher income countries.

Evaluate the Feasibility of Adopting CNG as a Transport Fuel in Selected Urban Areas

The FGN in partnership with selected state and local governments could conduct an assessment of the feasibility of using CNG as a transport fuel to combat air quality problems and also reduce GHG emissions. The assessment could be focused on urban areas located in proximity of gas pipelines.

CHAPTER 1

Introduction

The Federal Government of Nigeria (FGN) and the World Bank agreed, as part of the Country Partnership Strategy (CPS) 2010–13, to conduct an analysis of the implications of climate change for Nigeria's development agenda.

Challenges and opportunities related to climate risks and adaptation are addressed in a separate volume, *Toward Climate-Resilient Development in Nigeria*. The current volume focuses on low-carbon development. Building on the work under way on Nigeria's Nationally Appropriate Mitigation Actions, the authors here evaluate opportunities to pursue national development priorities using technologies and interventions that reduce emissions of greenhouse gases (GHGs), referred to here as *low-carbon options*.

Objectives

The objectives of the study were defined through a number of consultations held in 2010–11 between the World Bank team and several of the FGN ministries, departments, and agencies (MDAs) and are as follows:

- Develop a reference scenario of development in selected sectors for the next 25 years, based on a solid understanding of the country's development goals and sector plans.
- Evaluate the implications of the reference scenario on GHG emissions.
- Identify for the different sectors potential low-carbon options to achieve the same development objectives of the reference scenario.
- Evaluate the economic merits of low-carbon options and the additional incentives to be provided, or barriers to be removed, to encourage their adoption.
- Support capacity building for low-carbon planning, particularly in the energy sector.

This analysis offers an analytical platform to assist Nigeria in organizing and prioritizing efforts toward low-carbon development. Such efforts include promoting access to international climate finance, as well as building and expanding on activities included in the investment plan (IP) submitted in 2010 to the Clean

Box 1.1 Nigeria and the Clean Technology Fund

Nigeria has already mobilized efforts to partner with the international community for supporting low-carbon development, including through the Clean Technology Fund (CTF). An investment plan (IP) was approved by the CTF trust fund committee in November 2010, though funds for implementation under this program have only recently become available. The plan, developed by the FGN in consultation with the World Bank and African Development Bank Groups, supports the low-carbon growth objectives and priorities outlined in Nigeria's First National Communication (FNC) to the UNFCCC. This multi-year IP identifies transformational programs to be financed by the CTF jointly with the World Bank Group (including the International Finance Corporation, its private-sector arm) and the African Development Bank.

The CTF IP for Nigeria was developed before the present low-carbon study was conducted, so it was unable to take advantage of the insights the study helped generate. Nevertheless, it does take advantage of certain no-regrets options that were apparent even at the time of IP preparation. The plan contemplates investments of about US$250 million in two sectors: urban transport and energy efficiency/clean energy through financial intermediaries. However, at present, funding is available only for partial implementation.

In Abuja (Federal Capital Territory), the CTF will support development of high-capacity bus services, such as BRT (bus rapid transit), along a heavily populated corridor outside of the Central Business District. In Lagos, CTF resources will also support low-carbon transport initiatives, with specific modalities still being defined. In both cases, however, these projects would help Nigeria transform its urban transport sector toward a low-carbon trajectory, by supporting public transport delivery solutions that will reduce the total number of vehicle kilometers traveled.

The additional insights generated by this book can help Nigeria articulate future plans to further access international climate finance sources.

Source: Climate Investment Funds 2013.

Technology Fund (Climate Investment Funds, https://www.climateinvestmentfunds.org/cifnet) (box 1.1).

Scope and Limitations

On account of time and resource limitations, it was agreed to focus the analysis on four sectors: The two sectors that historically have accounted for the largest share of Nigeria's carbon emissions—upstream oil and gas and agriculture and land use change—and on the two sectors expected to exhibit most rapid growth in future emissions—electricity power and road transport.

The study did not seek to provide a comprehensive low-carbon plan for any of the sectors analyzed. Rather, it focused on what are likely to be the main sources of carbon emissions in each of the sectors in the next two decades and how they could be adjusted to enhance sustainable development while reducing GHG emissions.

Each of the four sectors was evaluated for the period 2010–35 using a bottom-up modeling approach comprising the following analyses:

- The study of agriculture focuses on changes in land use, cropping patterns, and technology in response to population and economic growth; but it does not include agro-industry.
- In the oil and gas sector, the focus is on gas flaring, fugitive emissions, on-site energy generation, and how new fields could structurally change sources of GHG emissions.
- In the power sector, the analysis looks at the predominant use of off-grid and captive generation to meet needs for electricity, and how the mix of grid-based and off-grid supply is likely to evolve to meet a rapidly expanding electricity demand.
- The transport sector analysis looks exclusively at road transport of goods and people and the rapid growth in demand for transport services that can be expected over the 25 years. The study focuses on quantifying a plausible baseline (the reference case), and analyzing qualitatively some interventions that could help reduce GHG emissions while delivering co-benefits such as lowering congestion, improving air quality, and reducing travel time.

Costs and benefits of adopting low-carbon development options are evaluated in a partial equilibrium setting, using net present value (NPV) as the metric of choice. The study team recognized that there may be significant general economic equilibrium effects of moving the economy toward a low-carbon pathway, but it was found that the existing Social Accounting Matrices (SAMs) for Nigeria—the key ingredients for analyzing general equilibrium effects—do not have the required level of disaggregation across sectors and technologies. Building a customized SAM would have exceeded the study's time and resource limits. While this could be a desirable future extension of this research, the present analysis provides for the first time in Nigeria a comprehensive overview of low-carbon opportunities across multiple sectors, and should provide insights of relevance both for domestic policy making and for informing Nigeria's position in international climate negotiations.

Structure

Chapter 2 provides essential background on the country and the economic sectors. Chapter 3 describes the analytical approach, providing a summary of how the scenarios were developed, methods of analysis, models, and the data and general assumptions used. Chapters 4–7 present the analysis and results for each sector: agriculture and land use, oil and gas, power, and transport, respectively. Each chapter provides an introduction to the sector and the approach, findings, and recommendations for options and actions for low-carbon development. Further details on the analysis of each sector can be found in this book's companion volume (Cervigni, Rogers, and Dvorak 2013).

Chapter 8 summarizes the key findings across sectors. It describes the main scenarios that were modeled across all sectors and their implications for GHG emissions and the economy. It provides general recommendations on how Nigeria might reconcile national growth objectives with low-carbon development using a cross-sector perspective.

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CHAPTER 2

Country and Sector Background

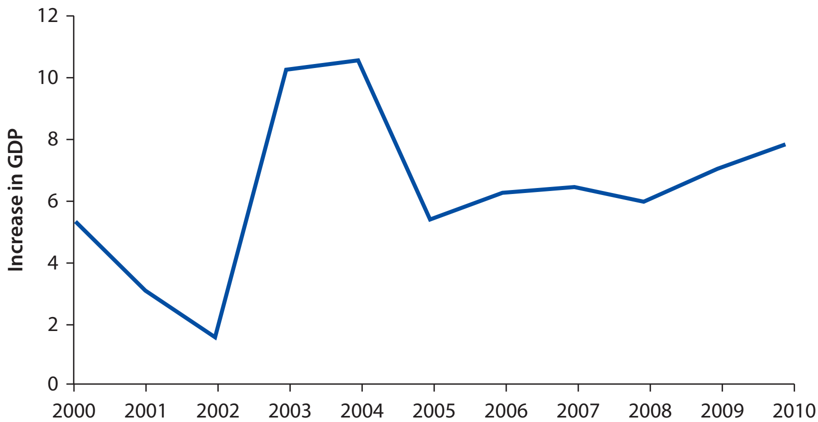
The Federal Government of Nigeria (FGN) has put forward an ambitious vision for the country's economic development by 2020: Nigeria Vision 20: 2020 (FGN 2010). It is a platform for socioeconomic transformation intended to position Nigeria among the 20 largest economies in the world[1] by the year 2020. It includes a growth target of gross domestic product (GDP) of US$900 billion, or $4,000 on a per-capita basis (FGN 2010). Achieving these targets would require a significant acceleration of recent growth rates, which in the last decade averaged 6.4 percent per year, although the rate ramped up to close to 7.9 percent in 2010 (figure 2.1).

To achieve sustainable growth, Vision 20: 2020 projects a significant transformation of the economy, with rapid expansion of non-oil sectors such as manufacturing, wholesale and retail trade, telecommunications, construction, and real estate. It calls for large investment in infrastructure and the strengthening of reforms to shift investment toward supporting private-sector activities and increasing the productivity of human capital.

Vision 20: 2020 also projected that while growing at a stable pace, the oil and gas sector would provide declining contributions to GDP growth, due to diversification and expansion of other sectors, currently underdeveloped. It is anticipated that growth in the oil and gas sector will be facilitated by higher capacity utilization resulting from a reduction of social unrest in the Niger Delta region, investment in new oil fields, and reforms in the sector.

Much of the progress to be achieved under Vision 20: 2020 will require significant investment in physical infrastructure, including power, transport, oil and gas infrastructure, housing, and water resources. Power has been a particularly serious bottleneck to growth due to inadequate generation capacity and poor maintenance of the installed capacity. As a result, the FGN attaches particular emphasis (both in Vision 20: 2020 and in "Roadmap for Power Sector Reform" [FRN 2010]) to aggressive rehabilitation of power installations, coupled with an accelerated expansion of electricity generation, transformation, and distribution networks.

Figure 2.1 Historical Real GDP Growth Rate
percent



Source: World Bank 2010.

It is important to note that Vision 20: 2020 is not only a road map for economic growth, but was also intended to be the foundation of future long-term sustainable development by giving equal value to these additional three pillars:

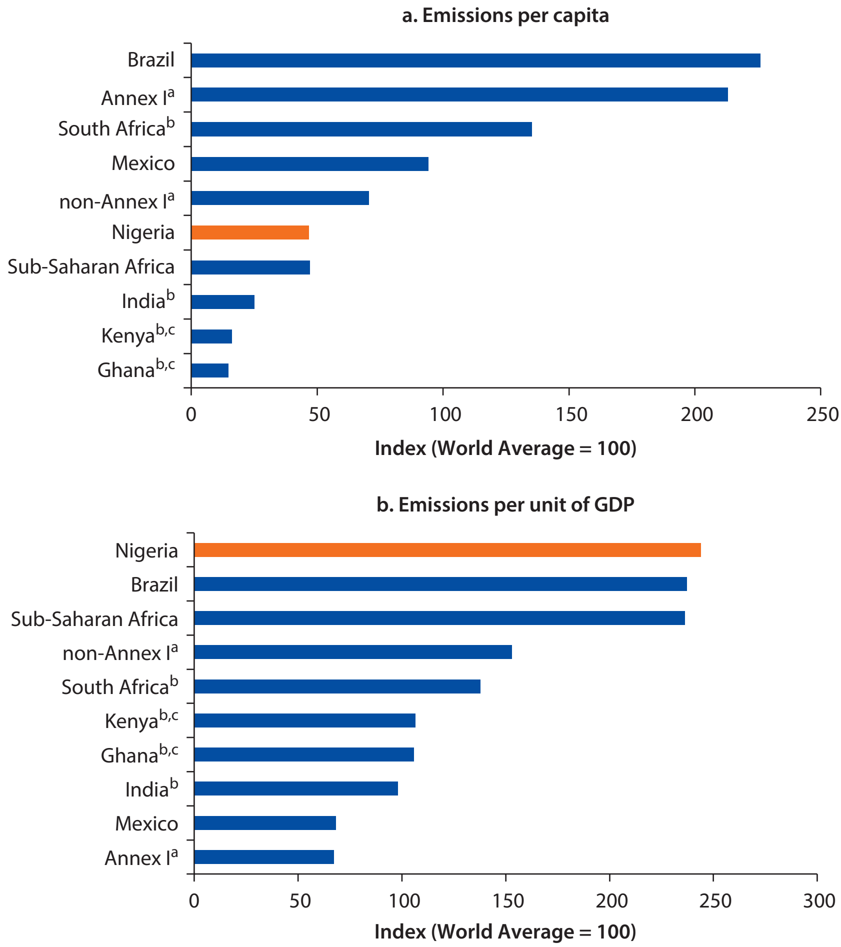
- **Institutional:** to promote responsible leadership, transparency, accountability, rule of law, and security of lives and property;
- **Social:** to improve the nation's prospects for achieving the Millennium Development Goals (MDGs) and creating employment in a sustainable manner; and
- **Environmental:** to halt environmental degradation and promote renewable energy and climate change mitigation and adaptation.

GHG Emissions: Recent Estimates

The latest estimates of greenhouse gas (GHG) emissions available for all countries, gases, and sectors (WRI 2011) indicate that in per capita terms, Nigeria stands at about half the world average, in line with others in Sub-Saharan Africa (SSA) and below middle-income countries such as South Africa, Brazil, and Mexico (figure 2.2). However, in terms of emissions per unit of GDP, Nigeria produces more than twice the world average, above all comparator countries (although not all of them have figures that include emissions from land use change).

Nigeria's relatively high rate of emissions per unit of income points to the importance of evaluating the change of emissions under a scenario of rapid GDP growth like that projected in Vision 20: 2020. If the carbon intensity of the economy remains the same as in 2005, achievement of Vision 20: 2020 targets would entail five- to six-fold growth in emissions by 2030.

Figure 2.2 Emissions in Nigeria and Comparator Countries, 2005

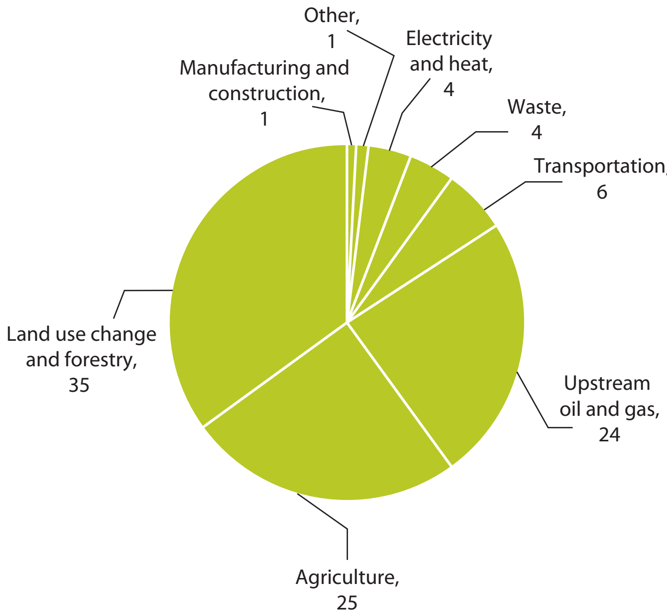


Source: WRI 2011.
Note: Figures refer to emissions in 2005 of CO_2, CH_4, N_2O, PFCs, HFCs, and SF_6, including those from land use change, with exceptions b and c.
a. Annex I parties are the industrialized countries listed in Annex I to the United Nations Framework Convention on Climate Change (UNFCCC); Non-Annex I refers to countries that have ratified or acceded to the UNFCCC that are not included in Annex I of the Convention.
b. These countries' emissions do not include those from land use change.
c. These countries' emissions do not include PFCs, HFCs, and SF_6.

However, inspection of World Resources Institute (WRI) Climate Analysis Indicators Tool (CAIT) data on the sector shares of emissions (which is largely consistent with Nigeria's first national communication to the UNFCCC) indicates that a simple extrapolation of the historical emission trend to the future is not justified (figure 2.3).

In 2005 over half of the country's emissions came from agriculture, forestry, and land use change. According to Vision 20: 2020, the GDP share of agriculture will decline. Barring vast expansion of the agriculture frontier at the expense

Figure 2.3 Sector Composition of Nigeria GHG Emissions, 2005
percent



Source: WRI CAIT database.
Note: Contributions to total 1994 GHG emissions are based on the global warming potential (GWP) projected for the next 100 years.

of remaining forests, it is likely that the contribution of these sectors to total emissions will decrease. Vision 20: 2020 also projects a declining GDP share for the oil and gas sector, which accounted for a quarter of total emissions in 2005. On the other hand, a rapid acceleration of GDP growth will need to be supported by growth in electricity generation and road transport. Thus their contribution to total emissions is likely to grow quite significantly from a relatively modest 10 percent share in 2005.

Agriculture and Land Use Change

As Africa's most populous country, Nigeria faces significant challenges in achieving food security, poverty reduction, and better natural resources management. Agriculture currently accounts for close to 40 percent of national income and almost 70 percent of the working population. While the sector's contribution to GDP can be expected to decline in the coming years, its productivity per unit of land, labor, and water will need to increase considerably to feed a rapidly expanding population. Historically, increased productivity has been generated by converting land such as pastures, forests, bush, wetlands, and woodlands into cropland, which has resulted in some of the highest rates of deforestation and land degradation in Africa. Chapter 4 analyzes the carbon balance of the Vision

20: 2020 policy in the agricultural sector under a reference scenario reflecting current policies, as well as under alternative scenarios intended to represent low-carbon options.

Oil and Gas Sector

Nigeria has the world's seventh largest gas reserves, with 187 trillion cubic feet (TCF) of high-quality proven reserves, of which around half is associated gas (AG). For years, most of the AG was flared, and the initiatives implemented to reduce flaring only recently started to produce results. For Nigeria to achieve the growth targets of Vision 20: 2020, gas must be the engine of growth through increased industrial and domestic use. However, lack of adequate infrastructure limits the easy movement of gas from extraction to consumers, and social unrest in the Niger Delta has discouraged the investment required to upgrade the gas network.

Chapter 5 evaluates potential options and measures to reduce the GHG emissions from the oil and gas sector, while at the same time making this energy source available for more productive usage. The analysis in chapter 6 attempts to address the barriers that have historically discouraged use of natural gas for power generation.

Power Sector

While currently a small contributor to energy-related emissions when compared with the oil and gas sector, electricity supply—both grid-based and captive—is likely to experience rapid growth in the coming years as the economy strengthens and energy demand rises with the improvement in living standards. The government has given high priority to the development of this sector. In the context of Nigeria's Vision 20: 2020, the existing grid-based generation capacity of about 4,052 megawatts (MW) should increase to 20,000 MW by 2015 and 35,000 MW by 2020. About 78 percent of this capacity today is thermal power (fuel oil, gas, and coal) and the remainder is hydropower. Besides increasing power capacity, Vision 20: 2020 seeks to increase access to electricity and improve demand-side energy efficiency (EE). Chapter 6 discusses the evolution of grid-based and off-grid demand, projects the associated evolution of carbon emissions, and identifies options for providing expansion of electricity access with a low-carbon footprint.

Transport Sector

In all countries, freight and passenger transport demand—particularly on-road—increases with growing population and per capita GDP. Up to around US$4,000 per capita, growth in transport demand tends to exceed GDP growth, driven principally by the increasing ability of households to own their own vehicles.

Chapter 7 develops an initial assessment of the expected growth in on-road freight and passenger activity and evaluates the resulting CO_2 emissions under a normal business-development scenario over the study period. It further identifies interventions at the national and local levels that could help decouple growth in transport from growth in emissions. A qualitative assessment of the impact of the proposed measures on other indicators that are of immediate interest to local stakeholders (congestion, travel time, health, economic development, climate resilience, and so on) is also included in the analysis. Because of time and funding limitations, the analysis in this sector did not look in depth at the multiple alternative development options for both urban and inter-city transport possibilities, but it identified priority areas for follow-up work.

Note

1. From the 39th largest economy now, in part due to Nigeria's status as the world's 8th most populous country.

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CHAPTER 3

Research Approach and Methods

The analysis of each of the four sectors of inquiry is based on a comparison between a *reference scenario* and one or more *low-carbon scenarios*. This chapter describes how these scenarios were developed and the value of comparing them. It describes the methods used, including software models for quantitative analysis of each sector, and the use of marginal abatement costs (MACs) to prioritize low-carbon options. It describes how data were obtained and key assumptions, including population, gross domestic product (GDP) growth, and other general assumptions used across sectors. Finally, it outlines the consultative process followed by the team to engage with Federal Government of Nigeria (FGN) agencies and other stakeholders in reviewing the data, assumptions, and methods used to define and evaluate the scenarios.

Comparing Scenarios

The *reference scenario* was designed as a plausible representation of how the country's economy might evolve in the period up to 2035 on the basis of historical trends and current government plans. It describes a reasonable trajectory for growth and structural change of the economy in the absence of targeted interventions to reduce carbon emissions. It assumes that future sector development decisions would be made without any specific focus on their climate change impacts or on their long-term resilience to a changing climate. It uses historical data to define the activity and resulting emissions in the base year. It takes into account existing, concrete, feasible investment plans (for example, power stations that are in the process of being built or are under firm commitment) and attempts to include the "best-business-decision" investments that could be made in future years within the constraints and barriers that are present in the economy.

Thus, the reference case is not a mere continuation of current practice, nor is it always the scenario with the highest greenhouse gas (GHG) emissions. Sometimes the "best-business-decision" investments will lead to higher energy efficiency, greater productivity per unit of energy used, or cleaner energy sources, even within current constraints and barriers. It follows existing policies and plans adopted by the government. For example, the reference scenario for oil and gas assumes significant reduction in gas flares following flare-reduction agreements and programs already in place. The reference scenario for electric power assumes building nuclear power and coal-fired power plants according to current government policy.

The *low-carbon scenarios* include technological, institutional, organizational, or management interventions designed to achieve at least the same development objectives of the reference scenario, but with lower GHG emissions and sometimes also additional benefits in other areas. Adoption of low-carbon solutions often will require policy changes to remove constraints and barriers. This process will necessitate making project financing available to enable changes that would not otherwise be practical.

Different stakeholders may approach the search for a realistic low-carbon development pathway from a different angle, illuminating important aspects of the economics of GHG mitigation and implementation strategies. Choosing which interventions or policy changes to include in the reference scenario and which to leave to the low-carbon scenarios is a delicate task crucial to the soundness of the analysis.

Selecting Low-Carbon Technologies and Interventions

The low-carbon scenario provides a list of low-carbon technologies, also termed mitigation options or interventions, designed to reduce carbon emissions, relative to the reference scenario. Examples are: for agriculture, conservation agriculture, agro-forestry, and sustainable rice intensification; for the oil and gas sector, reducing flaring of natural gas and using more efficient pumps for oil extraction; for the power sector, promoting energy-efficient lighting and generating power from renewables such photovoltaics and wind; and for transport, expanding bus rapid transit and tightening standards of fuel efficiency for road vehicles.

The study team considered a wide range of such mitigation options for each of the four sectors. They then evaluated each candidate option using the following criteria:

- **Potential resource availability,** such as the area of land affected or solar intensity for photovoltaics, in order to provide a rough estimate of the magnitude of the potential emissions reduction. The study selected only those options with the potential to have a substantial overall effect in Nigeria, ignoring some that, though beneficial, have only modest or local effects.
- **Technical-economic analysis** to estimate the technical and economic feasibility, comparing costs and emissions of each low-carbon option to a reference technology that it replaces or supplements.
- **Implementation feasibility** in institutional, market, and policy terms, which took into account feedback of sectoral experts, public and private sector stakeholders, and members of civil society. It entailed identifying potential barriers to implementation and measures and policies to remove those barriers.

As result of this process, the team selected some 30 options for inclusion in the low-carbon scenario, described in more detail for each sector in chapters 4–7 and summarized in chapter 8.

The Purpose of Scenario Modeling

Comparing the reference and low-carbon scenarios clarifies the relative costs, GHG emissions levels, and other economic, environmental, and social impacts of selected low-carbon options. It illuminates the potential tradeoffs when economic and environmental objectives are in conflict, and sometimes helps identify appealing "win-win" options that may reduce both costs and GHG emissions.

Like the reference scenario, the low-carbon scenario is not a prediction of what *will* happen. That would be impossible. Nor is it a recommendation of what *should* happen. Those choices will be made by the people of Nigeria and their government. The scenarios are intended as possible futures, indications of what *could* happen, consistent with the laws of physics, economics, and applicable laws and regulations. They are intended to illuminate and stimulate discussion about which paths are more desirable and what policies should be adopted to reach them.

Scenario modeling is a useful way to forge a consensus among stakeholders on what a plausible sector development pathway might look like, in the absence (reference case), or in the presence (low-carbon case) of dedicated efforts to reduce carbon emissions. By providing a structured and transparent framework to organize information, modeling helps understand where a country or sector—energy, transport, land use, agriculture, forestry, and oil and gas—currently stands, the direction in which it is developing, the impact on GHG emissions, and the resources needed for abatement.

Analysis Methods

A Bottom-Up Approach

This study uses a bottom-up approach to modeling low-carbon pathways: It uses engineering-style models to analyze micro-level activity and the impacts of a variety of specific abatement or policy options. It examines the ownership and use of energy-consuming devices, considering efficiency from an engineering point of view. Its output could be used by a top-down model, typically a computable general equilibrium (CGE) model, to evaluate feedback effects from adjustment in prices and the impact of each package of policy options on employment, taxes, and GDP growth.

A key advantage of the bottom-up approach is that it allows the assessment of efficiency scenarios based on other sector-specific pieces of information or modeling outputs. For example, in the case of road transport, it allows comparison of vehicle ownership, technology, usage, and modal shift to other means of transport as well as the impact of other economic, demographic, and geographic factors.

Modeling Tools

The study used several bottom-up modeling tools. The power and transport sectors used the Energy Forecasting Framework and Emissions Consensus Tool (EFFECT) model developed by the World Bank Energy Sector Management Assistance Program (ESMAP). EFFECT is a user-friendly, Excel-based, bottom-up, engineering-style model that was originally developed for the India low-carbon development program and has since been used in many other countries. EFFECT is freely available on the Internet, with extensive training accessible online. The study team for the power sector developed a model in Analytica[1] to supplement EFFECT to address elements not adequately addressed in EFFECT, including off-grid generation in four categories; energy efficiency options on- and off-grid; the changing future costs of fossil fuel and renewable energy technologies; total costs separating capital, operating and maintenance, and fuel costs; display of MAC curves; and more extensive sensitivity analysis.

EFFECT did not offer the level of detail required to analyze Nigeria's oil and gas upstream emissions, so the study team developed a new model in Analytica to evaluate this. This model is designed to work with the power sector model using EFFECT and Analytica to represent linkages between the future gas supply and its use in generating electricity.

The impact of land use change and agriculture on the country's net GHG emissions resulting from calculations in both the reference case and low-carbon scenarios were estimated using EX-ACT (Ex Ante Appraisal Carbon-Balance Tool) developed by the United Nations Food and Agriculture Organization (FAO). The tool, which is based on the Intergovernmental Panel on Climate Change (IPCC) 2006 methodology, enables comparison of emissions between scenarios involving different land use and management choices.

Marginal Abatement Cost Curves

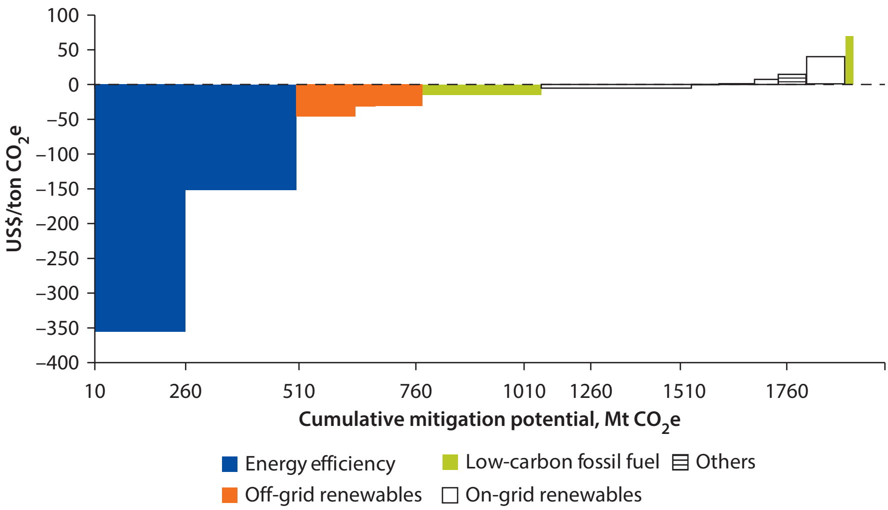
The two models generated MAC estimates to assist in the evaluation of GHG abatement measures (low-carbon options). The MAC evaluates and ranks individual GHG abatement measures according to their incremental cost-effectiveness—that is, the present value of costs to avoid (abate) 1 ton of carbon dioxide equivalent (t CO_2e) of GHGs emitted as an addition to the stock[2] in the atmosphere, relative to a reference technology. Emissions other than carbon dioxide are converted to carbon dioxide equivalent based on their relative contribution to greenhouse warming.[3]

The MAC (equation 3.1) is thus defined over any given period or point in time t as:

$$MAC_t = \frac{C'_t - C_t}{E_t - E'_t} \tag{3.1}$$

Here, $\boldsymbol{E_t}$ = level of emissions in the baseline scenario; E'_t = level of emissions associated with the low-carbon intervention; $\mathbf{C_t}$ = the net present value (NPV) of the cash flow associated with E; C'_t = NPV of the cash flow associated with E'_t.

Figure 3.1 Marginal Abatement Cost Curve for the Power Sector



Source: Calculations based on data sources listed in the references at the end of this chapter.

GHG emissions are not discounted over time because the timing of GHG emissions does not affect the calculations of differences in GHG emissions between two scenarios. Costs, however, are discounted over time to reflect the higher relative cost of near-term expenditures relative to longer term expenditures, using a discount rate throughout this analysis of 10 percent per year.

Combining the MAC data with the mitigation potential of each intervention (the difference in total emissions between the low-carbon and reference scenarios) and ordering these from lowest to highest marginal cost allows the MAC curve to be drawn. Figure 3.1 shows a typical MAC curve that ranks the cost-effectiveness of abatement options (y-axis) against the number of tons abated (x-axis).

Sources of Data and Key Assumptions

This kind of quantitative analysis, comparison of scenarios, and estimation of MAC curves is data-intensive. It required significant effort (6–12 months) to gather and verify historical data inputs. This effort should be viewed as an investment for the future, with data flows being designed to support future monitoring, reporting, and verification (MRV) needs; the tracking of real-time, on-the-ground GHG abatement efforts; and the maintenance of an updated, sector-by-sector, dynamic baseline against which GHG mitigation can be measured. In some cases, desired data or even forecasts were not available. In these cases, the team developed a set of coherent assumptions.

Data Sources

Both reference and low-carbon scenarios were based on data from Nigerian sources—official statistics and administrative records. Much of this data was generously provided by agencies of the FGN. Other data were obtained from the World Bank and other international agencies. Where Nigeria-specific data were inadequate or not available, the study team often used data from comparable countries, such as the relationship between per capita demand for electric power and transportation as a function of income per capita.

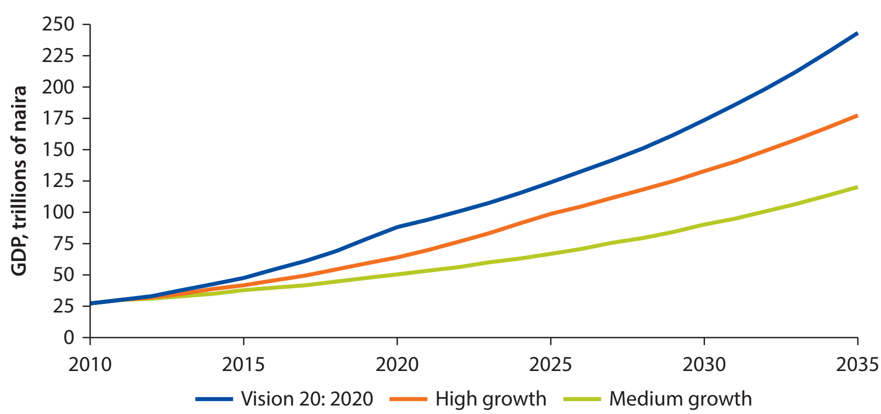
This book draws on a large body of supporting material, including the sector background reports in this book's companion volume, *Assessing Low-Carbon Development in Nigeria: An Analysis of Four Sectors* (Cervigni, Rogers, and Dvorak 2013), and a range of other low-carbon studies and supporting papers. The national and international sources of data used as inputs for all the modeling work undertaken in the rest of this book are listed in the reference section at the end of this chapter.

Economic Growth

Two key projections used as inputs in the study are Nigeria's GDP and its population through the modeling horizon of 2035. These drive the domestic demand for fuel, power, food, and transport. This section outlines these and other general assumptions.

The analysis is based on a conservative assumption that the economic growth targets of Vision 20: 2020 could be met, but with a slippage of five years from their originally proposed dates (figure 3.2). Even so, this results in a fairly aggressive rate of GDP growth of 9 percent per year through 2025, followed by 6 percent growth to 2035 (Vision 20: 2020 assumes a 13 percent annual GDP growth through 2020). Since achieving this economic and social development is the greatest challenge that the country faces, the researchers took care in the analysis to only propose changes (from the reference to the low-carbon scenarios) that would be consistent with meeting these objectives. Figure 3.2 also

Figure 3.2 GDP Evolution under Vision 20: 2020 and the Reference Scenario



Source: FGN 2010 and team calculations.

shows a "medium growth" scenario assuming a consistent 6 percent/year growth rate, used for sensitivity analysis.

Population

Nigeria is the most populous country in Africa, with about 155 million people in 2011, about one-sixth of the entire continent. Population projections of the *UN World Population Prospects* (UN 2010) assume growth rates of 2.53 percent in 2010 that slowly decrease to 2.2 percent by 2035. However, the short-term growth rate projection has been recently increased to 3.2 percent, which results in an estimated population of 293 million by 2035.

Nigeria's population is comparatively young, with 55 percent of the population under 20 in the base year. In the future, high birth rates are projected to help to retain a relatively youthful population over the forecast period; by 2050, 44 percent of the population is expected to be under 20, as shown in figure 3.3.

Figure 3.3 Nigeria Population Pyramids for 2010 and 2050

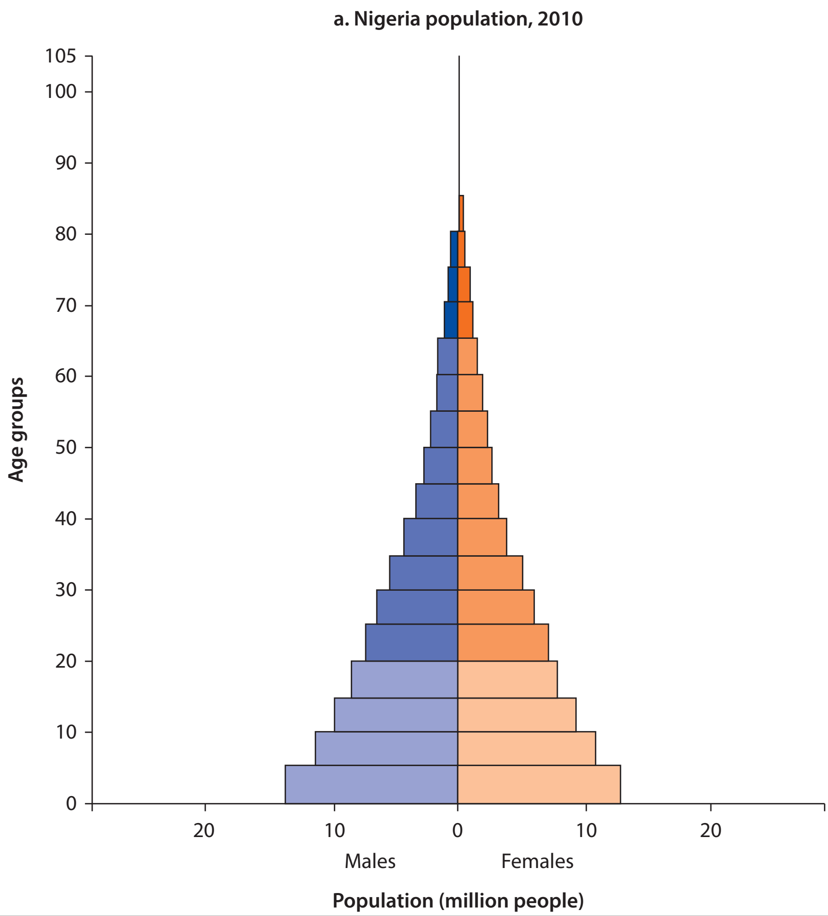
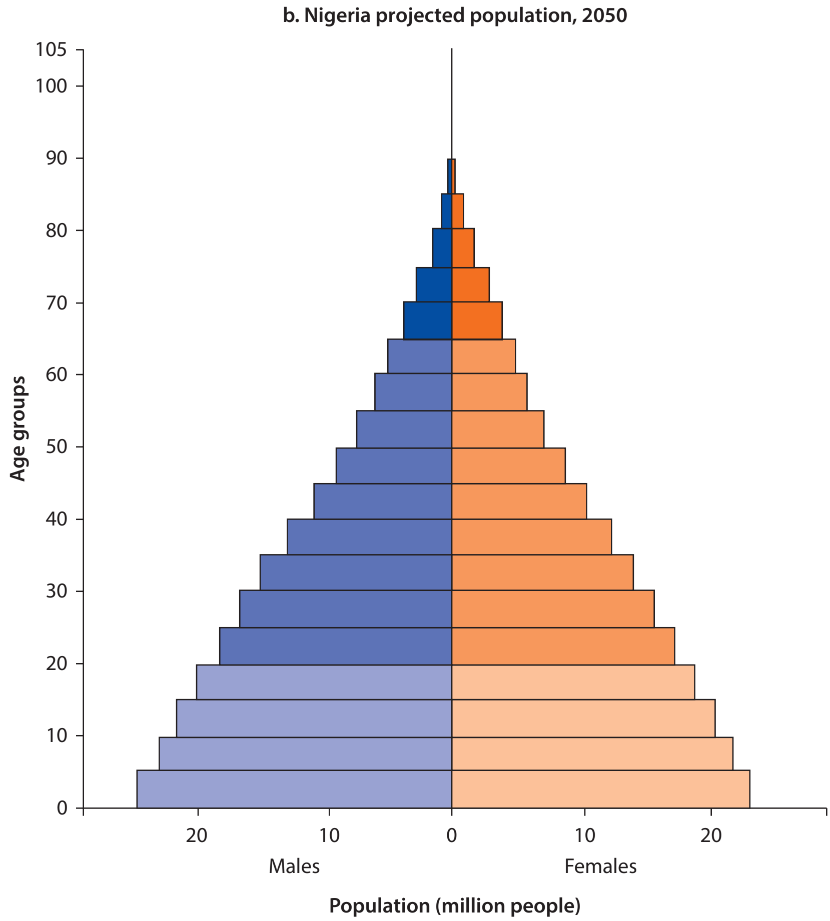


figure continues next page

Figure 3.3 Nigeria Population Pyramids for 2010 and 2050 *(continued)*



Source: UN 2010.

Other General Assumptions

General assumptions used across several or all sectors are as follows (sector-specific assumptions are described in chapters 4–7):

- The analysis was conducted over a 25-year period from 2010 to 2035. It ignores potential emissions and costs or savings of options beyond the study time horizon of 2035.
- Marginal abatement costs assume a 10 percent per year discount on costs and no discount on emissions, as described earlier.
- 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.
- Consistent with the bottom-up effect, the study ignores possible rebound effects—for example, changes that increase energy efficiency leading to lower

unit costs for a service (for example, lighting or travel) that might increase consumption of that service.
- The study ignores major future impacts of climate change on each sector—for example, reduced rainfall reducing availability of hydropower, or more severe storms affecting coastal areas. Some of these impacts are analyzed in a separate World Bank study for Nigeria (Cervigni, Valentini, and Santini 2013).
- Land use analysis assumes 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 the emissions effects flowing from the earlier changes are assessed.
- In projecting demand for electricity and transportation, the study assumes that future per capita demand in Nigeria will grow according to its projected growth in per capita income, corresponding to average trend lines for other countries with similar per capita income. The reference scenario assumes that Nigeria will follow a path similar to those followed by other developing countries, not substantially changed by the introduction of new technologies or practices.
- Where there was insufficient data or resources to estimate Nigeria-specific MACs for selected low-carbon options—for example, for several transport options or for the potential savings from energy efficiency—the study used estimates from other developing countries.

Consultations with the Nigerian Government and Other Stakeholders

The teams responsible for each of the four sectors held a series of consultative workshops in Abuja with staff and officials from key ministries, as well as stakeholders from private industry, universities, and nongovernmental organizations (NGOs). Teams also arranged bilateral meetings with individuals and groups from FGN agencies and other stakeholders in Abuja and Lagos to obtain data; review data, assumptions, and methods; and draft scenarios and results. The goals were to engage stakeholders in the process, obtain feedback, and identify low-carbon options, existing policies and programs, and institutional initiatives of interest to stakeholders to be considered by the study. These workshops and meetings provided the teams with extensive feedback from participants leading to numerous revisions and improvements in the analyses. In the case of the power sector analysis, several working sessions were convened by the Energy Commission of Nigeria (ECN) where the study team and Nigerian experts conducted hands-on interaction on the modeling tools to come up with a shared understanding of the model's inputs and a consensus on plausible results.

Notes

1. Analytica is a general modeling tool using visual influence diagrams, available from Lumina Decision Systems (http://www.lumina.com/).
2. Given the study's relatively short time horizon when compared to the permanence of CO_2 in the atmosphere, the long-term climate change impact of GHG emissions is

dependent on the stock of GHGs placed in the atmosphere by the end of the study period, rather than annual flows, and this is used for the purpose of computing marginal abatement costs (MACs).

3. For example, methane, the main constituent of natural gas, has about 23 times the warming potential of carbon dioxide per molecule.

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CHAPTER 4

Agriculture and Land Use Sector

Agriculture is a key economic sector: it currently contributes close to 40 percent of national income and almost 70 percent of employment (CBN 2002; World Bank 2007) and features prominently in the country's development plans.

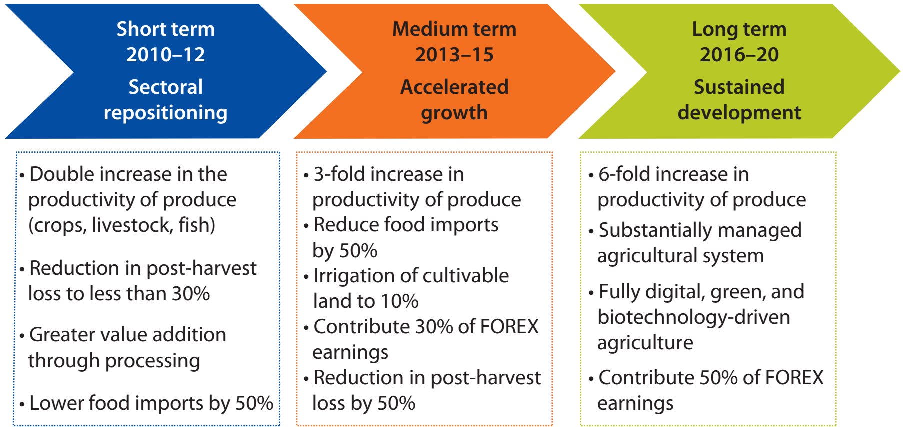
In Vision 20: 2020, the Federal Government of Nigeria (FGN) has laid out ambitious targets to increase the domestic agricultural production six-fold by 2020 through reduction in post-harvest losses, increased yields, and stabilization of cropland expansion. The overall objectives are to achieve food security and to fight poverty. Figure 4.1 illustrates the phased approach to achieving this goal.

The agriculture targets under Vision 20: 2020 are ambitious and arguably subject to many uncertainties. This study does not try to evaluate the feasibility of these targets. Use of the reference scenario does not represent an endorsement by the World Bank of the land use changes (including deforestation), which may be associated with meeting the Vision 20: 2020 targets. Instead, the objective of the analysis is to investigate whether those targets could be achieved with lower net carbon emissions, and at what cost to farmers and to the government. Thus, it uses the reference scenario as a basis of comparison to a low-carbon alternative.

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 to provide policy makers with an order-of-magnitude estimate of mitigation potential as well as an understanding of the value of dedicating further efforts, including through specific projects, at pursuing low-carbon development in agriculture; however, it is not meant to inform the design of specific, project-level interventions.

In consultation with government officials and other Nigerian experts, the team agreed to adopt a more conservative assumption than the Vision 20: 2020 targets—including a six-fold increase in agricultural productivity—which 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 made to achieve sector development targets, and a 10-year capitalization phase, in which benefits of those investments continue to accrue.

Figure 4.1 Implementation of the Nigeria Vision 20: 2020 Road Map



Source: Design based on FGN 2009.
Note: FOREX = Foreign Exchange.

Agricultural Growth Model

A simple growth model was used to estimate the magnitude of annual and perennial crop expansion, consistent with the Vision 20: 2020 targets.[1] 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, Food and Agriculture Organization (FAO), and World Bank staff to define key parameters, including the distributions of secondary forests, pastureland, degraded lands, and other lands, taking into account a spatial analysis of soil quality, slope, and other suitability factors for cultivation. The model accounts for growth via three factors:

- **Cropland expansion**: The annual rate of cropland expansion is assumed to decline from 2.3 to 0.8 percent linearly, resulting in a compound mean annual growth rate of 1.6 percent for 2010–25. Thereafter, the rate of expansion remains at 0.8 percent per year.

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

- **Annual growth due to the reduction of post-harvest loss**: Post-harvest 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 annum in the rate of post-harvest loss. This is equivalent to an annualized compound growth rate of the volume of agricultural production reaching market of 2.5 percent during 2010–25. After 2025, reductions in post-harvest losses are assumed to take place at a slower pace (less than 1 percent per year).

The assumptions and results of the growth model are illustrated, respectively, in table 4.1 and figure 4.2.

Land Use Changes

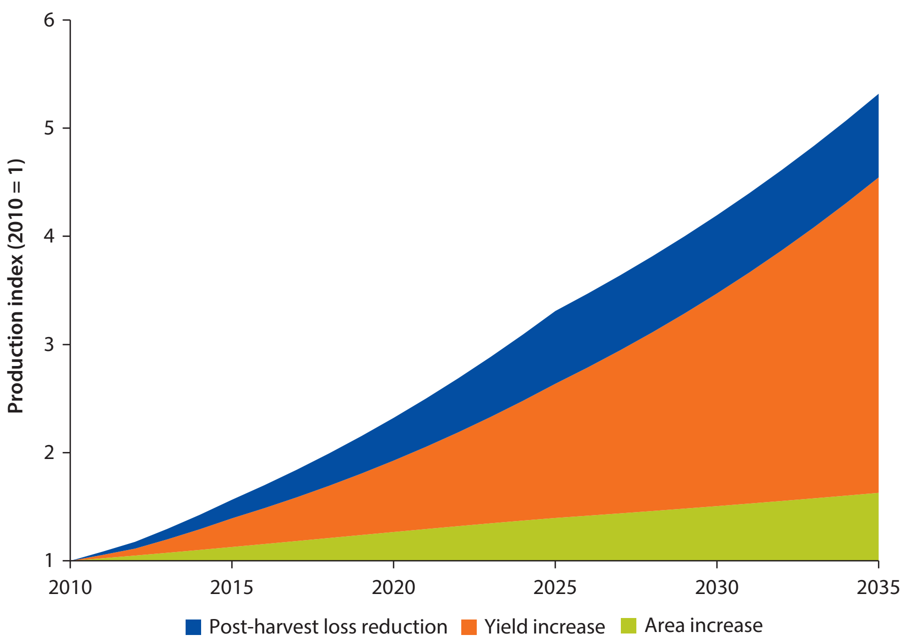
Land use changes are expected to contribute to greenhouse gas (GHG) emissions, albeit at a decreasing rate, particularly through conversion of forests,

Table 4.1 Agricultural Growth Model for the Reference Scenario

Type of growth	*Average 2010–25 (%)*	*Average 2026–35 (%)*
Annual cropland expansion	1.6	0.8
Annual yield growth	4.1	4.0
Annual growth due to post-harvest loss reduction	2.5	0.3
Total supply growth	8.3	4.9

Source: Calculations based on data sources listed in the chapter 3 references.

Figure 4.2 Reference Scenario: Relative Contributions to Total Production Increase



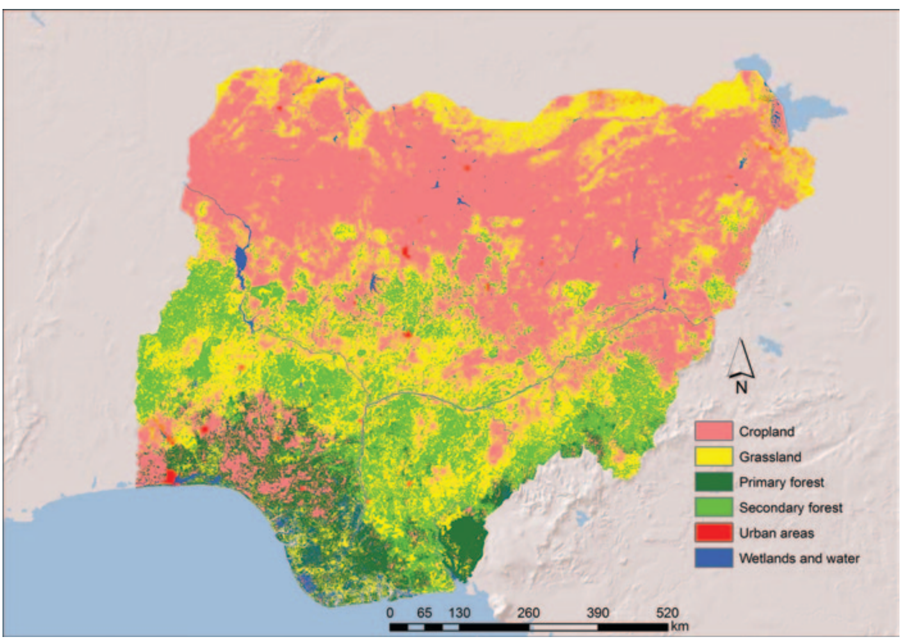
Source: Calculations based on data sources listed in the chapter 3 references.

grasslands (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 predominantly take place from 2010 to 2025. After 2025, land use patterns notionally follow the same trends as in earlier years of the 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 geographic information system (GIS)-based evaluation of the suitability of secondary forests for agricultural conversion was undertaken based on current land use (map 4.1), slope, and soil quality. Secondary forest areas were considered suitable for conversion if categorized as "partly with constraints" or as a higher suitability class. The results of the exercise are shown in map 4.2, which indicates that over 3 million hectares of existing secondary forest could be converted to agriculture.

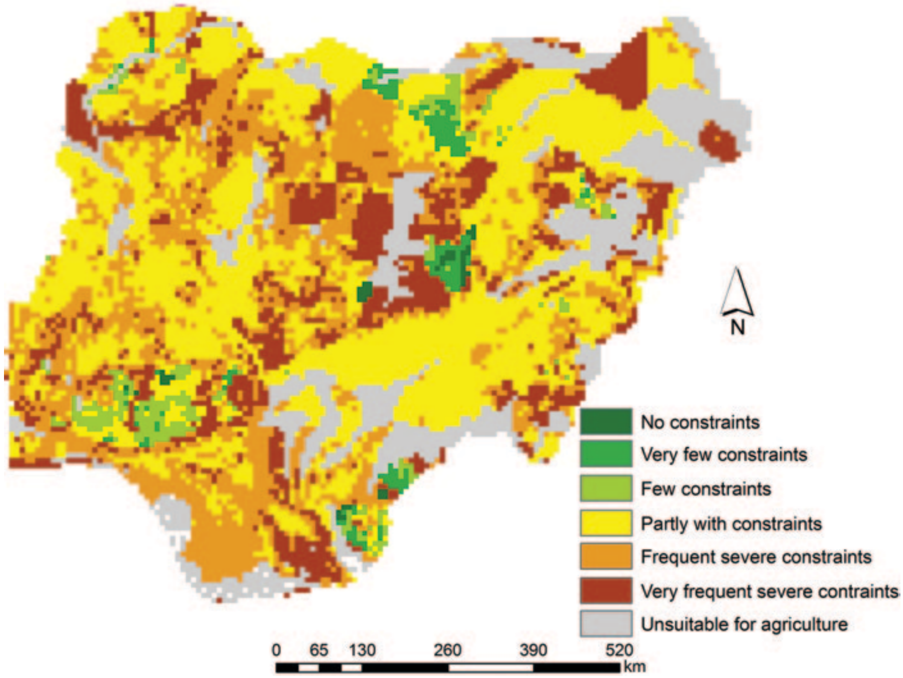
Figure 4.3 illustrates the change in land use over time and table 4.2 indicates the amounts of land used in 2010 and 2035. Overall, as of 2025 forest land shrinks by more than 50 percent, and annuals and perennials increase by a factor of 1.3. Grassland and other land remain quite stable or are slightly reduced. In 2010, crops (annual, perennial, rice) account for 46 percent of the total country area, forests 10 percent, pasturelands 20 percent, and the rest (degraded land, fallow, other) 23 percent. In 2025 crops are projected to account for 61 percent of total land area. Forests will shrink to 5 percent. Pasturelands remain stable at about 19 percent. From 2025, the crops expansion slows down, and in 2035

Map 4.1 Agricultural Land Use Map



Source: FAO GeoNetwork Database; World Bank 2007–2011.

Map 4.2 Land Suitable for Agricultural Use



Source: FAO GeoNetwork Database; World Bank 2007–2011.

crops account for 68 percent of the total country area, forest for 3 percent, pasturelands for 17 percent, and other lands for 12 percent.

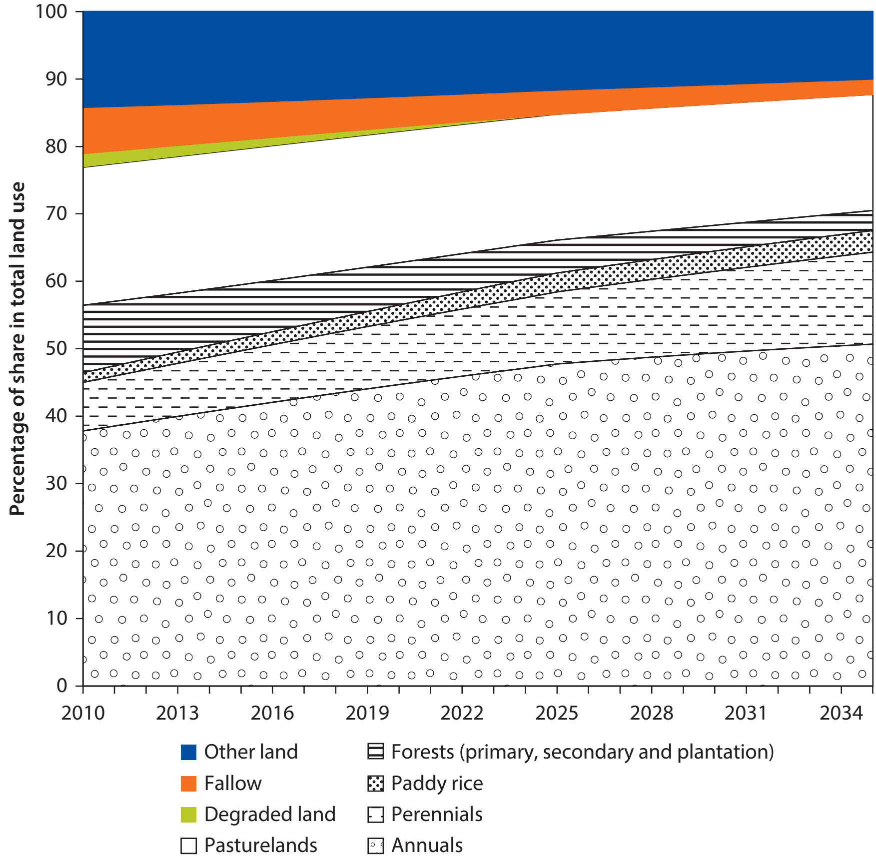
Sector Investments and Technological Change

The reference scenario assumes that the Vision 20: 2020 goal of increasing the share of improved crop cultivars, fish, and livestock breeds (50 percent of the total) will be met by 2025 (via linear growth), and that, where applied, these improved varieties will be accompanied by better management, namely, use of suitable fertilizers and no residue burning for crops, and improved breeding and feeding practices for livestock. Livestock numbers increase steadily at the same rate as for 2000 to 2010.

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 to 50 percent by 2025. Assumptions regarding

Figure 4.3 Land Use Evolution for the Reference Scenario, 2010–35



Source: Calculations based on data sources listed in the chapter 3 references.

Table 4.2 Land Use in 2010 and 2035 for the Reference Scenario

hectares, millions

Land use	*2010*	*2035*
Annuals	34.44	46.16
Perennials	6.55	12.42
Flooded rice	1.31	2.92
Forests	9.10	2.70
Secondary forests	8.80	1.80
Plantations	0.30	0.90
Live fencing/agroforestry	.	.
Pastureland	18.63	15.67
Degraded lands	1.85	.
Fallows	6.23	2.08
Other lands	12.94	9.10
Total	91.05	91.05

Source: Calculations based on data sources listed in the chapter 3 references.
Note: (.) = negligible.

the expansion of processing and storage infrastructure were derived from Vision 20: 2020 plans to strengthen agricultural export markets.

Reference Scenario Emissions

GHG emissions were calculated from 2010 to 2035 for land use changes and other factors 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 included in the calculation.

While emissions decrease over time, agriculture remains a net source of GHG in the reference scenario, and emits about 2.7 billion tons of carbon dioxide equivalent (t CO_2e) during the entire period from 2010 to 2035 (that is, an average of 1.2 t CO_2e/hectare/yr). Annual emissions reach 25 million metric tons (Mt) CO_2e from an initial 161 Mt CO_2e in 2010. Table 4.3 shows total annual emissions at the beginning (2010) and end (2035) of the simulation period, and figure 4.4 illustrates the overall net emissions pathway and the evolution over time of the four main emissions categories:

- **Crops** including annuals, perennials, and paddy rice;
- **Land use changes** that occur as a result of deforestation, afforestation, or non-forest land use change;
- **Livestock and pasturelands;** and
- **Agricultural inputs** that involve GHG emissions associated with fertilizer consumption, infrastructure construction, and fuel consumption.

The main reason for this improvement is a reduction in emissions from land use change, as land use patterns stabilize and in particular deforestation is halted, although 50 percent of secondary forest area is still lost by the end of the modeling period, leaving only 3 percent of secondary forest coverage for the country in 2035. Over this period pasturelands (−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/year by 2035. The results show that by improving land

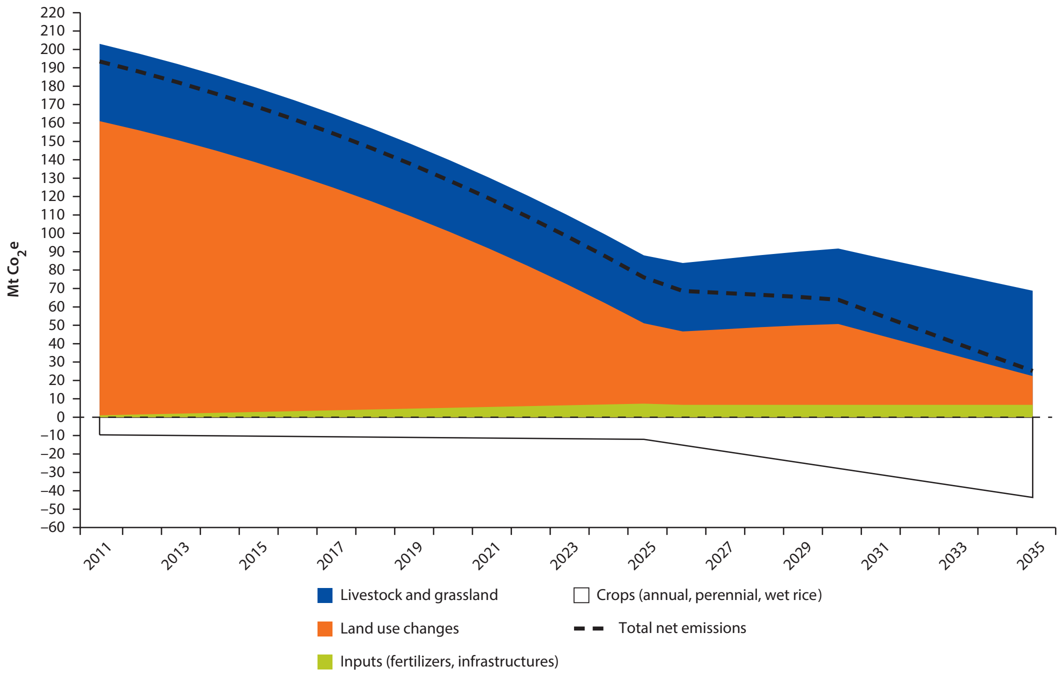
Table 4.3 Reference Scenario: Annual GHG Emissions in 2010 and 2035

Mt CO_2e/year

Activities	*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	+1,068
Total	160.6	25.2	−84

Source: Calculations based on data sources listed in the chapter 3 references.

Figure 4.4 Evolution of the Annual Emissions in the Reference Scenario by Agricultural Activity, 2010–35



Source: Calculations based on data sources listed in the chapter 3 references.

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 land use changes, and one-third come from livestock; therefore, these activities should be the focus for improvements under the low-carbon scenarios.

Low-Carbon Scenarios

Mitigation Options

The low-carbon scenarios include additional investments aimed specifically at reducing the net GHG emissions from the sector. The mitigation options reflect international experience (box 4.1) in proven sustainable land management (SLM) practices. The following mitigations options can be considered for agriculture, livestock, and forestry, and may be interlinked:

- **Conservation agriculture** aims to increase yields and environmental benefits through improved management of soil and water resources. Key agronomic practices include crop rotation/intercropping, minimal turning of the soil (minimum or no tillage), and maintenance of soil cover through cover cropping or mulching or both. However, the availability of mulch material (for example, crop residues, cut vegetation, manure, compost, and by-products of

Box 4.1 Conservation Agriculture in Brazil and Zambia

Conservation agriculture first emerged in the 1930s during the severe dust storms in the United States. It has been gaining momentum worldwide since the 1990s when it was employed to deal with soil erosion crises in southern Brazil. Its use is now widespread globally. By 2007, for example, zero-tillage practices were in use on about 43 percent of arable land in Latin America (World Bank 2012). In Brazil, conservation agriculture relies on a variety of technologies, depending on the region. For example, one popular approach supports a mixed livestock and crop system, rotating pastures with crops.

The zero-tillage system supplies cheap nutrients from residues to pasture, thereby reducing pests, weeds, and diseases. The most common rotation cycles include soybeans, cotton, and maize, followed by 1–3 years of pasture. These practices have increased pasture stocking rates and have reduced soil degradation and water runoff.

In Zambia, five basic conservation farming technologies are being used: retaining crop residues, concentrating tillage and fertilizer application in a permanent grid of planting basins or series of planting rows, completing land preparation in the dry season, weeding aggressively to reduce plant competition, and intercropping or rotating nitrogen-fixing legumes on up to 30 percent of cultivated area. Many farmers also incorporate nitrogen-fixing trees, which provide fodder and fuel-wood.

As of 2010, Zambia had restored 300,000 hectares in an effort that involved more than 160,000 households. Conservation agriculture practices doubled maize yields over those achieved with conventional plowing systems and increased cotton yields by 60 percent. A recent study finds returns of US$104 per hectare for plots under conservation agriculture in Zambia—5.5 times the $19 per hectare of plots under conventional tillage.

Source: FAO 2010.

agro-industries) is typically lower in semi-arid regions, which cover a significant part of Nigeria. Conservation agriculture could also facilitate another major mitigation option—avoidance of deforestation—as increased yield can reduce the need to convert additional forest areas to cropland (for the same overall production targets). This approach offers the opportunity to maintain vegetation cover (including secondary forests, live fences, agro-forestry) over an area equivalent to the one currently forested.

- **Agroforestry** refers to land use systems in which woody perennials are integrated with crops, animals, or both, on the same land management unit, 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.

- **Methane emissions** from rice paddy fields can be reduced by adopting *sustainable rice* practices, which 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 paddy, 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.

- **Livestock emissions** from enteric fermentation and manure can be reduced by adopting *better feeding and breeding practices*, and 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 so on. Sustainable rangeland management should also result in lower stocking densities.

Implementing these options would involve both public and private costs. Public costs are incurred through provision of government support for each option, for example, in the forms of provision of improved seed, fertilizers or feed, extension services, and administrative/management costs. Farmers and private landowners incur costs for labor, and producing/purchasing fertilizer, feed, and fuel, but also benefit from the incomes accrued from increased production.

Introduction of SLM technologies is assumed to be an accelerating process, but it is also subject to a technical constraint (seedlings, farmers' support), whereby no more than 800,000 hectares/year on average can be brought under new SLM technologies.[2] Subject to this constraint, two scenarios were explored:

- Resources available are allocated to alternative SLM technologies so as to maximize the total mitigation potential.
- Resources available are allocated to alternative SLM technologies so as to maximize profitability—that is, net present value (NPV) of private investment—for farmers.

In order to provide a minimally balanced mix of mitigation options, additional constraints were added on the minimum rate of adoption for each SLM technology, in line with their anticipated intrinsic appeal to farmers. Both scenarios affect approximately the same total land area subject to introduction of SLM technologies.

Adjusted Agricultural Growth Model

The agricultural growth model was adjusted to stabilize the land area needed for crops by 2025 while still reaching the same sector production targets, given the higher yields expected from the introduction of the above mentioned technologies (see table 4.4). Reduction of postharvest loss remains the same as in the reference scenario.

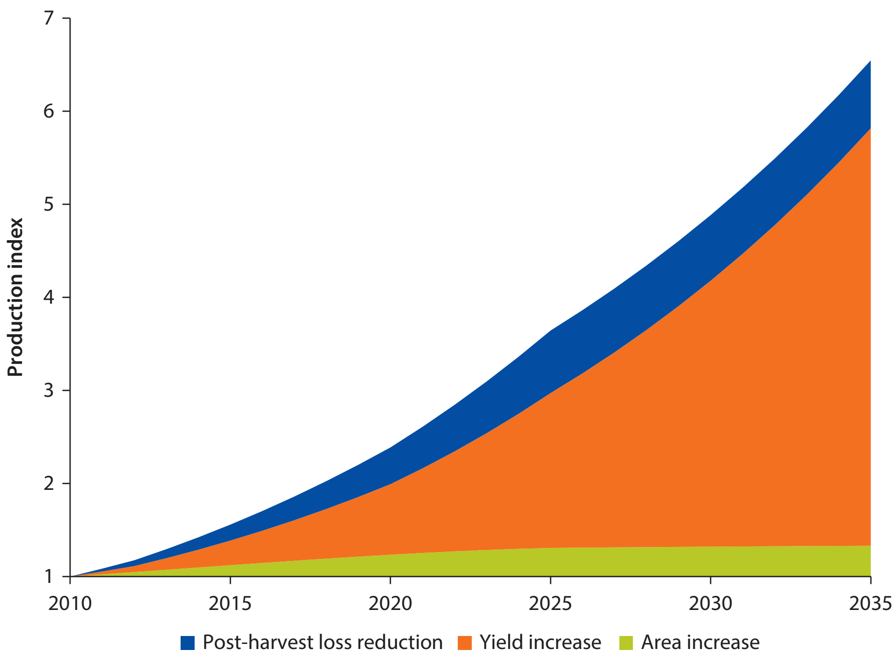
The annual growth yield is assumed to be the same as in the reference scenario for the first five years, then one point higher for the following five years, and 2 points higher the next five years. This gives an annual compound growth

Table 4.4 Agricultural Growth Model of the Low-Carbon Scenario vs. the Reference Scenario
% growth

	2010–25		2026–35	
Source of growth	*Reference*	*Low-carbon*	*Reference*	*Low-carbon*
Area increase	1.6	1.2	0.8	0
Post-harvest loss reduction	2.5	2.5	0	0
Yield increase	4.1	5.1	4.0	6.0
Total production growth	8.3	9.0	4.9	6.0

Source: Calculations based on data sources listed in the chapter 3 references.
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.

Figure 4.5 Low-Carbon Scenario: Relative Contributions to Total Production Increase
2010 output = 1



Source: Calculations based on data sources listed in the chapter 3 references.

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, as illustrated in figure 4.5.

Low-Carbon Scenario Emissions

All SLM technology options have a positive cost to the FGN, which is assumed to provide technical support and subsidies for their implementation. The balance of costs to private farmers and landowners is very different, however, depending

Table 4.5 Land Use in 2010 and 2035 for the Reference and Low-Carbon Scenarios
hectares, millions

		2035		
Land use	*2010*	*Reference*	*Low-carbon scenario A*	*Low-carbon scenario B*
Annuals	34.44	46.16	41.43	41.43
Perennials	6.55	12.42	9.72	9.72
Wet rice	1.31	2.92	2.63	2.63
Forests	9.10	2.70	10.30	5.93
Secondary forests	8.80	1.80	3.79	3.79
Plantations	0.30	0.90	0.90	0.90
Live fencing/agroforestry	.	.	5.61	1.24
Pastureland	18.63	15.67	14.88	17.78
Degraded lands	1.85	.	.	.
Fallows	6.23	2.08	2.29	3.11
Other lands	12.94	9.10	9.80	10.45
Total	91.05	91.05	91.05	91.05

Source: Calculations based on data sources listed in the chapter 3 references.
Note: (.) = negligible.

on the specific option selected. These costs were evaluated under two different scenarios (table 4.5):

- **Scenario A** focuses on those options which maximize emissions reductions potential per hectare of land, namely avoided deforestation and agroforestry.
- **Scenario B** 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 investments 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). It costs the government US$3.2 billion (in NPV terms), and it generates net returns 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$7.2 billion.

Other land use changes, such as expansion of perennial crops and paddies and restoration of degraded land, remain the same as the reference scenario. So 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. Table 4.6 and figure 4.6 illustrate the contribution of each subsector to the total mitigation potential of the two different scenarios. A negative number indicates higher emissions than the reference scenario.

Table 4.6 Mitigation Potential of Each Activity

	Scenario A mitigation		*Scenario B mitigation*	
Activities	*Mt CO_2*	*%*	*Mt CO_2*	*%*
Avoided deforestation	207	18	207	30
Afforestation and agroforestry (live fences)	712	61	158	22
Non forest land use change	−142	n.a.	−13	n.a.
Annual crops	124	11	222	32
Perennial crops	46	4	46	7
Wet rice	7	1	3	0
Grassland	34	3	32	5
Livestock	28	2	28	4
Inputs	−39	n.a.	−39	n.a.
Other investment	2	0	2	0
Total	976		646	

Source: Calculations based on data sources listed in the chapter 3 references.
Note: n.a. = not applicable.

Figure 4.6 Agricultural Mitigation Potential by Subsector for Two Low-Carbon Scenarios

a. Maximum mitigation potential of the Nigerian AFOLU sector (scenario A)

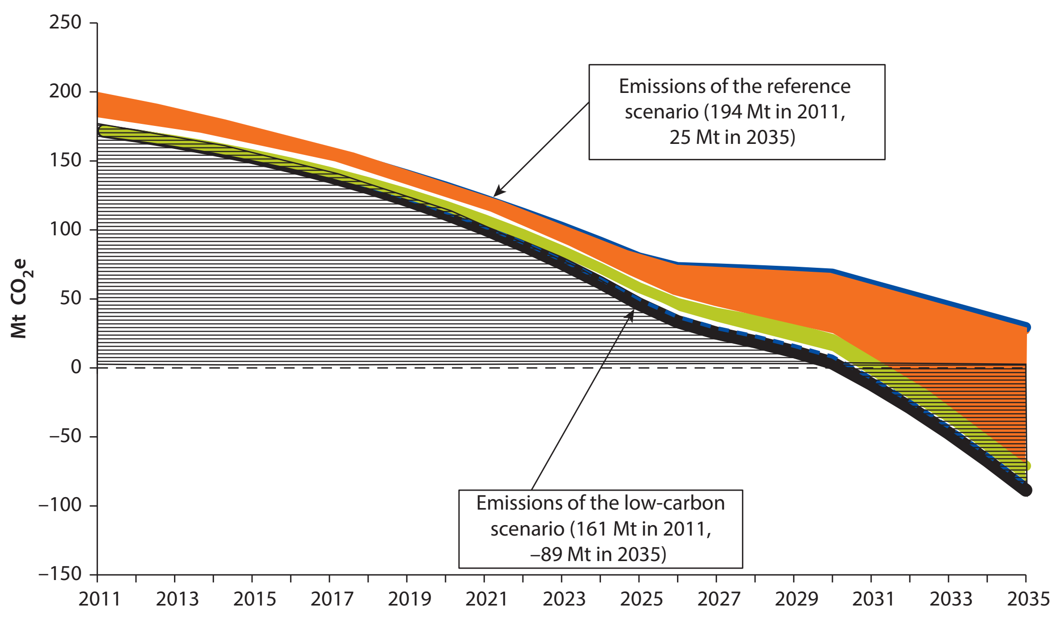


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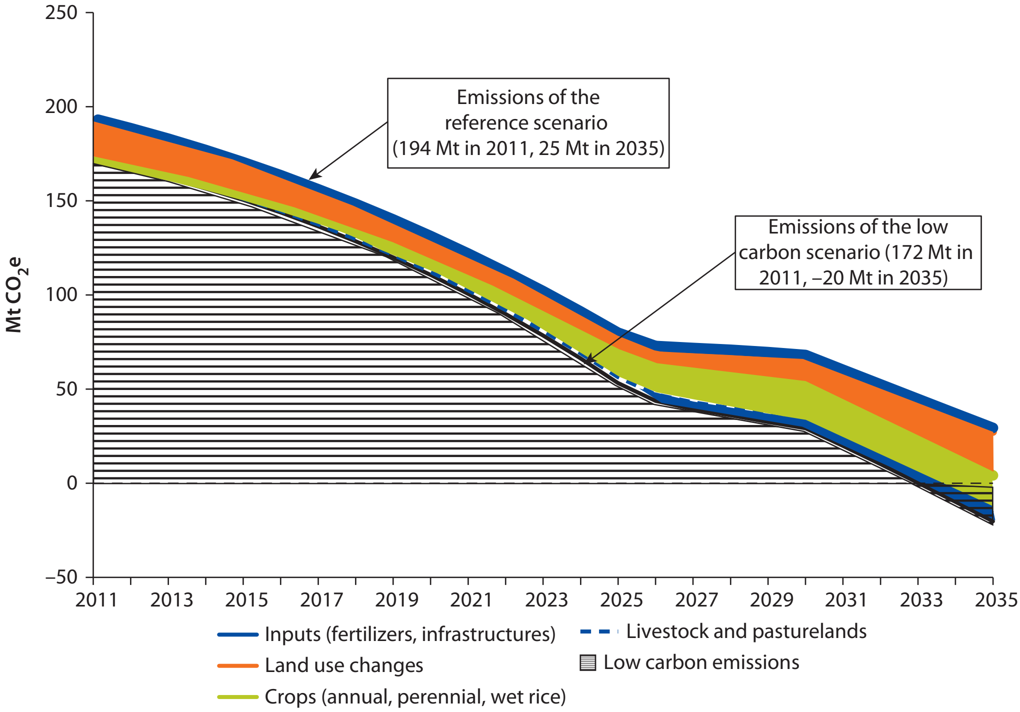
Figure 4.6 Agricultural Mitigation Potential by Subsector for Two Low-Carbon Scenarios *(continued)*

b. Mitigation potential of the Nigerian AFOLU sector (scenario B)



Source: Calculations based on data sources listed in the chapter 3 references.
Note: AFOLU = agriculture, forestry, and other land use.

Table 4.7 Results for the Two Low-Carbon Simulations from 2010 to 2035

Variable	*Scenario A*	*Scenario B*
Cumulative emissions, Mt CO_2e	1,687	2,017
Total mitigation potential, Mt CO_2e	976	646
Average mitigation potential, in t CO_2e/hectares/year	0.4	0.3
Cumulative public expenses (gross/NPV), $millions	10,211/3,207	6,983/2,228
Cumulative private revenues (gross/NPV), $millions	41,024/5,699	44,278/7,277

Source: Calculations based on data sources listed in the chapter 3 references.

Table 4.7 shows that scenario A has 1.5 times the mitigation potential of scenario B (976 vs. 646 Mt CO_2e/year), but at 1.4 times the public cost and 0.8 times the additional income to the farmers on a NPV basis. However, the additional GHG emissions reductions generated under scenario A offer the possibility to use carbon payments to incentivize landowners and farmers to adopt more carbon-beneficial land uses. On average, a carbon price of US$6.1 per t CO_2e per year paid to farmers would be sufficient to increase the private financial benefit of the land use choices under scenario A to the same level as that enjoyed under scenario B, effectively compensating farmers for adopting SLM options with higher mitigation potential.

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 for the foregone income at the macro level. Therefore, if the FGN could control the distribution of carbon incomes, these funds 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, as well as the additional positive environmental externalities from maintaining increased forest cover.

Recommendations for Agriculture and Land Use

Despite the demonstrated benefits of SLM technologies, adoption of low-carbon strategies is still often limited or slow in most countries, even for those options that involve significant private financial returns. Among practical obstacles that hinder rapid adoption are the need to convince and train risk-averse farmers about new ways of farming as well as the frequent need for up-front investment that pays off over a number of years. Financial support, training, and demonstrations are all necessary to encourage farmers to undergo the radical change in working and thinking needed to adopt new SLM techniques.

A further practical issue is that low-carbon technologies 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 added risk that over-exploitation of land might 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 capacity and the political framework to mainstream climate change in agriculture and forestry strategies is a complex and dynamic process, involving numerous stakeholders from central to field levels (see box 4.2).

Figure 4.7 is a schematic representation of the minimum necessary elements for capacity building: (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 conducive policy environment with interactions between experts and actors.

Strengthen Agriculture Research

Agricultural research has been shown to be one of the most effective forms of public investment. In Nigeria, although it is recommended that agricultural research spending not be less than 2 percent of agricultural gross domestic product (GDP), the federal funding of agricultural research in Nigeria has been well

Box 4.2 Partners for a Climate-Smart Agriculture (CSA) Network in Nigeria

Implementation of a low-carbon policy in the agriculture sector will require mobilization of major public institutions; development partners; and federal, state, and local level stakeholders, including banks, the private sector, legislators, NGOs, and other actors.

Key institutions to be mobilized are: (1) Federal Ministry of the Environment (FME) as the designated National Authority for Climate Change and Sustainable Development; (2) Federal Ministry of Agriculture and Rural Development (FMARD) as the main sector coordinator; (3) River Basin Development Authorities (watershed management–reforestation); (4) Nigerian Agricultural Insurance Corporation on risk management–weather based insurance; and (5) Nigeria Agricultural Cooperative and Rural Development Bank (fertilizer, input-investment credits).

Farmer organizations form one of the most important pillars of policy and institutional capability for agricultural development because of their ability to engage in dialogue with the government and to widely mobilize farmers. Participation of farmer associations in policy formulation and monitoring and evaluation (M&E) increases ownership and sustainability of policy measures. The All Farmers Association of Nigeria, an umbrella body for Nigerian farmers, is seen as the national platform for corporate and professional bodies, cooperatives, and commodity associations. Currently, there are 43 major farmers' associations in Nigeria, which are organized along commodity lines (FGN 2011). The association could act as a field support platform to promote CSA practices and gather smallholders to channel carbon funding and payment of environment services.

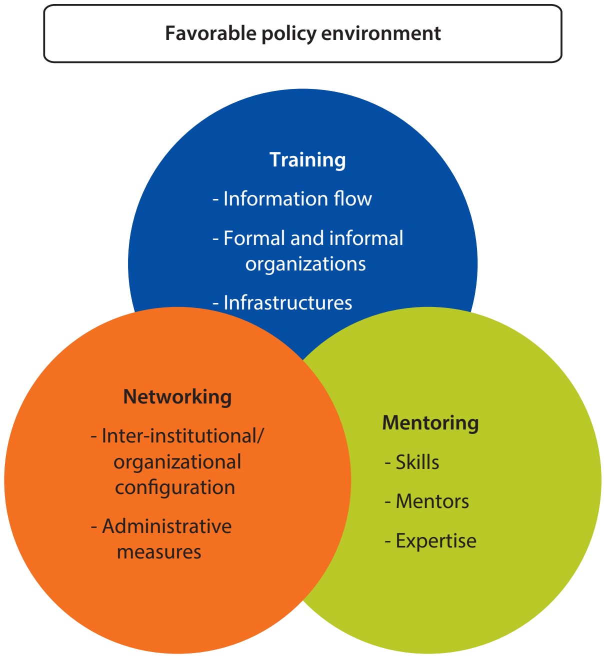
below the average for Africa (0.85 percent of GDP). Private-sector agricultural research is negligible, as it is in most of Sub-Saharan Africa (SSA). The Department of Agricultural Sciences (DAS) of the Federal Ministry of Agriculture and Rural Development (FMARD) is responsible for all aspects of agricultural research in Nigeria. DAS oversees the funding and management of 15 national agricultural research institutes located throughout the country. Those 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 for meeting the overall growth targets under Vision 20: 2020.

Policy Recommendation

FMARD could launch a dedicated program on climate-smart agriculture (CSA), with individual research lines to be awarded competitively to institutions

Figure 4.7 Capacity Building Model



Source: Design based on Sanni et al. 2010.

included in the National Agricultural Research System. The program could focus on both development of planning tools (for example, a CSA atlas) to define and prioritize opportunities for adopting "triple-win" agricultural options (higher yields, higher climate resilience, reduced carbon emissions) and the definition of solutions farmers can adopt on the ground. Strengthening of research should be accompanied by suitable measures to improve the effectiveness of extension services, including through greater involvement of state governments.

Improve Mechanisms for Knowledge Sharing and Technology Transfer

Diffusion of scientific and technical knowledge to farmers is a prerequisite to the adoption of SLM and climate-smart agricultural 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. Not "projects" in the conventional sense, ADPs are state-level parastatals working in the agricultural sector. The first generation ADPs were created during the mid-1970s and were supported largely by 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, improved seed varieties, fertilizer, machinery services), and helping the lead farmers teach other farmers.

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

Policy Recommendation

FMARD should promote "support platforms" for small farmers. A key issue in exploiting carbon finance in the agriculture sector is that, although the GHG emissions potential is significant, the contribution of each individual farm is often small. Thus it is important to find an efficient approach to aggregate the contributions of individual farmers to avoid excessive transaction costs. Farmers' federations with support from ADPs could be strengthened to become field platforms and potentially to channel carbon funds and payment for environment services. Their value chain–based structure and their capacity to gather small farmers give them an advantage as a farmers' aggregator.[3] Therefore to support these organizations it is important to:

- Build the capacity of these organizations to play an effective and sustainable role to promote improved practices and to control and monitor programs.
- Provide technical assistance to farmers' 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.
- Develop effective and scalable tools to support partnerships between government, private-sector operators, and leading local farmers' organizations and trade associations to broaden access by smallholder farmers to commercial and technical services.

Policy Recommendation

The FGN should strengthen 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 FGN while the state and local governments, which provide extension services, have no research institutes. This means that decisions on the funding, direction, and implementation of research activities are taken from Abuja, resulting in a discrepancy between local needs and current research and development (R&D) programs. An effort should be made by FGN to decentralize activities and strengthen the linkage to extension services and farmer organizations.

Integrate CSA into Mainstream Government Programs

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 has generally been lacking in Nigeria: inconsistent agricultural policies have often resulted in limited response by farmers due to the uncertainty

Box 4.3 Nigeria's Agricultural Transformation Agenda (ATA)

The 2012 Agricultural Transformation Agenda (ATA) is a comprehensive plan that aims to restore Nigeria's old glory as an agriculture powerhouse. To this effect, the ATA seeks 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. It targets a number of commodities, including rice, cassava, cacao, oil palm, cotton, sorghum, maize, soybean, tomato, onion, livestock, and aquaculture, differentiated across space.

The ATA is an important point of departure for transforming Nigeria's agriculture sector by providing: (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, and 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, which 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.

Source: Based on Nigeria Federal Ministry of Agriculture.

on how long any given policy might actually last. Also, erratic import policies characterized by frequent changes in both import tariffs and quantitative import restrictions have created additional uncertainty for producers. However, Nigeria has recently developed its Agricultural Transformation Agenda (box 4.3), which has the potential to act as a key long-term vehicle to champion sustainable and climate-smart sector policies.

Policy Recommendations

The FGN could strengthen the integration of CSA into the ATA by supporting the following:

- A dedicated program to promote climate-smart, SLM practices—that is, those that at the same time can raise yields, increase climate resilience, and reduce net carbon emissions—in up to 1 million hectares by 2020. The SLM Committee provides an institutional platform to promote the development and diffusion of climate-smart agriculture practices. This work could build on the experience accumulated under the Fadama project (Echeme Ibeawuchi and Nwachukwu 2010).

- The FMARD could introduce screening tools for the ATA to improve the ability of investment projects in agriculture to increase climate resilience and reduce emissions. Tools such as the FAO Guidance to Best Practices and guidance on carbon balance appraisal of projects and policies could help the country develop its climate change response from the strategy level down to the stage of project design and appraisal.

Notes

1. It is assumed that the six-fold increase in the value of agricultural output envisioned under Vision 20: 2020 is only partly met through increase in physical output, with the rest accounted for in terms of increases in price or value of output due to improved quality or competitiveness. Hence the growth in physical output to 2025 used as the basis of the growth model is less than a six-fold increase.
2. At an average farm size of two 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. The large number of small farmers in rural areas makes it hard to provide adequate incentives and extension support with manageable transaction costs. A key challenge is finding an entry point to reach them. Options include farmers' unions, cooperatives, value chains, and existing programs that cover a district with adequate services. The role of aggregator is to deliver the whole range of services and support to a wide number of small farmers, including the eventual delivery of payment for environmental services.

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CHAPTER 5

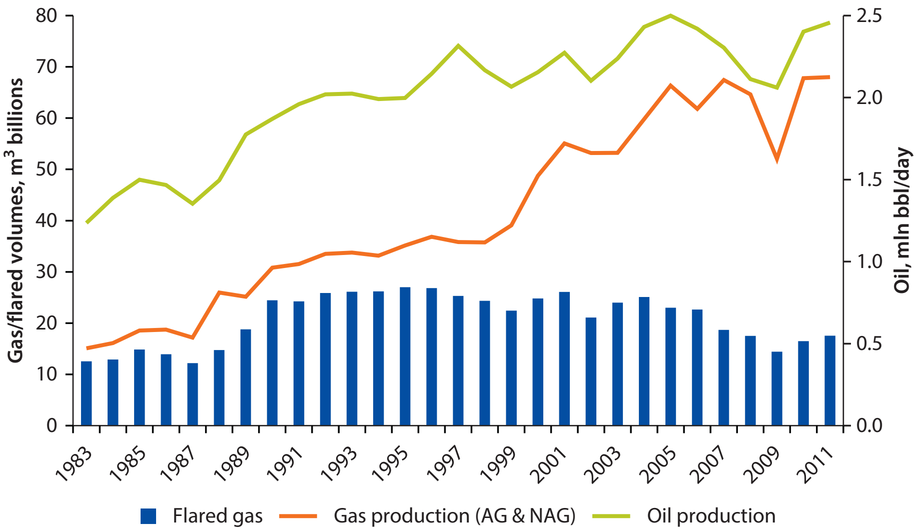
The Oil and Gas Sector

Nigeria's proven oil and gas reserves of 37.2 billion barrels and 186.9 trillion cubic feet (TCF), respectively, as of January 1, 2011, rank the country among the top 10 globally in wealth of these resources. Revenues from oil exports during 2010 reached US$70 billion, which, together with LNG (liquefied natural gas) exports, represents more than 90 percent of Nigeria's foreign exchange receipts. However, the rapid growth in sectors of the economy outside of oil and gas is causing the sector's share of gross domestic product (GDP) to decline.

In 1977 the Federal Government of Nigeria (FGN) created the Nigerian National Petroleum Corporation (NNPC) which has managed this sector through joint venture (JV) arrangements with the petroleum industry. This investment structure gave the state a significant direct interest in this industry but also required it to fund a significant share of all investments. This has become increasingly onerous in recent years, resulting in a shortfall in the funding of the NNPC's share of investments. More recent deep-water licenses—with increasingly expensive exploration and development costs—have been awarded in the form of production sharing contracts (PSCs) to relieve the government of any funding requirement. Over the last few years the government has proposed a complete restructuring of the industry, and until the new terms and conditions are clear, private industry is reluctant to commit to new investments. However, progress has been made in reducing gas flaring, even as oil and gas production have increased (see figure 5.1).

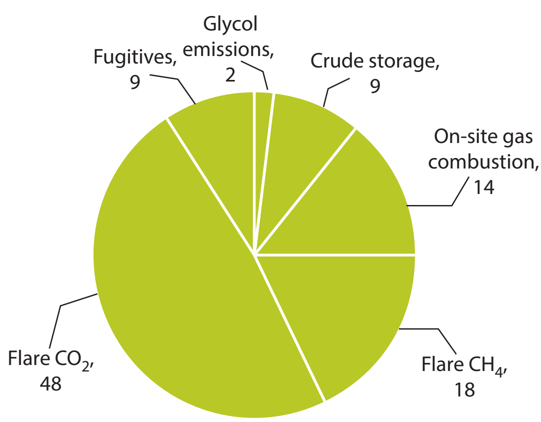
The oil and gas sector has historically been one of the main sources of greenhouse gas (GHG) emissions in Nigeria. Estimated annual emissions in 2010 were approximately 90 million metric tons carbon dioxide equivalent (Mt CO_2e) per year, of which the dominant source is gas flaring. The other major sources are on-site use of gas (mainly for power generation) for operating oil and gas production, transportation, and processing facilities; fugitive emissions of gas through leaks and other losses; and venting of gas from oil storage tanks (see figure 5.2).

Figure 5.1 Historical Oil and Gas Production and Flared Gas Volumes



Source: NNPC 2011.
Note: AG = associated gas; NAG = non-associated gas.

Figure 5.2 Oil and Gas GHG Emissions by Source, 2010
percent

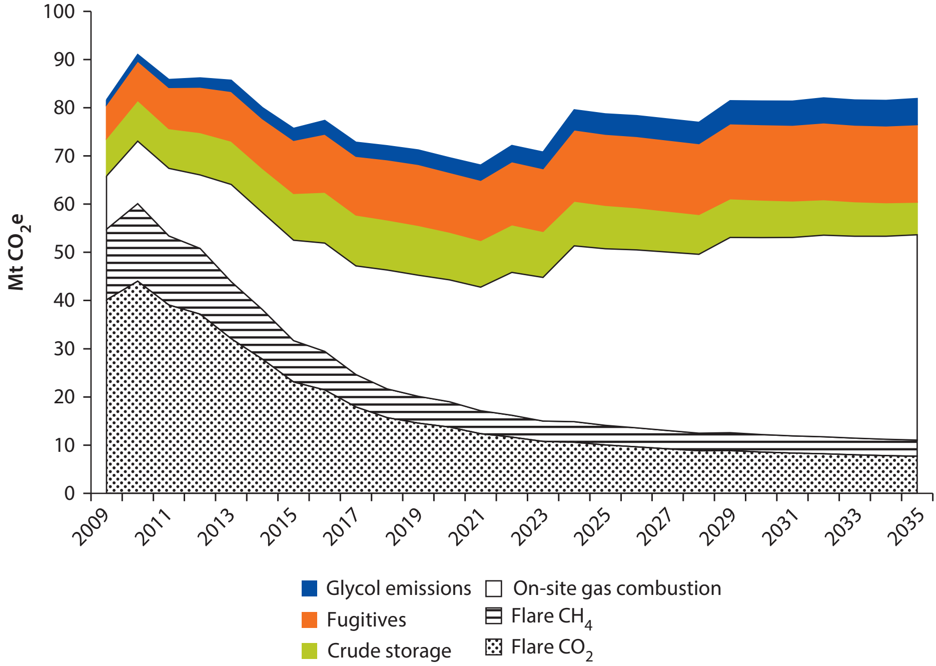


Source: Calculations based on NNPC oil and gas production data listed in the chapter 3 references.

Study Results

The study team developed the reference case scenario based on extensive interactions and feedback from the NNPC and oil industry representatives. It assumes a continuing decline of emissions from gas flaring based on existing flare-reduction programs agreed with the FGN and oil companies, as seen in figure 5.3. However,

Figure 5.3 Reference Scenario Oil and Gas GHG Emissions by Source



Source: Calculations based on data sources listed in the chapter 3 references.

the assumptions for the two oil and gas production regimes—JV and PSC—are different. In JV fields, flaring is projected to decrease over the study period from the current 37 percent of associated gas (AG) production to 5 percent by 2035. This reflects the high level of legacy flaring in these older fields. PSC fields, relatively recently developed, are assumed to have had gas gathering infrastructure incorporated in their design, and therefore to be flaring only 5 percent of the AG currently.

However, emissions from all other sources are forecast to increase. Major drivers are the expected growth in on-site use of gas to fuel power generation and other processes, particularly in LNG and gas-to-liquid (GTL) plants, as well as increases in gas production to meet domestic and export demand.

While flaring sources are clearly identified mitigation targets, no specific data are available on the fields and facilities in the Nigerian oil and gas industry. It is possible, therefore, that some emission mitigation options discussed in the study analysis may have already been completely or partially implemented. If this is the case, the emission estimates in the reference case scenario, and the potential for their reduction, may be overstated.

Based on the production projections and the assumptions described in the following sections, emissions for the next 25 years from the oil and gas sector can be expected to remain at approximately 70–80 million tons per year.

The Demand for Gas

In order to evaluate the future gas supply requirements, the study team developed a gas demand projection for the major gas users using the following assumptions:

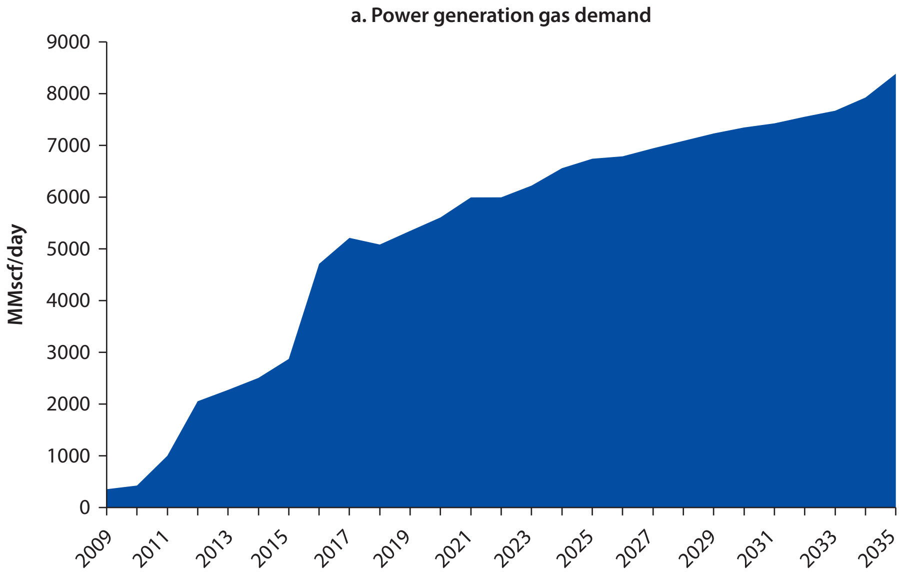
- **On-Site Use:** In the absence of other data, on-site use of gas for power generation, re-injection, and so on has been assumed to mirror current own-use throughout the study period, adjusted to take account of the changes in production levels over time.
- **Power Generation:** Nigeria's gas-fired power generating capacity is projected to increase rapidly; the rate of increase has been taken from the Power Sector reference case developed for this study.
- **Industrial Use:** The required volume of gas has been assumed to increase at approximately 10 percent a year.
- **LNG:** LNG exports are expected to grow both through additional trains at Nigeria LNG Ltd. and as the Brass and OK plants come on-stream. The timing of the LNG export increases is taken from the Wood Mackenzie 2011 global LNG report. Gas requirements assume 9 percent of the into-plant gas is required for on-site power generation and other uses.
- **GTL plants:** The Escravos GTL plant is assumed to come on-stream in 2013 with a capacity of 34 thousand barrels per day. A second plant (or expansion) of the same size is assumed to come on-stream in 2022. Gas requirements assume 35 percent of the into-plant gas is the volume assumed to be used for on-site power generation and other uses.
- **West Africa Gas Pipeline (WAGP):** The WAGP started exporting gas in 2010. Volumes by 2020 are assumed to gradually reach 474 million cubic standard feet per day, the current capacity of the line.

Figure 5.4 illustrates the evolution of the various demand components based on the above assumptions.

Oil and Condensates

The NNPC has forecast that oil and condensate production will reach a plateau of just over 3 million barrels per day in 2020 and will then decline at 9% per annum to under 0.9 million barrels per day by 2035. This scenario (shown as dashed lines in figure 5.5 panel a) is based on an assumption of constrained investment post-2020. However, Nigeria has more than sufficient proven oil and condensate reserves to sustain a higher level of production, and it seems unlikely that the FGN would allow such a fast and unnecessary decline in an essential source of revenue. Following discussions with stakeholders, the study team developed a modified projection (shown as solid lines

Figure 5.4 Reference Case Projected Demand for Gas for On-Site Use



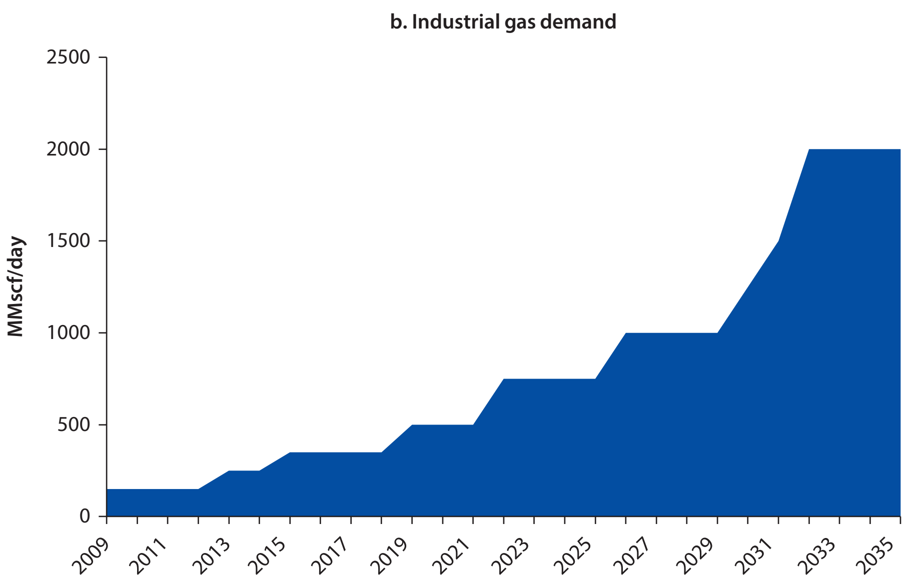


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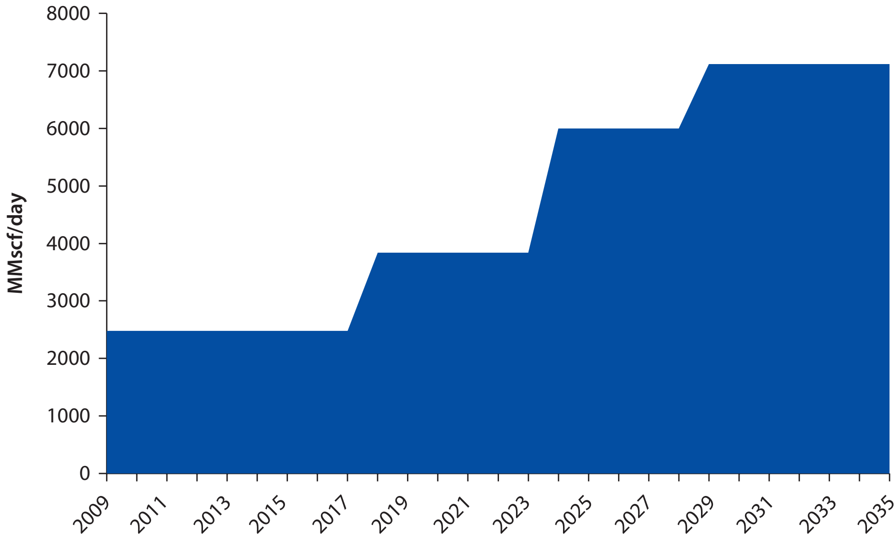
Figure 5.4 Reference Case Projected Demand for Gas for On-Site Use *(continued)*

c. LNG plant gas demand



d. GTL plant gas demand

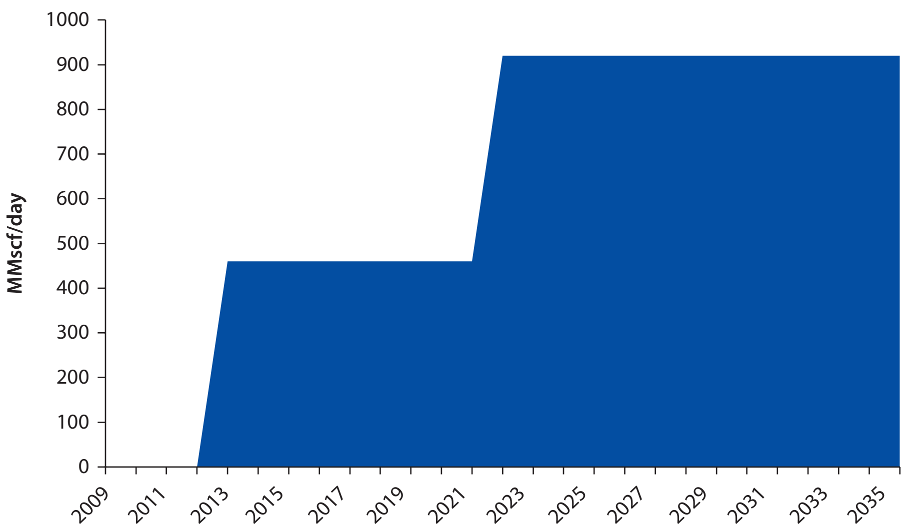


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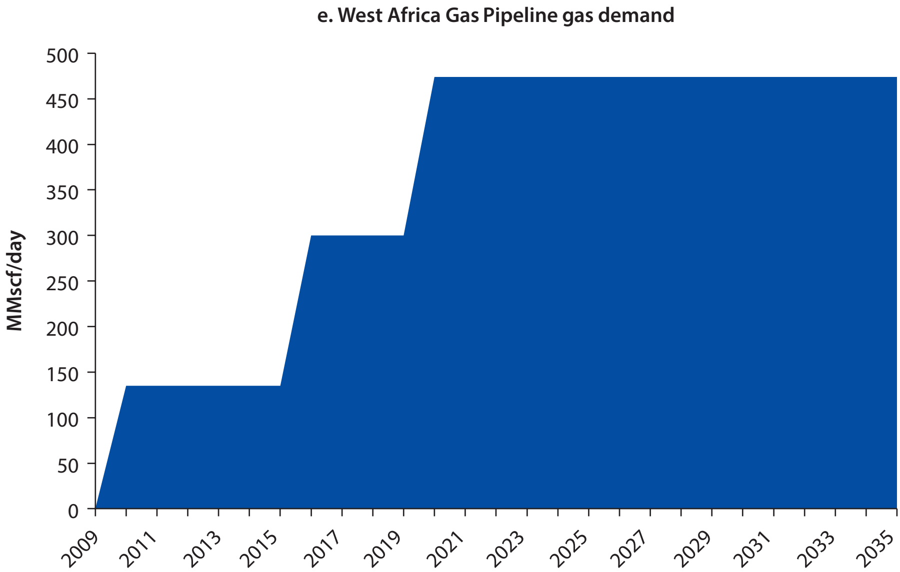
Figure 5.4 Reference Case Projected Demand for Gas for On-Site Use *(continued)*



Source: Calculations based on data sources listed in the chapter 3 references.
Note: MMscf = million standard cubic feet.

Figure 5.5 Projected Production of Oil and Condensate for Existing and New JV and PSC Fields

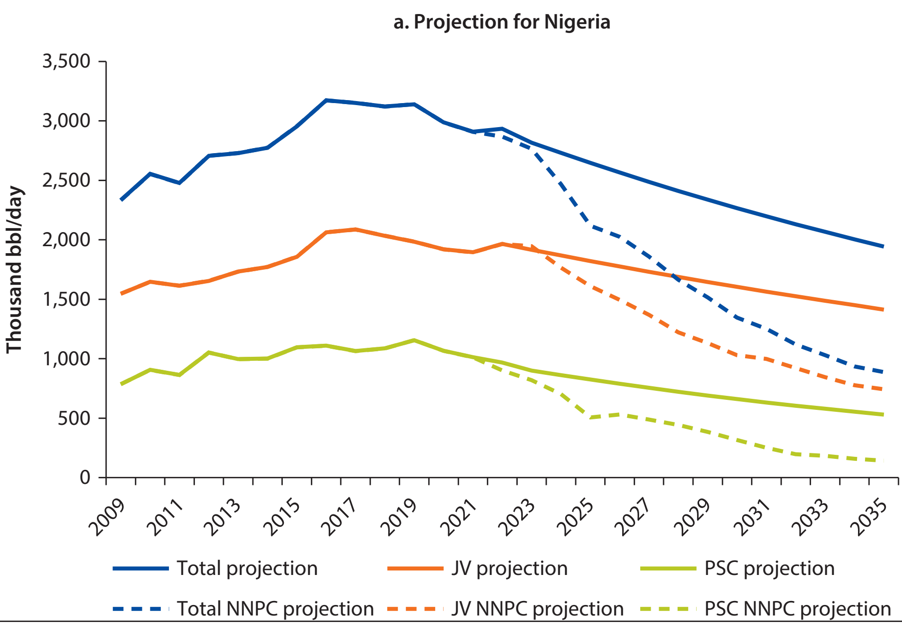


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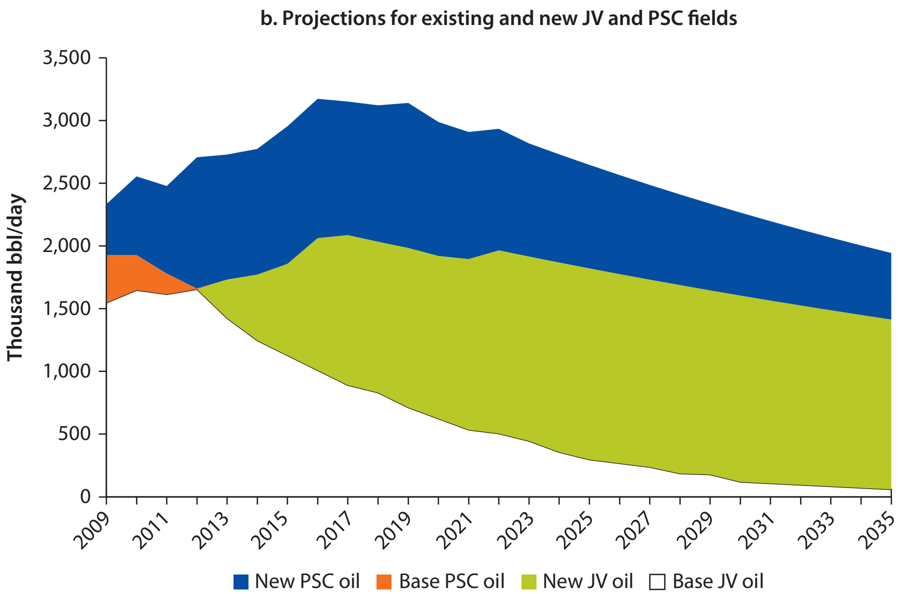
Figure 5.5 Projected Production of Oil and Condensate for Existing and New JV and PSC Fields *(continued)*



Source: Calculations based on NNPC projections data listed in the chapter 3 references.

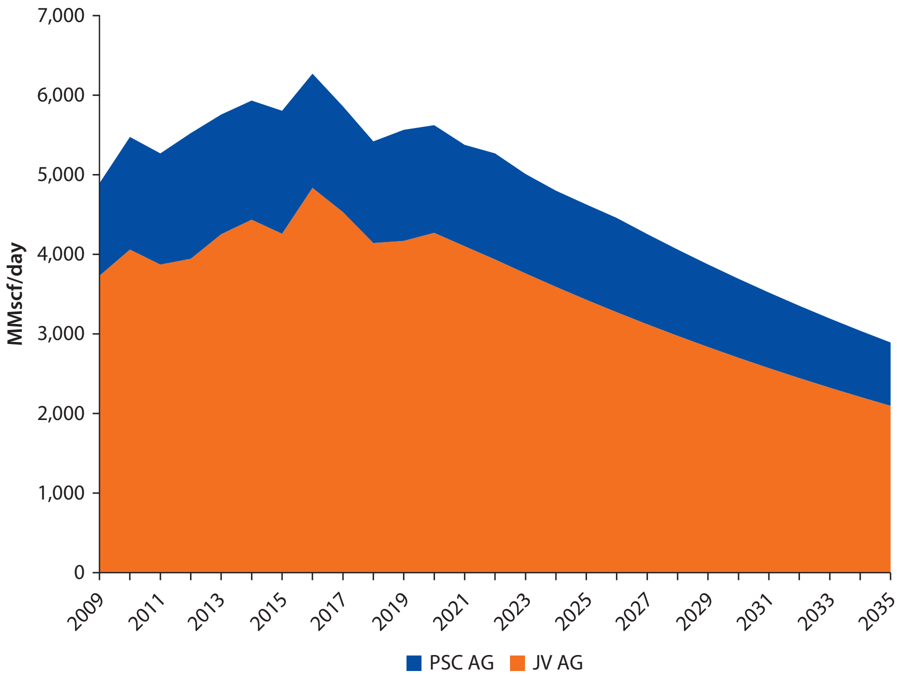
in figure 5.5 panel a) that assumes that, after 2022, oil and condensate production will decline at an annual rate of 3 percent (that is, at one-third the rate of decline in the "NNPC projection"). This decline rate is a weighted average of:

- A decline in PSC oil and gas production at an annual rate of 4.33 percent and
- A decline in JV oil and gas production at an annual rate of 2.5 percent.

This projection, which has been used as the basis for the GHG emission estimates, results in a cumulative production of 24.9 billion barrels of oil and condensate over the period 2009–35 that is well below the currently proven reserves of 37 billion barrels.

Total oil and condensate production was divided into four categories: old and new JV fields and old and new PSC fields. These distinguish the cost of implementing new low-carbon options, where old fields (pre-2009 developments) have higher costs due to the need to retrofit existing installations. The differentiation between the PSC and JV fields was made to reflect the significantly lower flaring rate—as advised by the Department for Petroleum Resources (DPR) and observed from satellite data—in the PSC fields compared to the JV fields. This resulted in production profiles as shown in figure 5.5.

Figure 5.6 Associated Gas (AG) Production



Source: Calculations based on data sources listed in the chapter 3 references.

Associated Gas

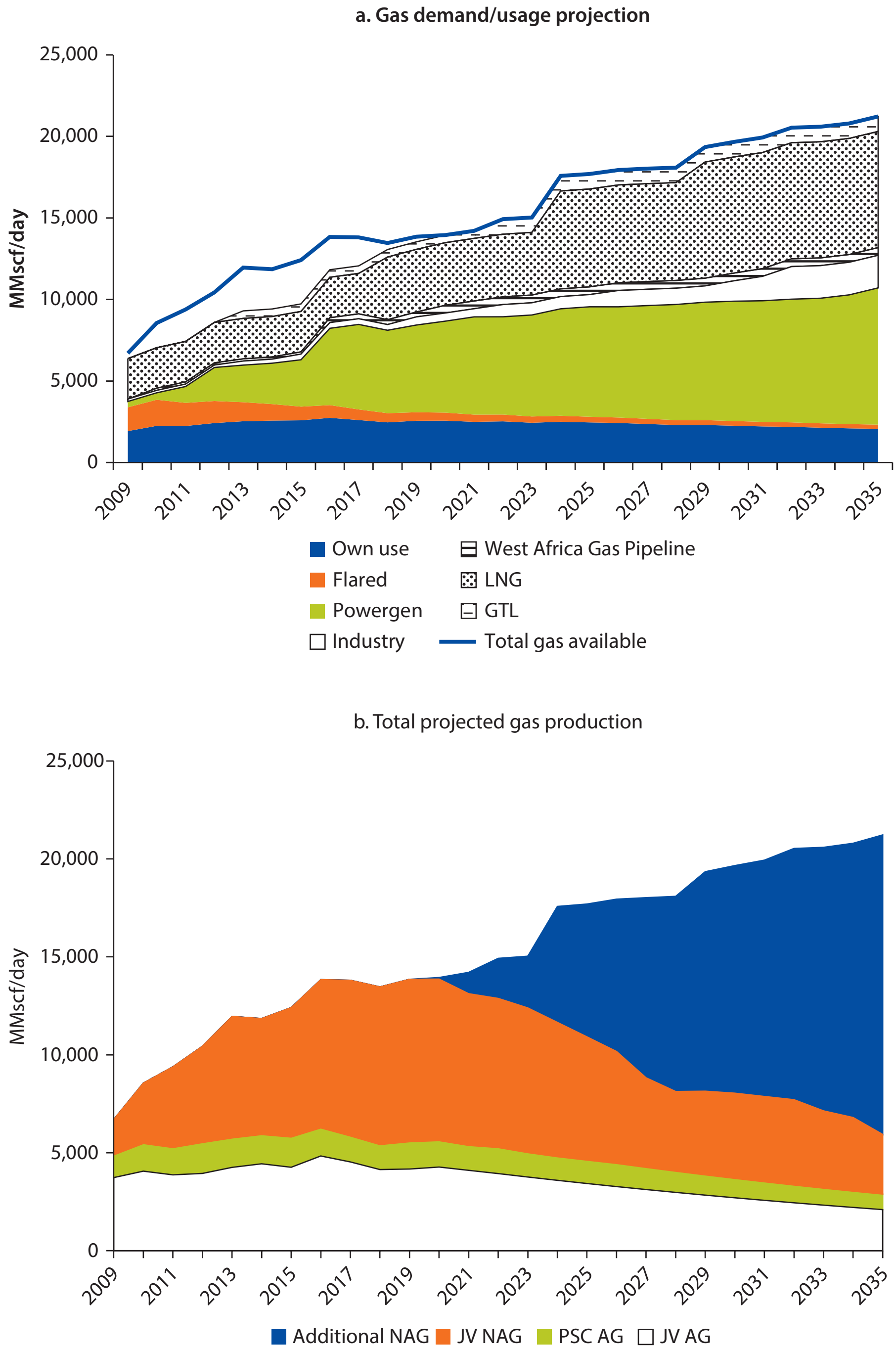
The gas-oil-ratio (GOR) projection provided by NNPC combined with the modified oil projections was used to estimate AG production projections (figure 5.6).

Non-Associated Gas

The volume of AG production is determined by the oil production and gas-to-oil ratio. Production of non-associated gas (NAG) is therefore needed to ensure that total gas production (AG + NAG) meets expected gas demand. The NAG projection provided by NNPC peaks in 2020 and declines thereafter, based on their assumption of constrained investment. When added to the AG projection, the resultant total gas supply will be insufficient to meet projected demand for gas through 2035. Therefore, additional investment in developing new NAG fields before 2020 will be required if the demand for natural gas for both the domestic and export markets is to be met. This total gas demand is shown in figure 5.7 panel a, and the corresponding supply requirement in figure 5.7 panel b.

As figure 5.7 panel a shows, the estimated supply and demand projections suggest that there will be an excess of gas supply available prior to approximately 2020. Thereafter, as NAG production has been assumed to increase as required to meet demand, supply and demand are in balance.

Figure 5.7 Gas Demand and Supply Projections



Source: Calculations based on NNPC data listed in the chapter 3 references.

GHG Emissions for the Reference Scenario

Based on the above oil and gas production projections, GHG emissions were estimated for each of the major emission sources:

- Combustion of fuels
- Flaring of AG
- Venting of gas
- Fugitive emissions
- Other emission sources (such as venting from oil storage tanks and facility maintenance activities).

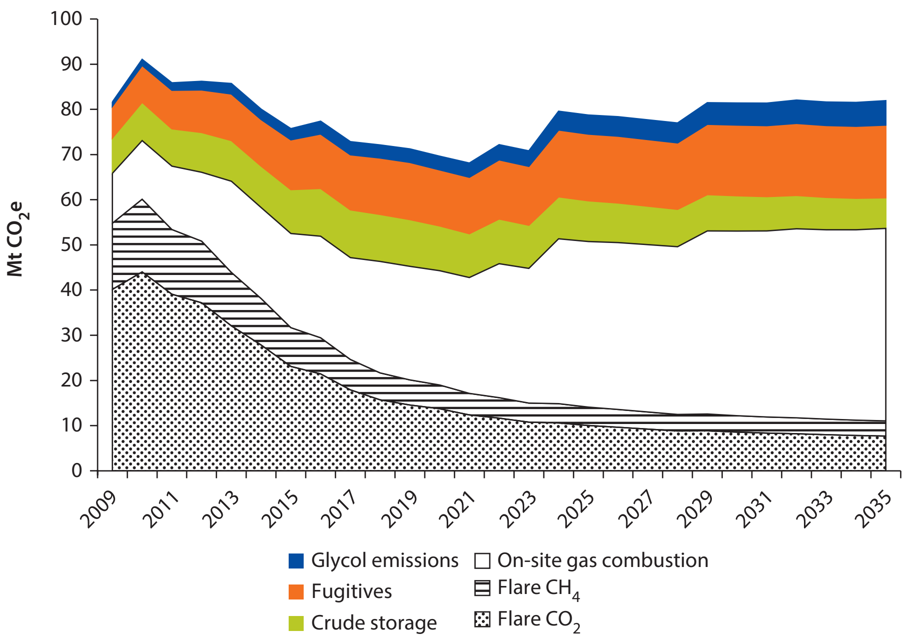
The reference case scenario GHG emissions forecasts by source are presented in figure 5.8.

GHG Emissions in the Low-Carbon Scenario

This study has identified a large number of potential mitigation options for each of the various parts of the oil and gas production, transportation, and processing chain, as well as provided estimates of the capital and operating costs and emission reductions that would be achieved through their implementation.

In order to establish a low-carbon emissions scenario, a selection was made from these options assuming (1) an annual budget ceiling for implementing

Figure 5.8 Reference Scenario: Oil and Gas GHG Emissions by Source



Source: Calculations based on NNPC data listed in the chapter 3 references.

low-carbon options of US$3 billion per year, about 5 percent of projected net revenues from oil and gas production and (2) limited engineering capacity to implement these options; for example, no more than 35 flare reduction options were considered implementable each year. A brief description of the low-carbon options included in the analysis is provided in Box 5.1.

Box 5.1 Low-Carbon Interventions for the Oil and Gas Sector

The options that can be considered to reduce carbon emissions fall into three main categories:

- Gas flaring
- Leakage and emissions of natural gas, which is primarily methane
- Use of gas within oil and gas sector operations

Gas flaring

Gas flaring, which takes place at many areas of oil and gas operations (including production facilities, gas processing facilities, and LNG and GTL plants), can be reduced if viable alternative uses for the gas being flared can be identified. In Nigeria, these uses include:

- injection either for enhancement of oil recovery or purely for disposal/storage;
- power generation, heating on-site to run the operations;
- domestic power generation, both on a large scale with electricity delivered to the national grid or on a small scale, to supply electricity to local communities;
- supply to LNG and GTL plants;
- supply to domestic industry; and
- export via the West Africa Gas Pipeline.

Extraction of natural gas liquids (LPGs) for sale can be employed to reduce gas volumes flared, even where no viable use for the dry gas is available.

Although the bulk of gas flaring can be reduced by using the gas as described above, some flaring will always continue primarily for safety reasons. These smaller, but still significant, emissions can be reduced by redesign of the flare itself to remove the need for pilot flames, and to improve combustion efficiency.

Leakage and emissions of natural gas

Natural gas leakage and emissions take place, to a greater or lesser extent, in all oil and gas operations. The bulk of these emissions are called "fugitive emissions," which take place through gas seals and pipe connections, from gas-actuated process control equipment, during maintenance operations, and from equipment designed to vent small volumes of gas during normal operations. These fugitive emissions can be reduced by:

- replacing wet seals on gas compressors, which continuously leak gas through the seal, with dry sealing devices;
- installing vapor recovery units on glycol pumps and dehydration units;

box continues next page

Box 5.1 Low-Carbon Interventions for the Oil and Gas Sector *(continued)*

- using air rather than gas to actuate process control equipment;
- installing low-bleed pneumatic control devices; and
- carrying out enhanced and directed maintenance programs for production and processing facilities, gas compressors, pipelines, and meters.

Emissions also take place as gas evolves from oil stored in fixed-roof tanks at oil and gas facilities. These emissions can be reduced by replacement of the fixed roofs with internal floating roofs that minimize the leakage and/or installation of vapor recovery units to collect the gas evolved.

Use of gas within oil and gas sector operations

The main use of gas within the oil and gas sector is for power generation to run oil and gas production, transportation, and processing operations. Options to reduce emissions from this on-site power generation equipment include:

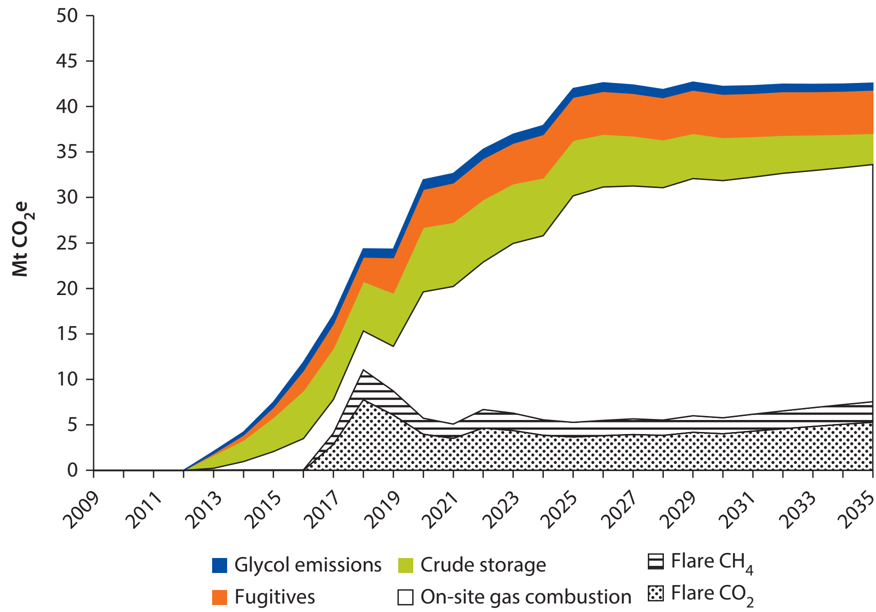
- replacement of low-efficiency gas turbines/reciprocating engines with modern, high-efficiency equipment;
- installing variable speed drives on gas compressors and oil pumps to maximize compressor and pump efficiencies;
- replacement of the power generation equipment itself with modern higher efficiency equipment, such as combined-cycle units;
- replacement of equipment with a high demand for power, particularly gas compressors, with modern higher efficiency equipment;
- installing optimal system control units to reduce the power requirement in the various oil and gas operations; and
- carbon capture and storage of combustion gases.

Under the low-carbon scenario, GHG emissions are significantly reduced, as illustrated in figure 5.9, with better utilization of Nigeria's gas resources through reduced waste of AG. The total potential abatement over the 2010–35 period is estimated to be 750 Mt CO_2e. Figure 5.9 also shows the resultant low-carbon scenario emissions by source.

The emission reductions attributed to reducing gas flaring in this scenario are significant. However, it should be noted that the main flare reduction has already been included in the reference case scenario. Without these reductions, the reference case scenario emissions would be significantly higher. Reduction in gas flaring is the single most effective activity to increase AG utilization and reduce emissions.

Early implementation of flaring reduction is critical, as declining oil (and hence AG) production reduces the economic attractiveness of the low-carbon investments. Implementation of low-carbon options in fields where flaring is continuing will have limited or no impact because the gas saved would then be flared. Therefore, elimination of routine flaring should typically precede implementation of other low-carbon options.

Figure 5.9 Low-Carbon Scenario: Emissions Reductions from Oil and Gas



Source: Calculations based on NNPC data listed in the chapter 3 references.

Gas Prices

Most carbon mitigation options generate revenues from sale of natural gas, LNG, liquefied petroleum gas (LPG), and electricity. Considerable uncertainty about the future prices of these products is inevitable. For base and low gas price scenarios, projections from the U.S. Department of Energy *Annual Energy Outlook* (USDOE 2011) have been used, consistent with analysis of low-carbon options for the Nigerian power sector. The high gas price scenario is based on the United Kingdom Department of Energy and Climate Change (DECC 2011) high gas price scenario, which is notably higher until 2026 than *Annual Energy Outlook* (USDOE 2011) high-scenario (see table 5.1).

Natural gas supplied to LNG plants is calculated at the value of LNG exports to Europe, less $1.67 for marginal production cost, $1.33 for shipping, and $0.37 for regasification, for a total netback reduction of $3.37/millionBtu from the price of LNG to estimate the value of gas.

For gas sold domestically, the price in 2012 is assumed to be at current low gas prices, with an increase to export parity by 2015 in accordance with the assumptions used in the power sector analysis.

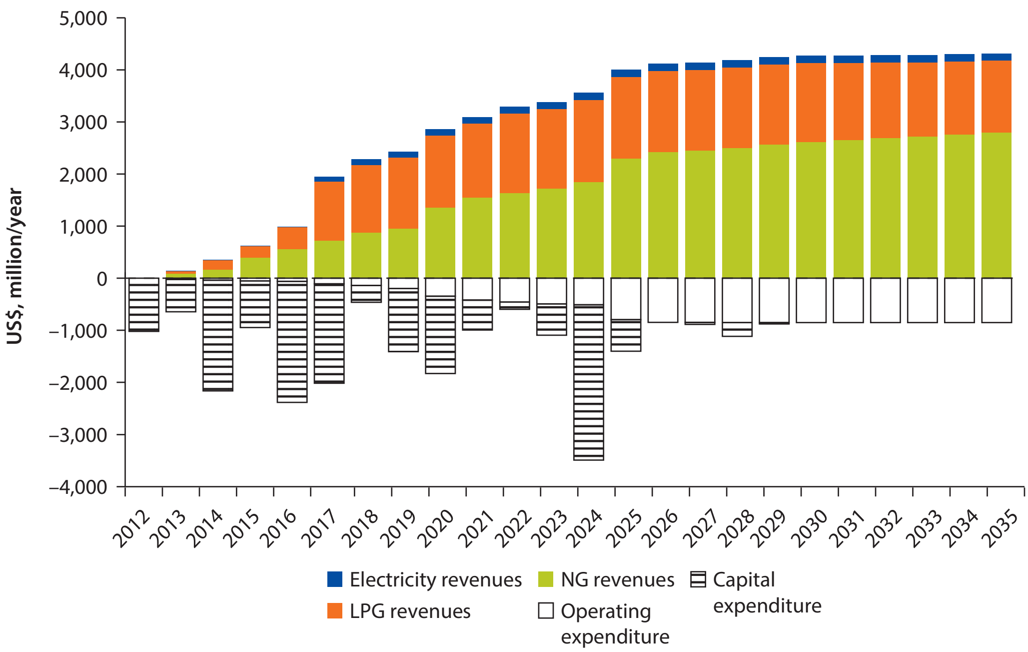
Revenues for large-scale LPG volumes are estimated at gross primary productivity (GPP) plant outlet at $400/ton, based on a Rotterdam price of $800/ton, less shipping and transportation. For small-scale domestic LPG sales near the wellhead, net revenue is estimated at $150/ton. LPG prices are projected to increase over time indexed to the price of oil, using base, low, and high scenarios.

Table 5.1 Low-, Mid-, and High-Cost Product Price Scenarios, 2012–35

Year	*2012*	*2015*	*2020*	*2025*	*2030*	*2035*
Natural gas ($/millionBtu)						
Low	4.41	4.55	4.78	5.02	5.28	5.55
Mid	4.50	4.71	5.07	5.46	5.89	6.34
High	8.34	9.23	10.71	11.45	11.45	11.45
LPG ($/tonne)						
Low	316	315	323	317	335	319
Mid	404	427	488	516	531	539
High	532	597	681	732	760	772
Electricity ($/MWh)						
Low	55	60	61	63	65	67
Mid	57	63	65	68	71	75
High	87	99	104	104	104	104

Sources: DECCC 2011; USDOE 2011.

Figure 5.10 Revenues and Costs for the Low-Carbon Scenario



Source: Energy Redefined 2012.

The revenues from the sale of electricity generated from gas utilized by low-carbon options are estimated to be the same as the generation cost for grid-connected gas turbines used in the analysis of the Nigerian power sector, at $52/megawatt-hour (MWh) in 2010, increasing to $63/MWh in 2015, as gas price approaches export parity.

Using the mid-prices, figure 5.10 shows the costs and revenues for the low-carbon scenario. The largest capital costs occur in the early years. Revenues are dominated by gas sales, with significant contributions from LPG. As the graph shows, the early low-carbon options generate sufficient revenue to fund further implementation after 2016.

Recommendations for Oil and Gas

Recommendations for the Federal Government of Nigeria

Policy Recommendation: Establish A Joint Government-Industry Group

The FGN might want to consider setting up a joint government-industry group to develop a low-carbon strategy and action plan for the oil and gas industry.

Policy Recommendation: Fund Mitigation Projects

The FGN might want to ensure that NNPC's annual budget includes sufficient funding for implementation of the high-priority mitigation options. The FGN should consider implementing a "fast-track" budget approval process for mitigation options.

Policy Recommendation: Improve Collection and Availability of Data

For many emission estimates, this book has relied on realistic assumptions with regard to the oil and gas facilities in Nigeria and their condition. In order to develop better and more detailed emission estimates that can form the basis of a detailed plan for their mitigation, it is recommended that the FGN promotes the following:

- The creation of a sector-wide inventory of emission sources. Apart from information on current GHG emissions, the inventory should include the status of each source—for example, age, condition, emission reduction actions already taken—and identified potential emission reduction options.
- Application of the Tier 1 methodology of the Intergovernmental Panel for Climate Change to establish the current level of emissions. If Tier 1 is considered to be unrealistic to carry out in a reasonable time frame, at least a Tier 2 estimate (both Tier 1 and Tier 2 estimation methodologies are described in the API Compendium [API 2009]) should be prepared.

Policy Recommendations for the Oil and Gas Industry (including NNPC)

Address Gas Flaring Reduction

Flaring reduction should be the highest priority action, not only to reduce the direct emissions from the flaring, but also to extract maximum benefit from conserving gas through implementation of other mitigation measures.

Because of the high cost of installing gas gathering and processing facilities at small flare sites, it is recommended that consideration should be given to collecting the small volumes of AG in clusters for processing and export of the dry gas and LPGs.

Improve Energy Efficiency

(1) Consider replacement of older and/or smaller on-site power plants with new equipment and (2) Consider use of variable-speed drives on pumps and compressors to improve efficiency.

Other Recommendations for Reducing Emissions

(1) Since some flaring will still occur (for example, for safety), consider improvement of the combustion efficiency of remaining flares. (2) Where not already done, consider replacing fixed roof tanks with floating roof tanks, with gathering systems for the liberated gas. (3) Enhanced and directed inspection and maintenance programs have been very effective in reducing emissions in other oil and gas ventures. Consider gradually implementing such programs in Nigeria.

Longer Term Recommendations for Oil and Gas

A number of technologies may become economically attractive to implement in the longer term, including alternative energy sources such as wave power to replace on-site gas/diesel combustion and carbon capture and storage. The cost trend for these technologies should be monitored and, when they appear to be viable, their potential for implementation in Nigeria should be considered.

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CHAPTER 6

The Power Sector

Nigeria's electricity grid faces many challenges, including insufficient grid-connected capacity to meet demand, inadequate infrastructure to make the country's abundant gas available for power generation, and an inefficient transmission and distribution system with limited coverage. In part for these reasons, an estimated 50 percent of the electrical energy consumed in the country is currently produced off-grid by diesel and gasoline generators of all shapes and sizes. Unmet demand is also high, particularly amongst the many citizens who have no access to the grid and cannot afford off-grid power.

This is fully recognized by the current government. Within the last 5 years, four major power sector planning studies have been carried out for the country; increasing the amount, accessibility, and reliability of electricity supply is a major political priority for Nigerian President Goodluck Jonathan, who has recently established two multi-agency bodies for power sector development.

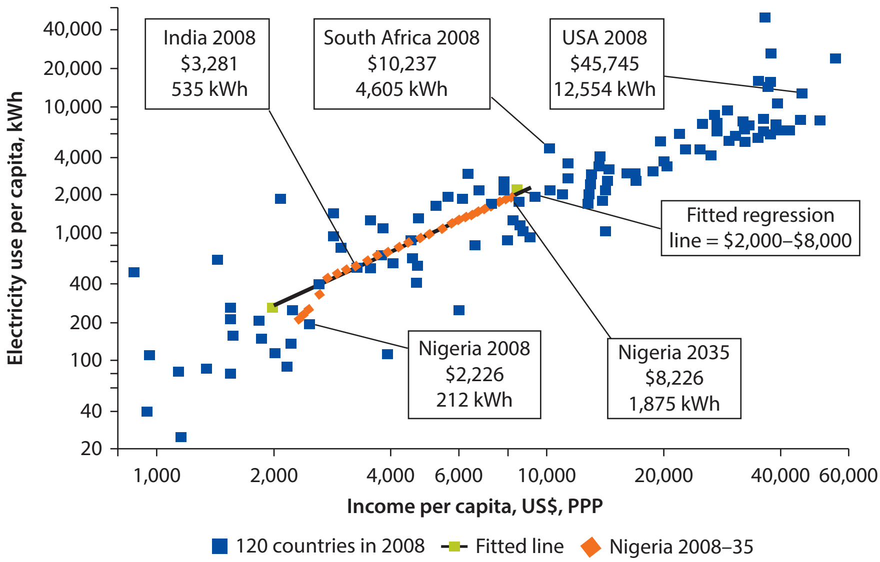
Projecting Development of the Sector

Electricity Demand

Projecting the demand for electricity in Nigeria is especially challenging because of the difficulty in estimating the large amount of electricity produced by small, unregulated petrol and diesel generators, and quantifying the suppressed demand. The study team addressed the issue by using cross-country evidence of the relationship between income and electricity use (both on a per capita basis). Figure 6.1 suggests a constant elasticity of electricity demand to income, which enables the analysis to predict the growth in power demand as income grows to meet the Vision 20: 2020 objectives: the relationship is displayed by the orange diamonds, which project the trajectory of Nigeria's per capita electricity consumption and income 2008–35.

Figure 6.1 also highlights how Nigeria's recent grid electricity supply has lagged far below that of similar countries. Nigeria's base year consumption is estimated at 212 kilowatt-hours (kWh) per capita (of which half is off-grid

Figure 6.1 Annual Per Capita Electricity Use vs. Income for 120 Countries, 2008; Nigeria Projections, 2008–35



Sources: Income and population, World Development Indicators 2011; Electricity use, USDOE 2009.
Note: Graph points show electricity use per capita against income per capita (at purchasing power parity) for 120 countries in 2008. The trend line in green is fitted to countries with per capita incomes $2,000–8,500, excluding outliers. Projected values for Nigeria's per capita electricity consumption and income are shown as orange diamonds, 2008–35).

generation), which is well below the trend line of 300 kWh per capita at the same income of $2,226 per capita (purchasing power parity [PPP]). The reference scenario projects a rapid expansion in electricity supply through 2015 that reflects the Federal Government of Nigeria's (FGN) Vision 20: 2020 plans. The reference case scenario also projects that post-2015, Nigeria will follow the trend line, which is an average of other developing countries. This would result in a per capita consumption of 1,875 kWh/capita in 2035, at a per capita income of $8,226 (2009 USD at PPP).

The result is that total demand (grid and off-grid) for electricity grows by a factor of 5.0 by 2020 and 16.8 by 2035 relative to 2009.

Demand is met by a mixture of the five source categories listed in table 6.1, which includes grid supply, as well as off-grid generation, divided into four classes, A, B, C, and D, following the Energy Commission of Nigeria (ECN).

The base year estimates of current grid and off-grid generation by category are based on data and estimates developed with the ECN and the Federal Ministry of Power (FMP). Because of the considerable uncertainty in these estimates, the sensitivity of the results to the underlying assumptions is examined in box 6.1. As grid supplies increase in quantity and reliability, the study projects that off-grid generation will decline over time. However, the energy used by those with no grid access, mainly in rural areas (category D) increases over time as incomes

Table 6.1 Source Categories of Electricity Supply in Nigeria

Supply source/category	*Description*
Grid-supply	Generation from the power grid
Off-grid A: Backup	Off-grid generation only when on-grid power is unavailable
Off-grid B: Full-time ≥ 1 MW	Off-grid generation which is used full-time even though there is grid access, with generators greater than or equal to 1 MW (which require government registration)
Off-grid C: Full-time <1 MW	Off-grid generation used full-time even though there is grid access, with generators under 1 MW (not needing government registration)
Off-grid D: No grid access	Generation in rural locations with no grid access

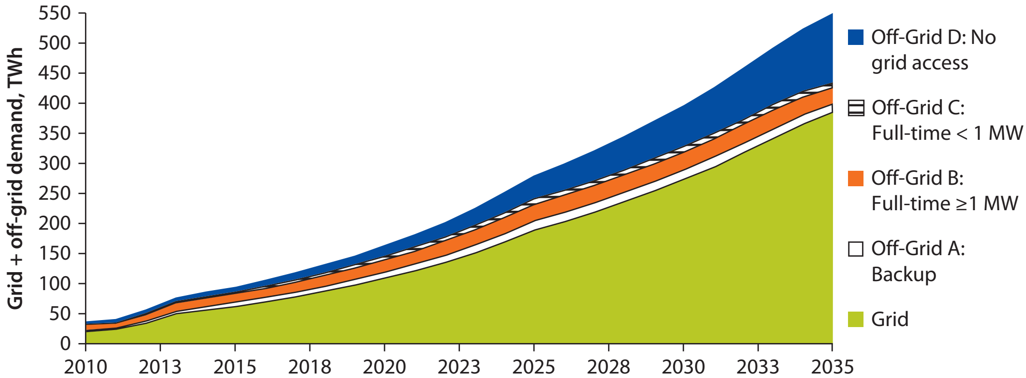
Box 6.1 Estimating Off-Grid Generation and Emissions: A Sensitivity Analysis

Estimating current off-grid capacity and generation is undoubtedly challenging. Generators of 1 MW or greater must be registered with the Federal Ministry of Power (FMP), but there are limited data on actual usage and the capacity of other off-grid generation beyond some local surveys. It is yet more challenging to project the future of off-grid generation. For these reasons, studies of power systems for developing countries have usually ignored off-grid generation. However, given the large contribution of off-grid generation in Nigeria, which is unlikely to disappear entirely within 25 years, ignoring it would seriously compromise the practical value of the study. Consequently, the study team chose to include off-grid generation in its projections, while recognizing the inevitable uncertainty.

Examining the effects of this uncertainty via a sensitivity analysis asks what the results would be if 2009 off-grid generation was 40 percent less or 40 percent more than the current estimate. We assume the same percent change in off-grid generation relative to the base case through 2035, and the same off-grid generation mix over time as described below for each scenario. The resulting plus or minus 40 percent change in off-grid generation would change the cumulative total emissions through 2035 by plus or minus 14.9 percent for the reference scenario and plus or minus 15.6 percent for the low-carbon scenarios, respectively. It would change the reduction in total emissions from the reference to low-carbon scenario only slightly, from 42.9 percent up to 43.4 percent, or down to 42.6 percent, due to the higher carbon-intensity of off-grid generation relative to grid-based generation in both scenarios.

rise. As a result, the reference scenario projects that off-grid consumption will decrease from an estimated 50 percent of total power consumption in 2010 to about 30 percent in 2035 (see figure 6.2). It is anticipated that off-grid supply will be increasingly provided by micro-grids—that is, local grids in residential or industrial areas with their own generation and distribution but not connected to the national grid.

Figure 6.2 Projected Grid and Off-Grid Power Consumption, Reference Scenario



Source: Calculations based on FMP and Power Holding Company of Nigeria data and UN 2010 rural/urban population data (for off-grid D projections) listed in the chapter 3 references.

The Roadmap for Power Sector Reform (FRN 2010) calls for extensive expansion of transmission capacity to existing grid load centers, but limited expansion of transmission and distribution to new areas. It is likely that the grid coverage will be further expanded by 2035 under the auspices of the re-established Rural Electrification Agency (REA), but given the magnitude of generation and transmission capacity expansion required just to meet the currently unmet and growing demand in existing areas (projected to expand by a factor of 6 by 2020, and 10 by 2035), it seems unlikely that Nigeria will achieve substantial coverage of rural areas by 2035. However, the projected economic growth of villages and towns in rural areas will require the benefits of electricity. Accordingly, the projections of energy consumption for Category D (off-grid) include a significant increase of total electricity from 12 percent in 2009 to 21 percent in 2035, or a factor of 30 by 2035 in kWh.

Grid Transmission and Distribution Losses

The increase in grid-connected generation will require a similar expansion of transmission capacity. An important sector policy objective is to reduce losses from transmission and distribution (T&D) in the Nigerian grid, which averaged about 20 percent in 2009 (NERC 2011). As a result of significant investment planned for the coming years, the reference scenario projects that technical losses could be reduced down to about 12 percent after 2025, as shown in table 6.2. The reference scenario for investment in T&D for 2009–35 assumes a constant cost of $92.5 million for improvements. The low-carbon scenario assumes a somewhat more aggressive reduction in T&D losses to 8 percent losses by 2035, consistent with international best practice. Thus, the low-carbon scenario assumes that Nigeria could reach a level comparable to that of other developing countries in the last decade.

Table 6.2 Planned Reduction in Electricity T&D Losses
percent of generation

	2010	*2015*	*2020*	*2025*	*2035*
Reference	20	19	16	13	12
Low-carbon scenario	20	19	15	12	8

Sources: NERC, Multi-Year Tariff Order 2011 (data for 2009–12); long-term projections based on discussion with stakeholders at the ECN.

Table 6.3 Nameplate and Available Capacity for Existing Plant and Planned Additions

	Plant type	*Nameplate capacity (MW)*	*Available capacity (MW)*
Existing plants in 2010	Hydro	2,230	1,108
	SCGT	6,150	2,286
	CCGT	1,100	769
	Total	9,480	4,164
Planned additions 2011–22	Hydro	3,550	2,286
	SCGT	6,921	5,506
	CCGT	960	778
	Total	11,431	8,571
Total	Hydro	5,780	3,395
	SCGT	13,071	7,793
	CCGT	2,060	1,547
	Total	20,911	12,735

Source: Summarized from the Nigeria Federal Ministry of Power.
Note: SCGT = single-cycle gas turbine; CCGT = combined cycle gas turbine. Totals may not sum exactly due to rounding.

Grid Generating Capacity in the Base Year

Existing grid-generation capacity in Nigeria is about 26 percent hydropower; the rest is by gas turbines, which are 56 percent open cycle and 18 percent combined cycle. As shown in table 6.3, in 2010 nameplate capacity totaled about 9.5 gigawatts (GW), of which about 4.2 GW was actually available because of problems with maintenance, gas supplies, and, in the case of hydro, dam siltation and low river flows. However, these numbers are increasing rapidly as units are refurbished and new capacity comes online. About 11.4 GW nameplate capacity is planned by 2022, most of it by 2016.

These estimates have been used in the modeling of installed capacity over time, as shown in table 6.4.

Fossil-Fuel Price Projections

The prices of fossil fuels, especially natural gas, diesel, gasoline, and coal, are key factors in determining the competitiveness of generation technologies. In Nigeria, the diesel market is relatively open: most diesel is imported and prices are close to global market prices. Natural gas has long been regulated and gasoline subsidized, resulting in prices much lower than global market prices.

This study assumes that natural gas will move toward "export parity" by 2015—that is, the global market price, less a percentage reflecting export and

Table 6.4 New Generation Capacity by Technology for the Reference Scenario

	Installed capacity (GW)			
Reference scenario	*2010*	*2015*	*2025*	*2035*
Grid technologies				
SCGT	6.5	18.0	30.0	52.0
CCGT	1.1	2.0	5.0	21.0
Hydropower	1.9	2.1	7.2	7.2
Coal subcritical	0.0	0.0	3.5	10.0
Nuclear	0.0	0.0	1.0	1.0
Subtotal[a]	9.5	22.1	46.7	91.2
Off-grid technologies				
Diesel generators	3.0	4.6	9.6	19.0
Gasoline generators	1.3	2.6	5.0	6.0
Gas turbines	0.0	1.3	7.0	13.0
Subtotal	4.3	8.5	21.6	38.0
Total	13.8	30.6	68.3	129.2

Source: Calculations based on data sources listed in the chapter 3 references.
a. Less than half of the 2010 installed capacity was actually utilized due to lack of fuel, inadequate maintenance, and other problems.

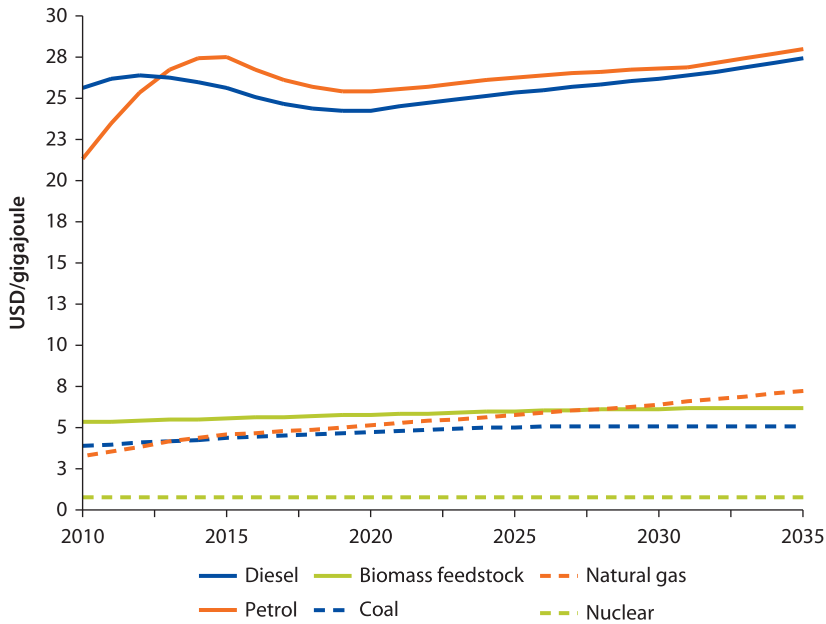
transportation costs from Nigeria. It also assumes that diesel and gasoline will tend to "import parity" by 2015—global market prices plus 12 percent reflecting the cost of transportation and import to Nigeria. It further projects that Nigeria's refinery capacity, much of which is currently nonoperational, will be refurbished and expanded between 2015 and 2020, with the result that most domestically consumed diesel and gasoline will be produced domestically. Hence, it projects that their prices will shift from import parity to export parity over that time—global market prices less 12 percent to reflect the savings from domestic production, a net reduction of 24 percent. Global fuel price projections are based on the U.S. Department of Energy *Annual Energy Outlook* (USDOE 2011) reference scenario for fuel prices through 2035. Figure 6.3 shows the resulting levelized fuel prices, which are estimated as the net present value (NPV) of fuel costs over the plant life of a given type of technology that uses that fuel, cut off at the modeling horizon.

Costs of Grid-Connected and Off-Grid Technologies

Figure 6.4 projects the LCOE for a wide variety of grid-connected technologies in Nigeria by year of installation to 2035. Those technologies that use fuel are based on the fuel costs in the figure. The costs of most of these technologies, especially solar and wind, assume a reduction in capital cost over time to reflect learning curves, driven by the increase in global capacity of a technology as a result of both technological improvements and economies of scale.

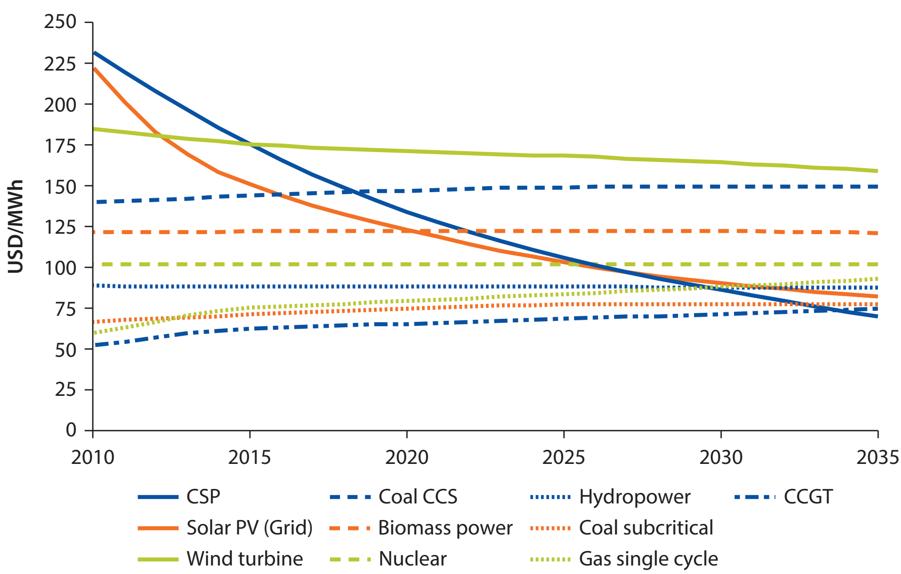
The early growth in the LCOE for gas turbines (both single-cycle gas turbine [SCGT] and combined-cycle gas turbine [CCGT]) is driven by the

Figure 6.3 Levelized Fuel Costs over Plant Lifetimes, 2009



Sources: NERC, Multi-Year Tariff Order 2011 (data for 2009–12); USDOE 2011; World Bank 2011a.

Figure 6.4 LCOE Projections for Grid Supply Technologies



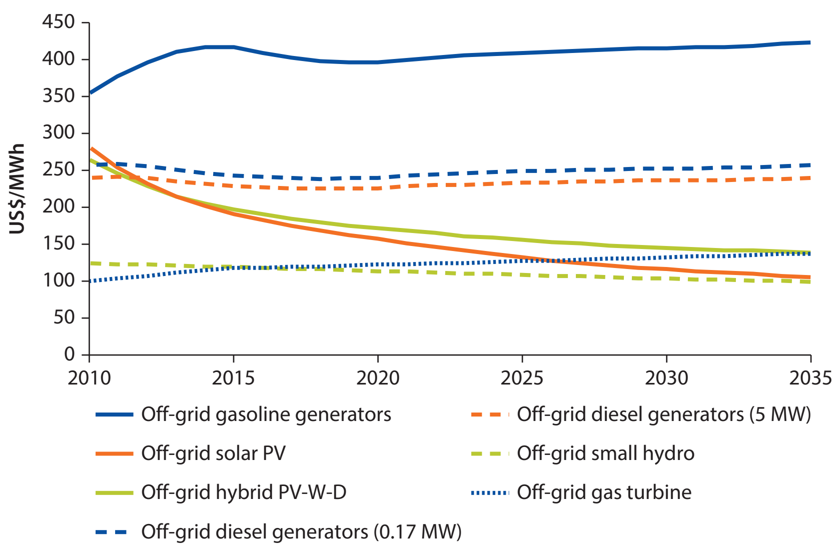
Sources: USDOE 2009; IEA 2010b.

expected increase in gas prices, reflecting FGN policies to allow gas prices to approach global market prices. The economic benefits of more efficient CCGTs over SCGTs increase over time as gas prices increase. The projected LCOE for concentrated solar power (CSP) and photovoltaic (PV), assuming International Energy Agency (IEA) learning rates, suggest that they are likely to become cost-competitive with SCGT before 2030 and with CCGT before 2035.

Wind energy does not seem competitive in Nigeria based on the limited wind-speed data available, but a more extensive survey of wind speeds may still identify economically viable locations. Neither coal with carbon capture and storage (CCS) nor biomass power is likely to be competitive with gas purely on economics, unless the carbon savings can be monetized with Clean Development Mechanisms (CDMs) or other means. However, it should be noted that there is great uncertainty about future learning rates for renewables, as well as the possibility of larger increases in global fuel prices than the Energy Information Agency's (EIA) reference scenario.

Off-grid generation typically uses diesel and gasoline generators. Current costs for these were based on information obtained from vendors in Nigeria. For other off-grid technologies, the cost estimates were obtained from international sources, adjusted to reflect the more rapid cost reductions in PV from 2008 to 2012 and local conditions. The costs of hybrid PV-wind-diesel system derive from a project analyzing the economics of hybrid systems for a small community in Egbeda, Nigeria. Figure 6.5 compares these projected LCOE estimates for off-grid technologies.

Figure 6.5 Projected LCOE for Off-Grid Technologies in Nigeria



Sources: ESMAP 2007; IEA 2010a.

The Reference Scenario

The reference scenario projects the rapid addition of new grid-connected generation capacity to meet the existing known suppressed demand and the anticipated rapid growth in demand over the coming years. It adds to the current capacity and planned expansion a fuel mix that does not change substantially from Nigeria's existing use of natural gas, hydropower, and diesel, except for the addition of 10 GW coal and 1 GW of nuclear power by 2035. Both of these are in existing plans but not currently used in Nigeria.

Natural Gas

Nigeria's abundant natural gas supplies make natural gas the current dominant source for the grid-connected generation of electricity. Most existing generation uses SCGT because of the low domestic price of gas and its more favorable investment requirement. In recent years, power generation has been limited by insufficient access to natural gas because of difficulties with transportation from gas production wells in the Niger Delta and offshore and because foreign sales (as LNG) have offered higher prices. The FGN has made it a top priority to remove these bottlenecks by adopting new policies allowing local gas prices to increase approaching global market prices to encourage greater supply.

Based on existing FGN plans and consultations with Nigerian power stakeholders, the reference scenario projects that new gas plants will include CCGT—leading to up to 22 percent of gas-fueled capacity by 2035—which through their greater efficiency give a lower LCOE at future higher gas prices, despite their higher initial cost.

Hydropower

Nigeria has significant hydropower potential. It currently has 2.2 GW hydro capacity installed, although some of that requires maintenance and is not being used for generation. The reference scenario follows FGN plans and feedback from stakeholders calling for rehabilitating all installed capacity. It projects increasing hydropower up to 7.2 GW by 2035.

Coal

Nigeria has significant reserves of coal. The coal industry produced over half a million tons per year in the 1950s and 1960s, until production declined precipitously due to combined effects from the discovery of oil and the Nigerian Civil War (1967–70). The coal industry has not yet recovered substantially. However, plans to develop coal mines with electricity generation at the mine mouth are in early stages.

Based on consultations with members of the FGN and stakeholders, the study team projected for the reference scenario 10 GW of coal generation being brought on-stream between 2020 and 2035, using subcritical technology.

Nuclear

In recent years, the FGN has developed plans for its first nuclear power plant. The NAEC has provided a road map that calls for 1 GW of nuclear power by 2020. Based on this policy decision to pursue nuclear power, FGN is inviting a first bid for construction, which is unlikely to begin till at least 2020 (Lowbeer-Lewis 2010). The reference scenario includes 1 GW of nuclear power.

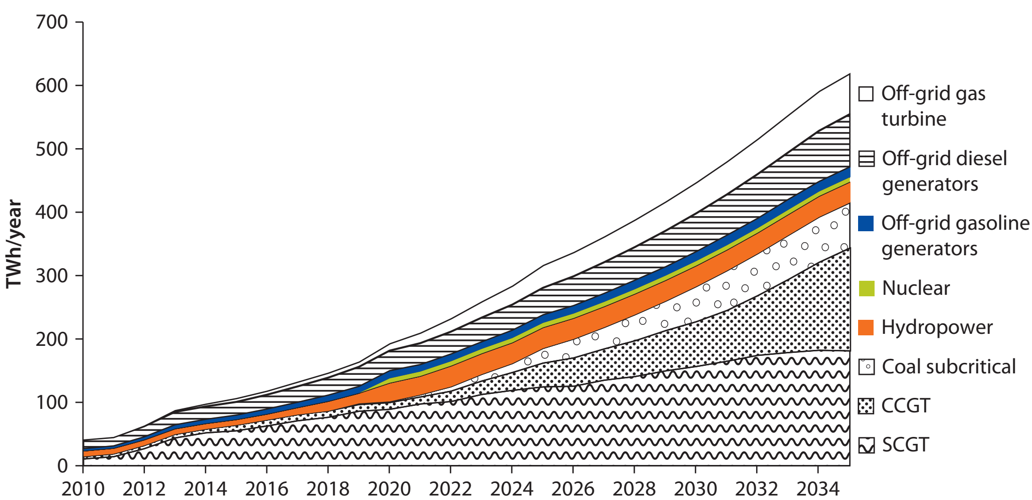
Diesel, Gasoline, and Gas Turbine Off-Grid Generation

Currently, off-grid power generation is significant, and diesel is the principal fuel, accompanied by many additional small gasoline-fueled generators. The reference scenario adds, in future years, 5.5 megawatts (MW) of off-grid gas turbines where the pipeline distribution network makes this fuel available, principally in the Niger Delta and South Coast. In the reference case, one-third of total off-grid generation is expected to be gas-based by 2035, while diesel will be the fuel of choice in less accessible regions. The resultant reference scenario of installed on- and off-grid generating capacity is shown in table 6.4.

The electricity generated by each technology in the reference case scenario and the resultant carbon dioxide equivalent (CO_2e) emissions are shown in figures 6.6 and 6.7, respectively.

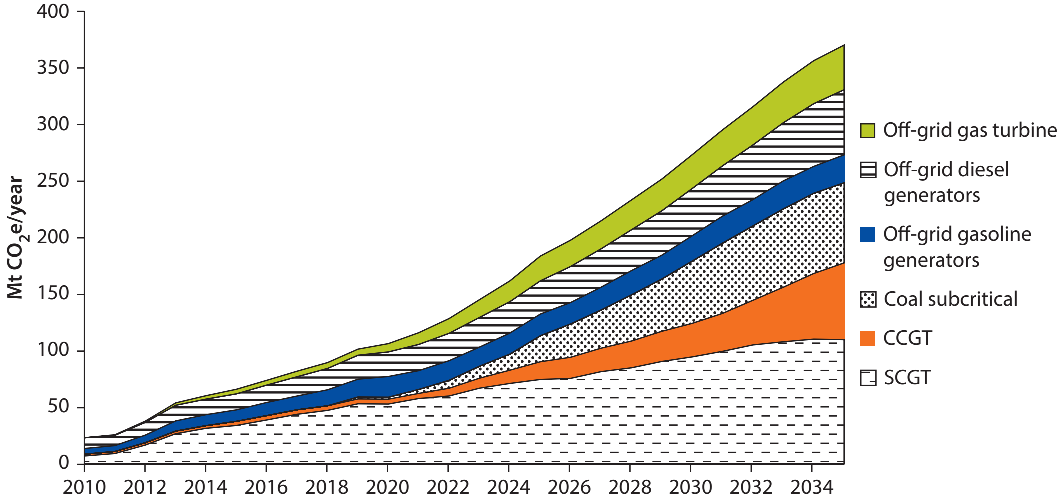
The average carbon intensity in the reference scenario changes little over time. The increased emissions from coal are approximately counterbalanced by the lower carbon intensity from additional hydro, larger proportion of CCGT, and off-grid gas. Figure 6.8 compares total emissions for the reference scenario with a Business-As-Usual (BAU) Scenario that generates the same quantity of energy using a constant technology mix as in the base year.

Figure 6.6 Reference Scenario: Electricity Generation by Technology



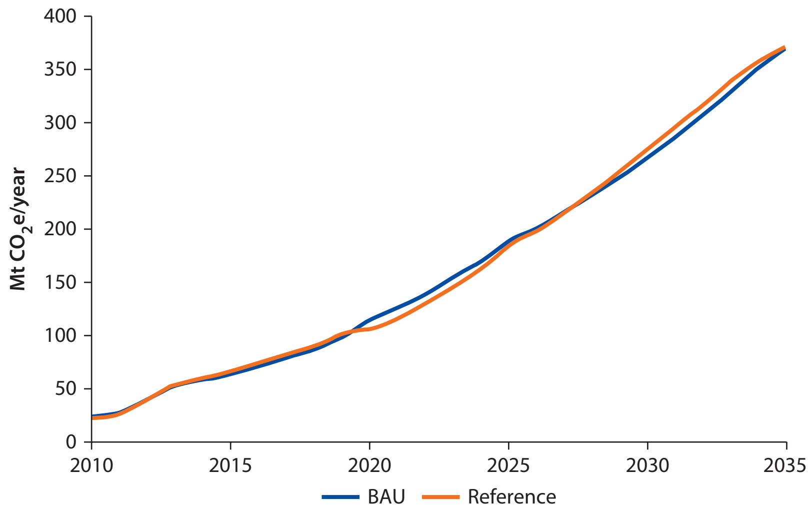
Source: Calculations based on data sources listed in the chapter 3 references.

Figure 6.7 Reference Scenario: Emissions by Generation Technology



Source: Calculations based on data sources listed in the chapter 3 references.

Figure 6.8 Total Carbon Emissions in the Reference and BAU Scenarios



Source: Calculations based on data sources listed in the chapter 3 references.
Note: The BAU scenario generates the same energy as the reference scenario, using a constant technology mix as in the base year.

Low-Carbon Power Technologies

The study developed an alternative low-carbon scenario which would enable Nigeria to achieve the same long term sector development objectives, at lower overall cost (7 percent less in NPV terms), through a mix of generation sources more diversified across technologies and geographically, and with a more significant future use of distributed and off-grid generation. As a co-benefit, such

Table 6.5 Two Scenarios for Power Sector Development to 2035

	Annual generation in 2035	*NPV of generation costs (US$billions)*			*Cumulative emissions*	*Diversity of generation*
Scenarios	*TWh*	*Capital and O&M*	*Fuel*	*Total*	*Mt CO_2e*	*Complement of Gini index (%)*
Reference case	620	52	127	178	4,335	17
Low-carbon	525	71	94	166	2,475	34

Source: Calculations based on data sources listed in the chapter 3 references.

an alternative model would also generate significant reduction of greenhouse gas (GHG) emissions, estimated to be in the range of 2–2.5 billion t CO_2e over the whole evaluation period (2010–35). A comparison between the low-carbon and reference scenario is shown in table 6.5.

The elements that change in the low-carbon scenarios (compared to the reference case) include demand-side energy efficiency (EE) measures, T&D loss reduction, power generation from renewables (wind, solar PV, concentrated solar, waste-to-power, biomass, large and small hydro), more efficient fossil fuel combustion, and hybrid off-grid solutions.

The process of defining the content of the low-carbon scenario involved evaluating the resource potential of each relevant technology option, projecting the impact of each option on the LCOE for each year in the study period, assessing the barriers to introduction, and carefully selecting the most favorable mix of technologies for inclusion. The analysis used criteria such as cost minimization, balancing intermittent solar and wind with dispatchable gas and hydro, and seizing opportunities to build a geographically balanced portfolio of generation sources and adding robustness in the face of uncertainties in fuel prices, the cost and availability of renewables, and the contribution of hydropower given increasing variation in levels of rainfall.

Combined Cycle Natural Gas

Nigeria's large reservoirs of natural gas make it natural that gas turbines will continue to play a major role even in a low-carbon scenario. In this scenario, most new gas turbines would be CCGT, which have higher capital costs than single-cycle gas turbines, but as fuel prices increase, generate electricity at lower LCOE and with lower emissions due to their greater efficiency. Despite its potential, CCGT will not often be spontaneously adopted by private-sector investors due to barriers to financing. In Nigeria, the tariff level offered under the Multi-Year Tariff Order (MYTO) by the National Electric Regulatory Commission (NERC) is currently being restructured to encourage more private-sector CCGT investment.

Supercritical Coal with CCS

The low-carbon scenario assumes that 5 GW of supercritical coal with CCS is added into the technology mix in the outer years. This assumption is based on expert judgment drawing on consultations with Nigerian agencies and World Bank staff and comparison with other countries. The inclusion of CCS allows for the offsetting of emissions from coal-fired power plants, thus offering potential for emissions reduction over time, but with a notable increase in fuel use and capital costs.

Large Hydropower

According to the ECN (Zarma 2006) Nigeria has a great potential for hydropower. Large hydropower currently accounts for over 20 percent of the total installed commercial electric power capacity. Hydropower is capable of load following to generate power when needed to compensate for peak demand and when other renewable sources are not available. The reference scenario assumes reaching 7.2 GW of hydropower by 2025. The low-carbon scenario should make use of the maximum potential for large-scale hydropower available, presently estimated by the ECN at 11.2 GW.

Wind

The potential for wind power has yet to be well-characterized for much of Africa and for Nigeria in particular. The Africa Wind Atlas prepared by the African Development Bank (AfDB 2004) gives average wind speed on a coarse meso-scale 50-kilometer grid based on a simulation model rather than direct measurement.

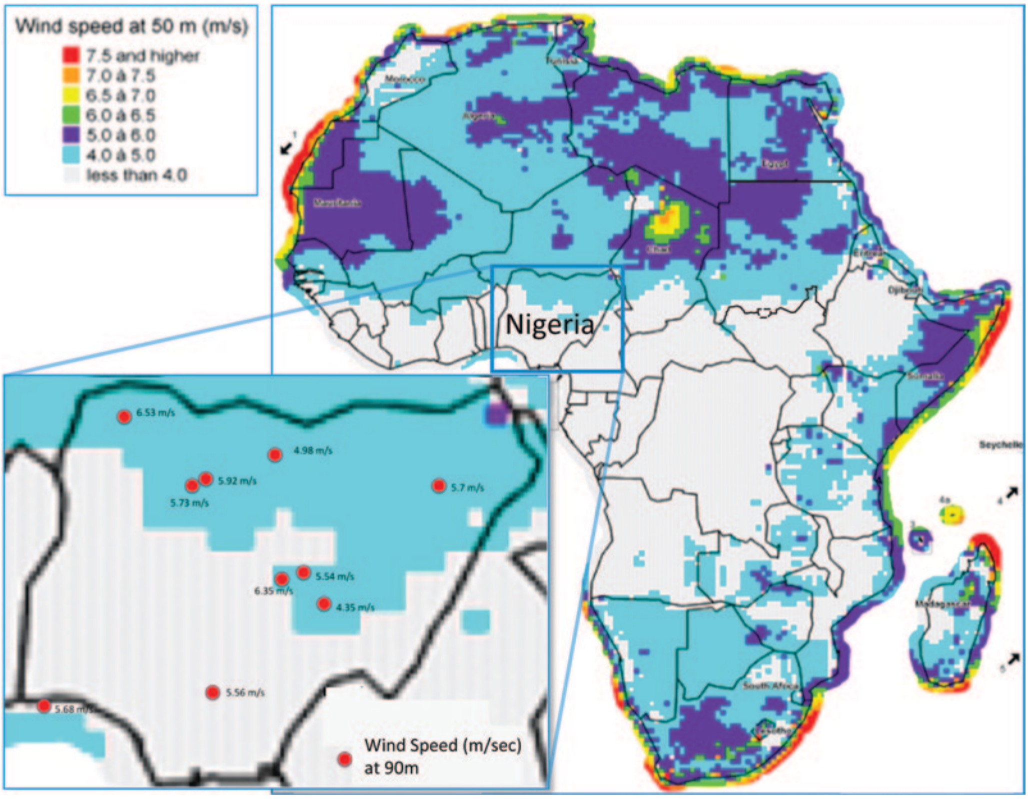
The atlas (see map 6.1) estimates average wind speeds of 4–5 meters/second at 50 meters' height in Northern and West Central Nigeria, which has been corroborated by limited measurements performed in 2005 by the Federal Ministry of Science and Technology (FMST 2005). The study team extrapolated these wind speeds to a height of 80 meters, more relevant for utility-scale wind farms in Nigeria. These results are roughly consistent with the meso-scale Africa Wind Atlas, except for Ninth Mile Corner (Enugu).

The study estimates that Nigeria has a potential for 19 GW of wind turbines producing about 50 gigawatt-hours (GWh) per year, mostly in the Northern and West Central regions. Expanding the fraction of suitable land developed from 1 to 2 percent of course would double these quantities. However, there is an urgent need for more extensive wind speed measurements to identify the most promising areas for wind development.

Concentrated Solar Power (CSP)

The potential for solar power, both CSP and PV, is better characterized than wind, since it is possible to get reasonable estimates from satellite observations. Due to its reflective design, CSP requires direct solar radiation, usually measured as direct normal irradiation (DNI). CSP developers typically suggest a minimum DNI of 1,500 kilowatt-hours per square meter per year (kWh/m^2/year) (Fluri 2009) or 2,100 kWh/m^2/year (IEA 2010a) for commercial viability. The northern, especially northeastern, regions of Nigeria are most suitable for CSP projects with DNI between 1,900 and 2,300 kWh/m^2/year (map 6.2), similar to Spain, the world's second largest developer of CSP.

Map 6.1 Average Wind-Speed Map for Africa and Nigeria



Source: Amended map, based on the Africa Wind Atlas, AfDB 2004.
Note: Average wind-speed at 50 m height as simulated by meso-scale (50 km grid) model from Africa Wind Atlas. Inset: expanded view of Nigeria overlaid with average wind speed at 90 m at 10 locations (red dots), extrapolated from measurements.

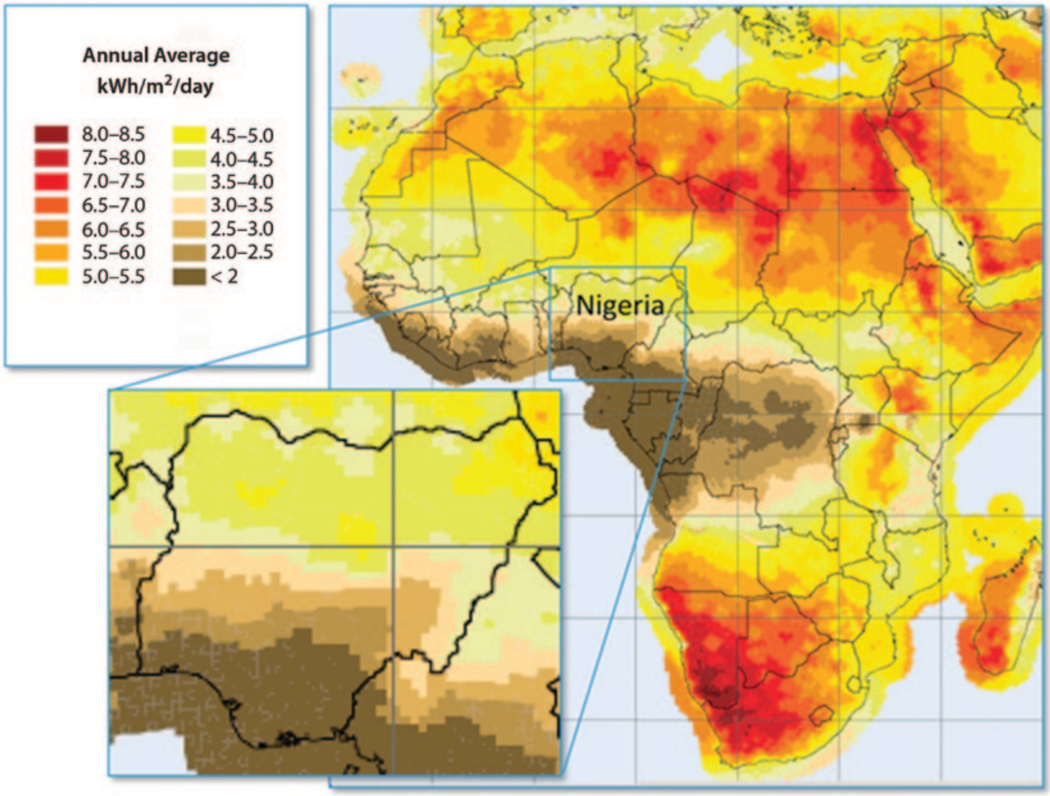
The study estimates that the fraction of each northern state suitable for CSP, eliminating areas with a slope greater than 3 percent, results in a total potential of 27,000 terawatt-hours (TWh) per year or 428 GW. These numbers are far greater than the plausible demand in Nigeria, implying that the CSP potential is limited by demand and capital rather than physical limitations of sun or land.

CSP may also be supplemented with gas in an integrated combined-cycle system to generate power during extended cloudy periods. However, integrated CSP and gas would require extending gas pipelines to the areas in northern Nigeria most suited for CSP, which is currently not part of the FGN's plans.

Solar Photovoltaics

Like most tropical regions, Nigeria has abundant solar radiation. Map 6.3 shows solar irradiation levels for Nigeria using the flat plate tilted at latitude at a 40-kilometer resolution (NREL 2005). This metric includes direct and diffuse radiation, appropriate for photovoltaic panels at the optimal fixed tilt for that

Map 6.2 Nigeria's Annual Direct Normal Solar Radiation for CSP



Source: NREL 2005. Adapted for this study with enlargement of Nigeria.

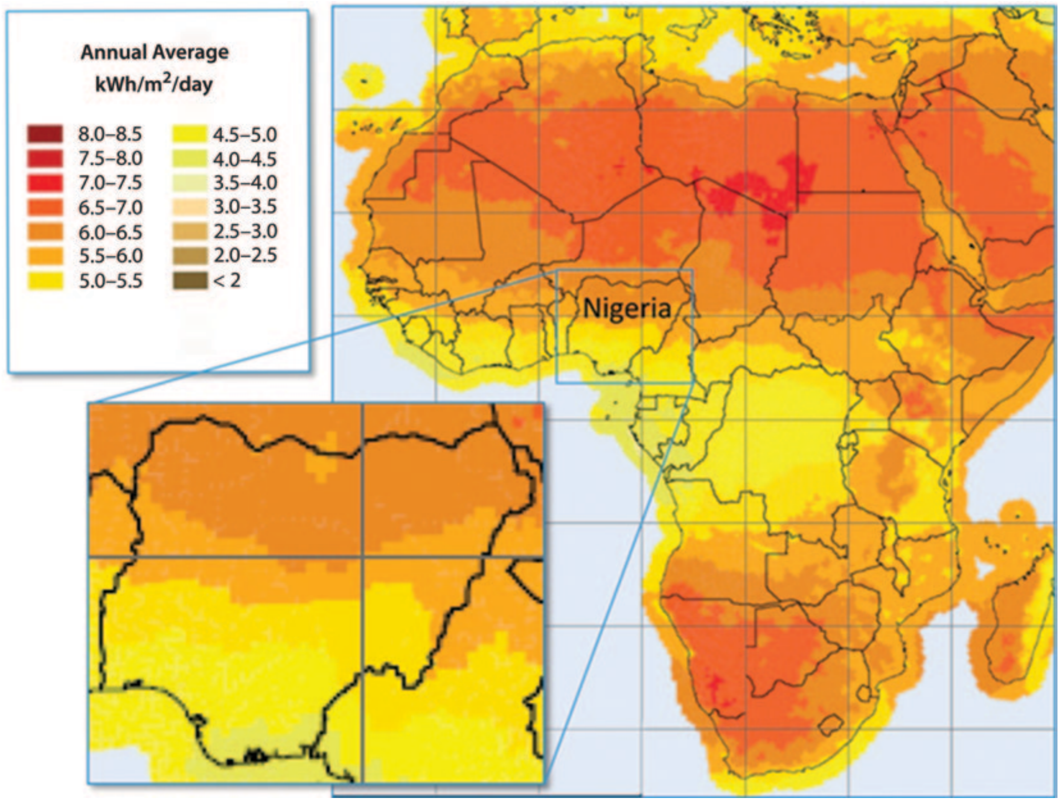
latitude. Using this metric, the radiation is adequate for PV, even in the South, in the range 1,500–2,000 kWh/m^2 per year.

The average solar irradiation in Nigeria is 2011 kWh/m^2 per year. Covering 1 percent of the land area of Nigeria would produce about 1,833 TWh/year of energy with an installed capacity of 1,046 GW.[1] This simple calculation makes clear that PV in Nigeria, like CSP, is not limited by the resource potential. The actual capacity installed will be constrained by capital costs and energy needs.

Waste-to-Power, Biomass, and Small Hydro

Other sources of power include using municipal waste to generate methane to generate power, combusting other biomass to make power, and small-scale (micro or pico) hydropower. Their potential is summarized in table 6.6. These technologies are promising and advantageous with suitable local conditions, and are well worth pursuing. However, their total potential is relatively modest compared to the overall demand for power.

Map 6.3 Insolation Levels for PV Power in Nigeria



Source: NREL 2005. Adapted for this study with enlargement of Nigeria.
Note: Map is based on average annual flat plate tilted at latitude.

Table 6.6 Potential Contribution from Waste-to-Power, Biomass, and Small Hydropower

	2015		*2025*		*2035*	
	GW	*GWh/year*	*GW*	*GWh/year*	*GW*	*GWh/year*
Waste-to-power	0.00	0	0.01	87	0.04	350
Biomass to power	0.25	1,643	1.00	6,570	2.00	13,140
Small hydro[a]	0.10	526	3.00	15,770	3.40	17,870

Source: Calculations based on data from UNIDO 2011 and USEPA 2010 and data listed in the chapter 3 references.
a. This calculation assumes 60 percent system efficiency.

Low-Carbon Generation Mix

The generation resulting from the technology mix defined in the low-carbon scenario is shown in table 6.7, and compared to the reference scenario. Over time, the alternative scenario develops a more diverse portfolio of technologies than the reference scenario. Grid-connected technologies still include a substantial amount of gas, but with a larger proportion of CCGT, because their greater efficiency results in a lower cost of generation than SCGT at projected higher gas prices, and somewhat lower emissions.

Table 6.7 Generation Capacity Mix in the Reference and Low-Carbon Scenarios

	Base	*Reference scenario*			*Low-carbon scenario*		
	Installed capacity (GW)						
Technologies	*2010*	*2015*	*2025*	*2035*	*2015*	*2025*	*2035*
Grid [a]							
Gas single cycle	6.5	18.2	30.2	51.8	16.7	15.8	15.6
Gas combined cycle	1.1	1.7	4.8	20.7	1.7	11.4	36.6
Coal subcritical	0.0	0.0	3.3	10.0	0.0	0.0	0.0
Coal carbon capture and storage	0.0	0.0	0.0	0.0	0.0	2.0	5.0
Hydropower	1.9	2.0	7.2	7.2	2.0	8.2	11.2
Biomass power	0.0	0.0	0.0	0.0	0.3	1.0	2.0
Concentrated solar power	0.0	0.0	0.0	0.0	0.1	1.7	10.0
Nuclear	0.0	0.0	1.0	1.0	0.0	0.0	0.0
Solar photovoltaics	0.0	0.0	0.0	0.0	0.1	1.7	10.0
Wind turbine	0.0	0.0	0.0	0.0	0.2	2.9	10.0
Off-grid							
Gasoline generator	1.3	2.6	4.9	6.3	2.5	2.9	4.2
Diesel generator	3.1	4.6	9.6	18.8	4.4	7.0	6.2
Gas turbine	0.0	1.3	7.0	12.6	1.2	2.9	5.2
Small hydro	0.0	0.0	0.0	0.0	0.0	1.5	3.6
Solar photovoltaics	0.0	0.0	0.0	0.0	0.1	5.9	16.3
Hybrid PV-wind-diesel	0.0	0.0	0.0	0.0	0.1	2.9	11.4
Total	13.9	30.4	67.8	128.3	29.3	67.7	147.5

a. Less than half of the 2010 installed capacity was actually utilized due to lack of fuel, inadequate maintenance, and other problems.

In 2015 the low-carbon scenario adds 100 MW each of PV, CSP, wind, and biomass power. These are intended as demonstration projects to evaluate their technical and economic viability in Nigeria and to build local expertise to enable rapid adoption of these renewable energy sources as soon as they become economically viable. The scenario projects further addition of these grid-connected renewable technologies by 2025 and more substantial capacity by 2035, reflecting the anticipated reduction in costs to reach "grid parity" during that time. It includes a more aggressive expansion of hydropower, which provides low-carbon electricity and is also dispatchable to balance intermittent solar and wind power.

Off-grid capacity, as described above, includes a more rapid addition of PV and hybrid, since they are rapidly becoming less expensive than diesel and gasoline generation, respectively reaching 16 GW and 11 GW by 2035. Off-grid generation is currently mostly for backup or replacement of unreliable grid power. Expanding off-grid generation in rural villages and towns away from the grid will supply pumping, irrigation, and public lighting, followed by residential applications and light industry associated with food and agriculture. The low-carbon scenario projects similar total capacity to the reference scenario up to 2025. It needs a higher total of 147 GW in 2035 to compensate for the lower capacity factors of solar, wind, and hybrid systems.

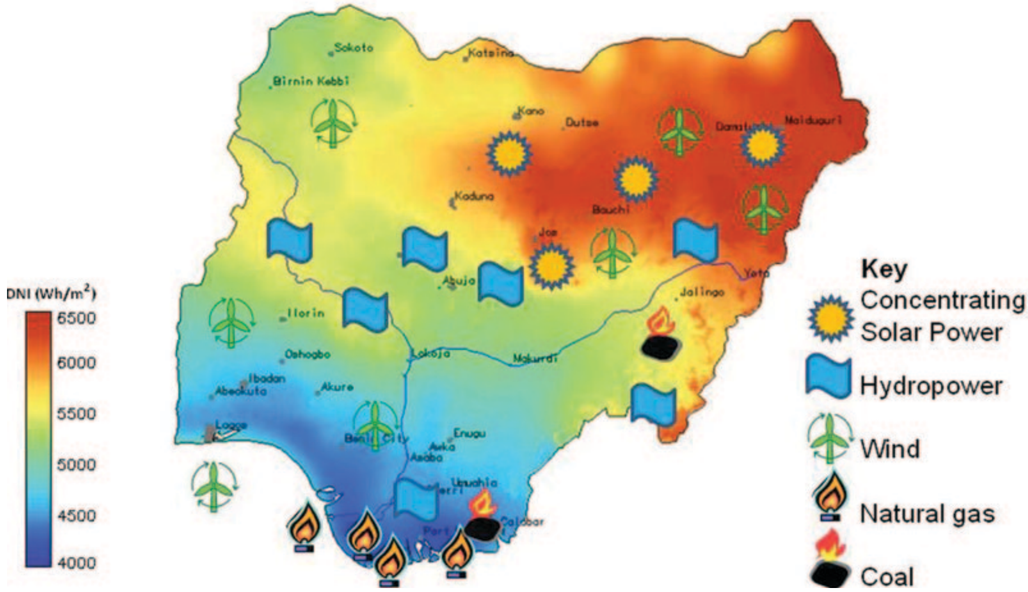
An important feature of the low-carbon scenario is that it entails a significant degree of diversification of energy sources across the national territory with grid generation near load centers in key regions (map 6.4). In particular, oil and gas are concentrated in the South and offshore, hydropower in central and southern Nigeria, coal deposits in the South and East, direct solar radiance for CSP in the Northeast (orange areas), good PV potential in most areas, and promising wind sites in the North and offshore.

As the country with Africa's largest population, with substantial revenues from oil and gas and a wide diversity of energy resources, Nigeria has the potential to become a regional leader in the energy technologies of the future. Growth prospects for grid-based solar power (PV and CSP) are significant: according to the EIA's *International Energy Outlook* 2011 (USDOE 2011) solar power generation will grow 10 percent a year worldwide in the next 20 years, but 24 percent a year in Africa. By investing early enough in renewable energy, Nigeria has the opportunity to become a regional leader in a quickly expanding market, and perhaps of establishing itself as a regional hub for technology development and deployment in the rest of Africa.

Demand-Side Measures in the Low-Carbon Scenario

Improvements in energy efficiency (EE) are often the most cost-effective options for reducing carbon emissions. The "costs" are often negative, that is, efficiency improvements pay for themselves within a few years or even months,

Map 6.4 Diversification of Energy Sources in the Alternative Case Scenario



Sources: PVGIS © European Communities, 2001–12, HelioClim-1 © MINES ParisTech, Centre Energetique et Procedes, 2001–08, amended and reproduced by the study team with the permission from PVGIS; further permission required for reuse.
Note: Map color represents Direct Normal Irradiation (DNI), a measure of solar intensity relevant to concentrated solar power (CSP). The map provides a stylized illustration of the distribution across Nigeria of sources of energy. Oil and gas are concentrated in the South and offshore; hydropower in central and southern Nigeria; coal deposits in the South and East; direct solar radiance for CSP in the Northeast (orange areas); good photovoltaic (PV) potential is found in most areas; and promising wind sites in the North and offshore.

even ignoring the benefits of reduced emissions. The advantages of EE programs are even more dramatic when electricity is expensive, for example, from off-grid generators or when the grid is capacity-constrained, as in Nigeria. Programs to improve EE include using compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs) instead of inefficient incandescent lights; clear labeling to help consumers understand the cost savings from efficient equipment; and efficiency standards for refrigerators, air conditioning, and other appliances. There are also programs to use more energy-efficient industrial equipment, including electric motors, chillers, and heaters. The ECN in partnership with the UN Development Programme (UNDP) has recently initiated a 4-year program to promote EE in the residential and public sectors in Nigeria (UNDP 2011).

In addition to end-user savings, demand-side EE measures can reduce the need for new generating capacity and its large associated capital costs. Assuming lighting is used at peak load, typically at 17:00–21:00 hours in Nigeria, each CFL can reduce peak demand by 46 watts per bulb compared to a 60-watt incandescent. The CFL's upfront capital cost is about US$51/kW (at a cost of US$2.33 per bulb). In comparison, the lowest capital cost of new generation capacity is US$408/kW for diesel generators and US$816/kW for grid-connected open cycle gas turbines (OCGTs), factors of 8 and 16 times, respectively. The low-carbon scenario assumes a lighting efficiency program, including an eventual ban on incandescent lamps, and replaces 50 percent of these lamps by 2016, increasing to 98 percent by 2020. Such a lighting program would decrease total electricity demand by 9.9 percent in 2020, including 4.4 percent on-grid and 5.5 percent off-grid.

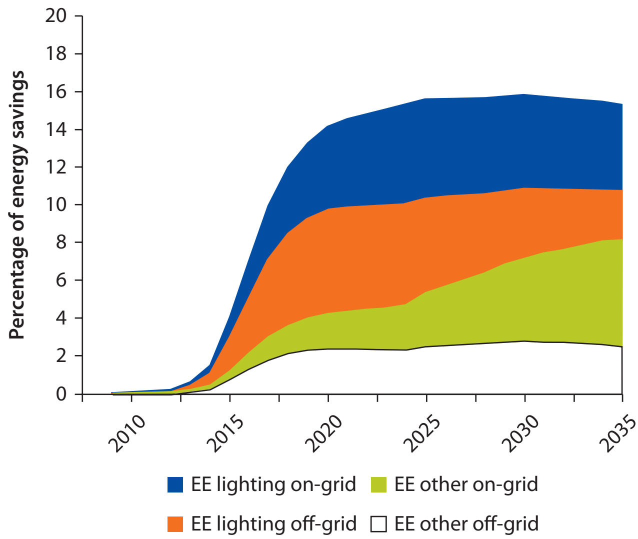
The proportion of electricity used for lighting tends to be high in economies with low gross domestic product (GDP) per capita and reduces as the economy becomes more developed. The ECN (2010) estimated that 48 percent of the nation's power was used for lighting in 2009. This is high relative to estimates for other countries, such as 10–15 percent in South Africa (Henderson 1997) and 13–29 percent in India (Mills 2002), but comparable with estimates for other countries in the Economic Community of West African States (ECOWAS), including Benin (41.9 percent), Burkina Faso (52.4 percent), Mali (31.8 percent) and Senegal (36.1 percent) (de Gouvello, Dayo, and Thioye 2008). For this study, the team estimates conservatively that 32 percent of power was used for lighting in 2010, decreasing to 23 percent in 2035. Much of the remaining fraction of electricity is used in different types of appliances. Appliance efficiency standards could significantly reduce electricity consumption. Negligible data are available in Nigeria on appliance energy consumption—which will soon be rectified through the ECN/UNDP program—so this analysis draws on other sources, such as a World Bank study of the potential of EE measures in India, which projects a reduction in demand by 2031 of 23 percent in residential use and about 10 percent each in commercial and industry applications and other programs for Latin America where savings range from 20 to 40 percent in Mexico, Brazil, and Argentina (UNDP 2000). The largest residential appliance energy savings come from improvements in refrigerators, televisions, fans, and—as income grows—air conditioning. Since most appliances are imported, a "top runner" program like that in Japan, in which the most efficient model on the market is used to set future efficiency standards, would also make sense.

The study ignores rebound effect in which the use of more efficient devices might lead to increased usage. Figure 6.9 shows the potential energy savings from EE programs as a percentage of reference case energy demand.

Lower Power Costs in the Low-Carbon Scenario

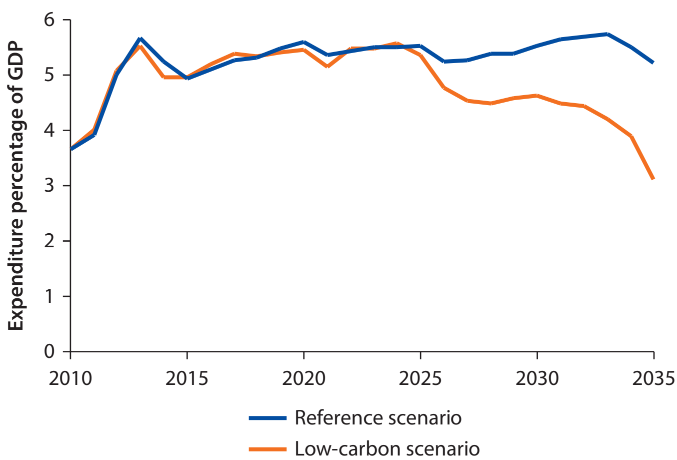
Long-term projections of costs of different generation technologies are inevitably uncertain, but the difference in LCOE separating renewable from thermal generation is likely to decline over time. The prices of natural gas and diesel in Nigeria are expected to increase from submarket rates toward "export-parity" and "import-parity," respectively. They are then expected to increase further with global fossil fuel prices, as projected by the U.S. Department of Energy (USDOE 2011). At the same time, the economies of scale and the learning curves are expected to reduce the costs of renewables. The total expenditures on generation of electricity over time for the two scenarios are shown in figure 6.10.

Figure 6.9 Potential Energy Savings from EE Programs in the Low-Carbon Option
% of reference case energy demand



Source: Calculations based on data sources listed in the chapter 3 references.

Figure 6.10 Total Annual Electricity Expenditure[a] for Reference and Low-Carbon Scenarios as Percentage of GDP

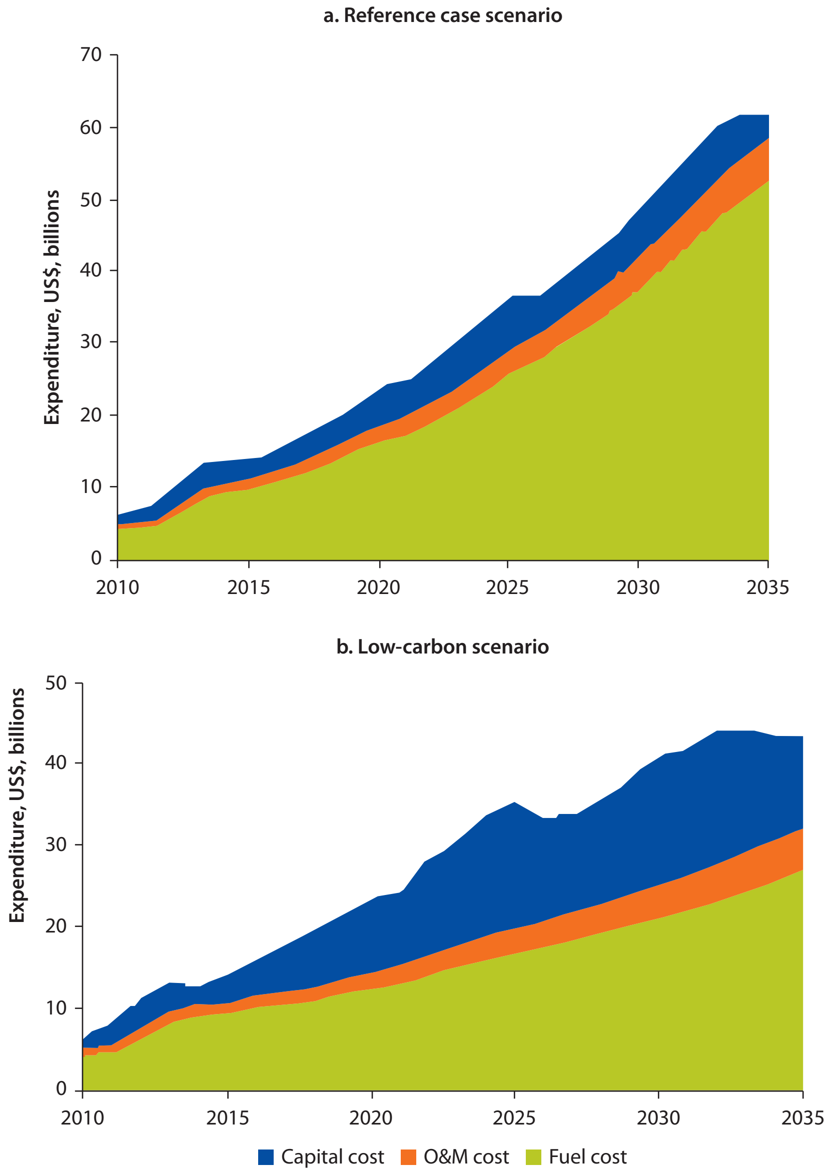


Source: Calculations based on data sources listed in the chapter 3 references.
a. Total annual expenditure includes capital, operation and maintenance, and fuel costs.

For both scenarios, the total cost increases from about 3.5 to 5.5 percent of GDP in 2013, reflecting the ambitious expansion and consequent capital expenditures planned in the Roadmap (FRN 2010).

After 2016 expenditures diminish as a percentage of GDP. The two scenarios remain very close until 2025. After 2025 the low-carbon scenario is consistently

Figure 6.11 Breakdown of Total Expenditure into Capital, O&M, and Fuel Costs



Source: Calculations based on data sources listed in the chapter 3 references.

lower in cost. This reflects savings from EE programs and, in later years, from the lower operating costs of renewable power, especially off-grid.

Figure 6.11 breaks down the total costs for the two scenarios by capital, operation and maintenance (O&M), and fuel costs. It clearly shows how capital costs are significantly larger for the low-carbon scenario, but that these are outweighed by its much lower fuel cost after 2025, resulting in noticeably lower NPV total costs.

GHG Emissions Reduction in the Low-Carbon Scenario

The wedge chart in figure 6.12 shows the reduction in emissions in each year as a result of implementing the low-carbon scenario. The topmost line shows the emissions from the reference scenario, reaching 372 million metric tons (Mt) CO_2e per year in 2035.

The bottom cross-hatched area shows the emissions from the low-carbon scenario reaching 164 Mt CO_2e/year in 2035. This is a reduction of 56 percent in annual emissions in 2035 or a reduction of 43 percent in cumulative emissions from 2010 to 2035.

The "wedges" located between the reference emissions line and the low-carbon area represent emissions avoided by the different low-carbon interventions. The interventions include abatement from EE for on-grid and off-grid lighting, respectively; other EE options; savings in emissions from CCGTs relative to OCGTs; and grid-based wind, PV, and CSP. The largest contributors to total abatement comprise off-grid PV and hybrid photovoltaic/wind/diesel.

Assumptions about Costs of Fossil Fuel and Renewables

While the cost assumptions in the low-carbon scenario are consistent with recent projections of a variety of credible international sources, including IEA (2011), USDOE (2011), and DECC (2011), inevitable uncertainty remains regarding the future domestic and export prices of fossil fuels and about the future capital cost of renewables. To evaluate these assumptions, the team used a sensitivity analysis to explore a "delayed low-carbon scenario" in which adoption of renewables is delayed by 5–10 years due to lower fuel prices and slower learning curves.

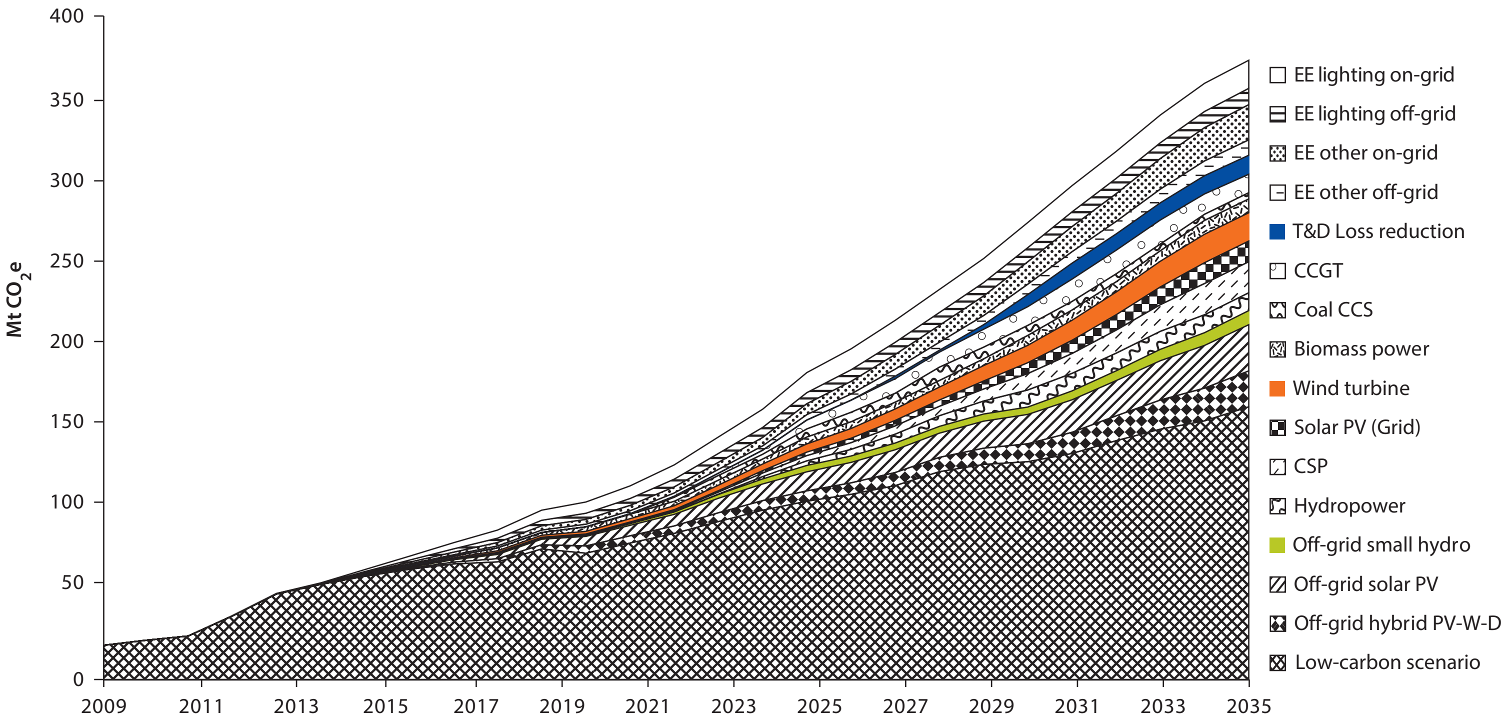
This scenario reduced cumulative emissions through 2035 by 40 percent relative to the reference scenario, compared to a 43 percent reduction in the original low-carbon scenario. It cost about the same as the original low-carbon scenario and slightly more than the base case. This implies substantial robustness to key uncertainties of the main findings of the analysis.

Sensitivity Analysis of the Effects of GDP Growth on Emissions

Long-term economic growth is hard to forecast. To capture this uncertainty, it is useful to consider, in addition to the "high growth" projection assumed for the study's reference scenario, a "medium growth" scenario (where the economy grows at a constant annual rate of 6 percent); as well as the more ambitious "Vision 20: 2020 growth" target, in which the economy grows at an annual rate of 13 percent through 2020 (see chapter 3 for a more detailed discussion of these scenarios).

Table 6.8 explores the effects of these three alternative GDP growth cases at the horizon year 2035. The resulting total GDP varies by a factor of 2 from $801 billion for the medium growth case up to $1,623 billion for the Vision 20: 2020

Figure 6.12 Projected Reductions of Emissions in the Low-Carbon Scenario



Source: Calculations based on data sources listed in the chapter 3 references.

Table 6.8 Effect of GDP Growth Cases in 2035 on Power Demand and Emissions for Reference and Low-Carbon Scenarios

GDP growth cases	*Medium growth*	*High growth*	*Vision 20: 2020*
GDP ($billions)	801	1,183	1,623
Change in GDP from high growth (%)	–32	0	37
Change in elec. demand for reference scenario (%)	–44	0	59
Emissions for reference scenario (Mt CO_2e/year)	210	371	590
Emissions for low-carbon scenario (Mt CO_2e/year)	92	164	260
Percent reduction in emissions from reference to low-carbon scenario	56	56	56

Source: Calculations based on data sources listed in the chapter 3 references.

case, compared to the $1,183 billion for the high growth reference case. Assuming the same population, this implies that per capita income would decrease by 32 percent for the medium growth case or increase by 37 percent for the Vision 20: 2020 case. The elasticity of demand for electricity per capita with respect to income per capita of 1.46 (estimated from the cross-country analysis in figure 6.1) implies that electricity demand would decrease by 44 percent or increase by 59 percent, respectively, relative to the high growth GDP case.

The next two rows of the table show the resulting effect of GDP growth on the total emissions for the reference and the low-carbon scenarios. They are projected to decrease or increase in direct proportion to the electricity demand, assuming that the percentage mix of generation technologies and EE options in 2035 remain the same (in these scenarios). While the changes in absolute emissions are substantial relative to the high-growth GDP case (decrease of 44 percent or increase of 59 percent), it is interesting that the *percentage* reduction in emissions from the reference to low-carbon scenario at 56 percent is unaffected by the GDP growth rate.

Recommendations for the Power Sector

Table 6.9 summarizes the recommendations for a low-carbon plan for Nigeria, divided into near term 2012–15, and mid-term to 2020. The immediate priority must be to expand generation and grid capacity in accordance with the Roadmap. Not only is an adequate electricity supply essential for economic growth, but it will start to reduce carbon emissions by replacing some off-grid diesel generation with more efficient and lower-cost gas turbines.

The low-carbon scenario projects capacity mix by technology to 2035. It is intended to indicate one possible future, not as specific recommendations about what *should* happen. Future decisions should be based on the evolving situation and information available when they must be made, especially the relative costs and practicality of energy resources and technologies.

Table 6.9 Recommendations for the Power Sector

	Near term: 2012–15	*Mid-term: 2015–20*
Improve energy data	Survey off-grid energy use and generation Survey power consumption Measure wind resources Share energy data online	
Energy efficiency (EE)	Promote efficient lighting (CFLs) Develop appliance efficiency standards Promote energy literacy and education programs Create efficiency incentives	
Grid-connected power	Barge-mounted gas turbines for rapid, flexible deployment Amend MYTO to incentivize CCGT via conversions and new builds Actively develop plans for large-scale renewables, especially hydro, but also large demonstration projects for PV, CSP, and wind	Expand hydropower Expand combined-cycle gas generation Demonstration projects for grid-connected PV, CSP, and wind.
Off-grid power	Promote solar PV for water pumping, irrigation, and lighting Promote natural gas where available to replace diesel	Promote solar PV and hybrid for other applications Develop small hydro
Integrated planning process	Develop a comprehensive, spatially disaggregated engineering systems analysis of generation, grid, and off-grid as a basis for long-range planning Consider siting of renewables when expanding power grid	Integrate planning for gas and CSP Encourage integration of distributed generation into the grid
Policies	Let prices of fossil fuels revert to global market prices and let electricity tariffs reflect full costs (already happening) Design net-zero, feed-in tariffs (FITs) and other incentives for low-carbon options Develop policies to promote off-grid hybrid and renewables Develop human resources for low-carbon technology and businesses Build demonstration and training projects Develop financing mechanisms	

Recommendation: Establish Supply Side Opportunities

- **Create incentives for high-efficiency CCGT** both via conversions of existing plants and new builds; this could be done by amendments to the MYTO (new tariffs) for CCGT generators, to offset their higher capital costs.
- **Actively develop large-scale renewables** (including hydropower plants, PVs, and perhaps wind) with a full feasibility analysis for three major projects to be ready for construction by 2014.
- **Develop a concrete policy framework to promote off-grid hybrid and renewable energy generation.** This framework might include exemptions from tax and import duties, and light touch regulation for renewable projects under 10 MW for renewables.

Recommendation: Promote Energy Efficiency with Short-Term Actions

As discussed earlier, EE projects can have a major near-term synergistic value when expanding access to power by reducing rate of growth in demand at a dramatically lower cost per peak watt than new generating capacity. Key programs might include the following:

- National roll-out of a program to promote CFLs;
- Acceleration of consumer metering program; and
- Implementation of EE standards for appliances and industrial machinery.

Specific activities to establish these programs follow.

Recommendation: Improve Energy Data

To develop a low-carbon plan to reflect actual conditions in Nigeria, rather than estimates adapted from other countries, there is a need for additional data to fill in critical gaps. Key areas include:

Action Recommendation: Survey Off-Grid Generation

While it is clear that a large fraction of the power in Nigeria is currently generated off-grid, little reliable data exists on the quantity, sizes, efficiency, and utilization rates for captive generators of various types, fueled by petrol, diesel, and natural gas. A survey could better estimate the contributions by each off-grid category, including (1) backup for the grid, full-time captive generation with (2) large generators and (3) small generators, and (4) generation in rural areas with no grid access. A well-designed survey should examine captive generation by residential, commercial, industrial, and institutional consumers in urban and rural areas around the country. The results would provide a solid basis for planning and evaluating programs to improve design of grid expansion to improve accessibility of power, and to coordinate planning for off- and on-grid generation, including future distributed generation as a complement to grid power.

Action Recommendation: Survey Power Consumption

Data are also very limited on the relative power consumption for lighting, appliances, cooling, and other applications. The ECN in partnership with Global Environment Facility (GEF)–UNDP has recently initiated studies to inventory the quantity, type, and energy rating of lighting, refrigeration, air conditioning, and other appliances (UNDP 2011). The survey includes a sample of 300 residential and 50 public buildings. The goal is to determine the market and energy-saving potential for CFLs and other improvements in EE. These studies are part of a 4-year project to promote EE in the residential and public sectors. It would be valuable to combine this survey of on-grid consumption with a survey of off-grid and rural generation and consumption to understand how usage patterns vary with source of generation.

Action Recommendation: Measure Wind Resources

Solar potential can be estimated remotely from satellite observations, but terrestrial measurements are needed for reliable estimates of wind potential. Data thus far are limited on the potential for wind power in Nigeria; measurements have been made at only 10 sites (FMST 2005) The Africa Wind Atlas (AfDB 2004) estimates for Nigeria are based on simulations rather than direct measurements. Since wind power goes up as the cube of wind speed, economic viability is highly sensitive to average wind speeds, which can vary substantially from one site to another within the same region (Vaughan 2011). A high-resolution wind atlas of Nigeria including offshore areas is urgently needed to obtain an accurate picture of wind potential and to identify the most suitable sites.

Action Recommendation: Empower Sharing of Energy Data

Finding existing data and projections for energy in Nigeria is often challenging. Many organizations are involved in collecting data, conducting studies, and developing plans related to the Nigerian energy sector, including government ministries, commissions, and other parastatals; companies; consultants; and NGOs; as well as international organizations, such as the IEA, the UNDP, and the World Bank. A unified online resource in which these organizations could find and share data, projections, and reports for the Nigerian energy sector could greatly facilitate and coordinate this work. The ECN is the natural organization to perform this task: One of its mandates is to gather, analyze, and disseminate information on energy, and to develop a national energy databank. To this end, there is a demonstrated need to achieve a continuing stream of data for measurement, reporting, and verification (MRV) purposes and to provide an accurate and up-to-date foundation for policy planning.

Energy Efficiency Recommendations

Improvements in EE are the lowest-cost options for reducing carbon emissions, since they pay for themselves in reduced energy costs, often in only months. Improving EE in Nigeria can improve grid reliability and enable limited power to serve more consumers, while saving funds, especially off-grid. EE programs should be the first priority for a low-carbon development plan. Key elements follow.

- **Promote CFLs and LEDs,** and consider banning sales of incandescent lamps.
- **Develop efficiency standards** for common appliances, including refrigerators and air conditioners, with phase-out of sales of less efficient appliances. Since most appliances are imported, a "top runner" program, as in Japan, using the most efficient model on the market to set future efficiency standards, would make sense.
- **Develop energy literacy and education programs** for schools, communities, and religious organizations on the value of using efficient appliances for the consumer and the community.
- **Create incentives** for utility companies and electricity retailers to promote EE to their customers instead of maximizing power usage.

Grid-Connected Power Recommendations

The immediate focus for grid-connected capacity is to refurbish existing gas turbines and hydropower generators and to build new ones. Some additional elements to be considered in the intermediate term as part of an integrated low-carbon plan are as follows.

Action Recommendation: Barge-Mounted Gas Turbines

Many areas with high population and electricity demand, such as Lagos and parts of the Niger Delta, are in coastal areas near natural gas pipelines, which may be supplied by barge-mounted OCGTs. Their immediate advantage over building land-based generators is that they are relatively inexpensive and can be purchased or leased, shipped and moved into place, and put online much more rapidly. Their longer-term advantage is that they may be moved or sold when better options become available, such as CCGTs or renewables. In this way, they enable energy planners to retain the flexibility to adapt to future opportunities with low upfront cost.

Action Recommendation: Expand Hydropower

Large-scale hydropower is generally competitive with fossil generation where rivers and topography offer the potential—and it has near-zero carbon emissions. Some existing hydropower facilities are not generating at full capacity due to poor maintenance. Other facilities could be expanded. Generation capacity can be sized to be greater than that required for average river flow so that power can be dispatched to meet peaks in demand. Rapid dispatchability may be even more valuable in the future as a complement to intermittent solar and wind energy. While hydropower projects promise low-carbon electricity, it is essential to consider the social and environmental impacts of large dams, especially putting in place appropriate measures to prepare for population displacement and resettlement.

Action Recommendation: Expand Combined-Cycle Gas Generation

While CCGTs have higher capital costs than SCGTs their greater efficiency reduces their fuel costs resulting in lower levelized cost as well as lower carbon emissions. Over time, it may make sense to shift to a higher proportion of CCGTs when adding new gas capacity. Existing SCGT plants may be retained to provide peaking power where their lower capital costs reduces their cost at lower utilization factors. This could be incentivized by adjusting new tariffs (MYTO) for CCGT, to offset their higher capital costs.

Action Recommendation: Develop Demonstration Projects for Grid-Connected PV, CSP, and Wind

It is likely that wind, PV, and CSP will reach grid parity in Nigeria during the next decade in the most suitable regions. To prepare for that time and to provide a realistic test of the technology and economics, Nigeria should develop large-scale grid-connected demonstration projects totaling about 100 MW each for PV, CSP, and wind before 2020. These projects would enable Nigerian planners, engineers, installers, and operators to develop expertise with these technologies so that the country is well-positioned to build new capacity as soon as they become economical, as well as to obtain greater clarity about when that time arrives. Financing for these demonstration projects might be obtained from CDM or other international funding mechanisms. Such an initiative would lay the foundation for expanding the grid to allow future connection of clean energy generation around the country.

Action Recommendation: Develop a Smart Grid for Nigeria

In developing countries like Nigeria where power grids have not been fully built, smart-grid technology presents a unique leapfrog opportunity to grow the power sector. This strategy entails skipping outdated traditional systems and starting with smarter, IT-based technology. Smart wireless meters offer more reliable accounting, can be integrated with efficient mobile-phone–based payment schemes, and can discourage power theft, which is a problem for Nigeria. Smart-grid technologies would also be helpful in managing supply intermittency from large amounts of solar and wind energy, and for integrating distributed and off-grid generation (Tongia 2009). While smart grids need additional investments, the expected growth in energy needs for Nigeria and the corresponding growth of power consumers are likely to help with return on investment.

Off-Grid Power Recommendations

Today less than 50 percent of Nigerians have access to the power grid. An estimated 50 percent of energy is generated off-grid, mostly by diesel-fueled captive generators. While expanding grid capacity, reliability, and coverage is a key priority, off-grid generation will continue to play a large role as an enabler of economic growth where grid power is insufficient or unavailable. The reference scenario projects that the fraction of electricity generated off-grid will fall to about 30 percent by 2035, but this still implies that the absolute amount of off-grid electricity will grow by a factor of 3.6 by 2025, due to the huge increase in total generation.

Historically, widespread use of off-grid power has been viewed as a sign of backwardness. However, in recent years, electricity planners in advanced economies are increasingly seeing advantages in off-grid and distributed generation as a valuable complement to the grid. Distributed generation can reduce the need for expensive and inefficient transmission lines. It can improve reliability and security of power supply. Microgrids, using distributed PV and hybrid generation, present a "leapfrog" technology by which emerging economies may jump directly to a more advanced technology, bypassing historical paths to industrialization. Nigeria has already done this in telecommunications, where mobile phones have leapfrogged conventional landlines. Telephone access in Nigeria increased over 100-fold in 10 years, from 867,000 lines (fixed and mobile) in 2001 to 94 million in 2011, reaching 58 percent of the population (NCC 2011).

Power systems are inherently more challenging to install than mobile telephone systems. But, arguably, rapid rollout would be easier for off-grid PV and hybrid systems, which can be purchased and installed more easily than grid-connected systems that depend on a chain of complex national-scale infrastructure. Furthermore, if enabling factors are carefully designed to draw private-sector investment to off-grid renewable options, it could potentially free up investment potential for longer-term options like smart-grid extensions.

PV and hybrid systems are already economically competitive for many off-grid applications. Gasoline and diesel generators produce power at LCOE between US$0.23 and $0.42/kWh. The cost of electricity from PV and hybrid PV-wind-diesel systems are in the range of $0.3/kWh and $0.22/kWh, respectively. As the costs of renewables continue down the learning curve, and fossil-fuel prices in Nigeria revert to global market prices ("export parity"), the economic advantages of renewables will become ever greater.

There are several areas in which the FGN could encourage independent power producers (IPPs) to expand low-carbon off-grid generation and microgrids as an essential complement to grid power. This can bring the benefits of electricity to rural areas without having to wait until the grid reaches them, which may be a long time.

Action Recommendation: Use Natural Gas Where Available to Replace Diesel

In areas where natural gas distribution pipelines are available, such as off-grid generation in urban areas, gas turbines are clearly preferable to diesel generators for reasons of both cost and carbon emissions. Small gas-powered turbines up to about 5 MW can generate power at about half the cost of off-grid diesel generators, with 54 percent of the GHG emissions. Even as natural gas prices increase toward export parity, overall generation costs will still favor gas over diesel.

Action Recommendation: Use Solar PV for Water Pumping and Irrigation

Initial deployments in Nigeria have confirmed the advantage of PV over diesel generators for pumping water for domestic use and irrigation (SELF 2008). Unlike other applications, there is no need for batteries or back-up power for such applications, since water is easy to store and intermittency is not a problem. Typically, small PV installations need less care and maintenance than diesel generators and do not need expensive fuel. These applications are "low-hanging fruit" for PV, providing substantial economic benefits to agriculture, while reducing vulnerability to changes in rainfall patterns.

Action Recommendation: Use Solar PV with Batteries and Hybrid PV-Wind-Diesel

For many other residential and commercial off-grid applications, PV and hybrid power generation are already competitive with small gasoline and diesel generators based on levelized cost. The cost advantages of PV with batteries, versus hybrids with diesel generators, and/or wind, vary by location, depending on solar and wind resources. However, PV modules and hybrid system costs are declining rapidly and so their advantages over pure fossil sources will increase over time.

Action Recommendation: Develop Small Hydropower

Small hydropower (micro- or pico-hydro) can provide low-cost and low-carbon power in those places where the resources are available. Dispatchable hydro is a valuable complement to intermittent solar and wind. A more extensive survey of resources would assist in identifying the most promising opportunities.

An Integrated Planning Process

As Nigeria expands its power system according to the Roadmap (FRN 2010), it will become increasingly important to develop a longer-range plan to integrate low-carbon options as part of a balanced portfolio of energy sources, on-grid and off-grid. An integrated plan can provide the robustness and flexibility to take advantage of low-carbon technologies as and when they become economically practical. Following are actions to be considered in the development of such a plan.

Action Recommendation: Comprehensive Electricity Systems Analysis and Planning

A comprehensive, spatially disaggregated engineering systems analysis of generation plants, load centers, and transmission networks is needed to develop detailed longer-range plans, both for reference and low-carbon options. It should include off-grid demand and generation to enable study of trade-offs between expanding the reach of the grid and expanding off-grid generation. Such an analysis will require much more comprehensive data than are currently available and was beyond the scope of this study.

Action Recommendation: Consider Siting of Renewables When Designing the Grid

Nigeria is planning an ambitious expansion of the capacity and coverage of the power grid. When selecting sites for generation and corridors for new and expanded transmission lines, it will be useful to consider not only existing and near-term additions to gas and hydro capacity, but also the future transmission needs for potential low-carbon capacity, especially new hydro, solar, and wind. For example, lines from the South to the North should be able to transmit gas-generated power from southern areas and hydro from central areas, but also potential future CSP generation from the North to the South. The comprehensive systems model can assist in evaluating power load and supply balances, especially with intermittent renewables and geographically distributed supply. Even if the future rate of adding renewable capacity is uncertain, developing the grid with those possibilities in mind retains the option for easy integration of renewables as soon as they become economically viable.

Action Recommendation: Integrate Planning for Gas and CSP

Even if Nigeria opts to build significant capacity of wind, PV, and CSP, gas will remain a key element of the energy mix. In particular, hybrid CSP and gas combined cycle provide an attractive combination, with gas using the same

CCGTs as a back-up when the sun isn't shining. For example, Turkey has recently approved the Dervish integrated solar combined cycle (ISCC) plant, which includes 50 MW CSP with 570 MW gas turbine to come on line in 2016. When gas pipelines reach the northern areas, selection of new sites for gas generation plants might consider locations with high solar intensity and sufficient land area to enable adding CSP as that technology becomes economical.

Action Recommendation: Encourage Integration of Distributed Generation into the Grid

As the national grid expands, it can take advantage of existing microgrids and distributed generation to expand more rapidly at lower cost to the grid. To accomplish this strategy, the national grid and its IPP suppliers should treat off-grid and microgrid generation IPPs as partners, not competitors. The FGN can encourage this with policies such as net-metering, feed-in tariffs (FITs) and accessible standards for technical system integration.

Recommendations for Policies and Facilitation

Even as low-carbon technologies become economically competitive in Nigeria, institutional, regulatory, and financial obstacles to reaping their full benefits may remain. The FGN has an important role to play in creating institutions, policies, and programs to remove these obstacles. Their design is a central part of developing a successful low-carbon plan. Key elements of such a plan follow.

Policy Recommendation: Let Domestic Prices of Fossil Fuels Gradually Revert to Global Market Prices

Regulated and subsidized low prices for natural gas and gasoline are subject to market distortion. They have unfairly disadvantaged alternative sources of energy, and, in the case of gas, have led to severe shortages for domestic power. The FGN has already taken action to reverse these problems by establishing policies in 2010 to let gas prices increase from a floor of $0.40/million British thermal units (MMBtu) for power usage, up to $1.00/MMBtu in 2013, although this is still significantly below export parity, which may be in the region of $3.00/MMBtu. Gasoline has been subsidized by the FGN, resulting in a drain of 1.2 trillion naira (US$7.4 billion) per year from the national budget, with most refined petroleum imported due to the poor state of Nigerian refineries. On Jan 1, 2012, the FGN tried to remove the subsidy on gasoline entirely which resulted in prices more than doubling. After the resulting unrest, they compromised by reducing subsidies by more than half. In the long run, it appears the FGN is already committed to allowing fuel prices to reach global prices.

Policy Recommendation: Let Tariffs Fully Reflect Electricity Costs

In 2002, electricity tariffs in Nigeria were among the lowest in the world, at US$0.043/kWh, a significant cause of the underinvestment in maintenance and new capacity. In 2009, the Multi-Year Tariff Order (NERC 2011) established the principle of cost recovery for each link in the supply chain—fuel, generation, transmission, distribution, and retail—so that prices should fully reflect costs by 2013. Adequate prices are essential to the successful privatization of each segment of the industry. Full market prices for grid electricity are also essential to provide incentives for the adoption of EE, renewable energy, and other low-carbon technologies. Additionally, full market prices for grid electricity are still much cheaper than for off-grid generation.

Policy Recommendation: Design Net-Zero, FITs, and Other Policies to Encourage Low-Carbon Options

Carefully designed policies and incentives could play a key role in encouraging adoption of cost-effective low-carbon technologies. A recent review of FITs, renewable portfolio standards (RPS), and Renewable Energy Certificates (RECs) in developing countries finds that policies have had mixed success (World Bank 2011a). FITs have proved effective in stimulating renewable energy, for example in India and Turkey, but the results are not always economically efficient. The study recommends tailoring policies carefully to the local situation, considering their interactions, adopting policies in sequence, and refining them over time in the light of experience. In tailoring policies for Nigeria, it will be valuable to review what has and has not worked elsewhere and why.

Policy Recommendation: Develop Human Resources

Successful development and execution of a low-carbon plan will require a growing corps of Nigerian scientists, engineers, policy analysts, and technicians with expertise in key technologies. Steps to build this corps might include establishing and expanding degree courses and R&D centers at key Nigerian universities, attracting overseas Nigerians back home with relevant expertise, creating regional technical training centers, and expanding a curriculum on energy and environment for secondary schools.

Policy Recommendation: Build Demonstration and Training Projects

The number of small-scale pilot and demonstration projects using PV has been growing in Nigeria, but PV and hybrid systems are still much less familiar than gasoline and diesel generators. Further deployments are essential for practical training of technicians and operators and to develop the markets. As renewables become more economically competitive, especially for off-grid applications, there is a growing business opportunity for new or existing firms and cooperatives to develop, install, and manage renewable off-grid generation. Programs to accelerate adoption and demonstrate its associated economic benefits could include studies to identify the most promising sites and technologies, additional demonstration projects, promoting training organizations, and developing financing mechanisms to encourage growth of these businesses. Once the business opportunities have been convincingly demonstrated and there are enough experienced people, the FGN should be able to step back from direct support and the private sector can take over, as has happened with mobile telephones.

Policy Recommendation: Develop Innovative Financing Schemes

Some off-grid applications of renewables may already be competitive with diesel generators in terms of LCOE at a 10 percent discount rate, and grid-connected renewables may become competitive over the next decade in selected applications. But their initial capital costs are still significantly larger than those of gas- and diesel-fueled generators. Businesses and residential consumers of electricity have been unable or unwilling to make such large upfront investments. There is a commercial opportunity for banks and larger businesses that can borrow at lower interest rates to provide financing to consumers for off-grid renewable generation. This strategy also creates a business opportunity to create microgrids run by small power companies or local cooperatives with the economies of scale and access to finance not directly available to individual consumers. Financing mechanisms may include the following:

- Low-interest loans for large and small low-carbon projects. As an example, the Nigerian Bank of Industry (BoI) has recently partnered with the UNDP to provide finance to micro, small, and medium enterprises (MSMEs) to support energy projects. According to Evelyn Oputu, Managing Director of BoI, "Women are the main beneficiaries of the BoI loan on MSMEs because women constitute more of MSMEs in Nigeria" (Business Day Online 2011).
- CDM offsets and other sources of international financing for low-carbon projects.
- Leapfrog funds from global mitigation finance channeled through international donors are poised to play a catalytic role in helping Nigeria realize its full low-carbon development potential (Eleri, Ugwu, and Onuvae 2011).
- Emerging mobile phone-based payment systems can support microfinance and payments for small off-grid systems, such as solar lighting. The Central Bank of Nigeria (CBN) has started a cashless project that is planned to reach 20 million Nigerians by the end of 2014. As a related example, Eight19, a solar light company based in the United Kingdom, is distributing solar lights in Africa for a modest (about US$10) initial payment, plus small periodic payments mediated by mobile text messages enabling purchase of systems at a lower periodic cost than kerosene for a lantern (Eight19.com).

Note

1. This calculation assumes a total land area of 911,521 square kilometers, an average PV conversion efficiency of 10%, and a 20% capacity factor.

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CHAPTER 7

The Transport Sector

Vehicle ownership in Nigeria is currently low by international standards, standing at approximately 29 cars per 1,000 people in 2010. However, aspiration for car ownership is high due to the status it conveys, and increasing income levels are expected to bring Nigeria into line with other countries based on expected per capita income levels. The resulting projected growth in car ownership is considerable, with a four-and-a-half fold increase expected by 2035. The combined impact of population growth and growing car ownership is expected to increase the private car fleet in Nigeria from 4.65 million to over 20 million over the forecast period. However, growth in public transport and commercial vehicle numbers and activity is expected to be even more pronounced.

Passengers traveling by public transport are typically served by paratransit minibuses known as *danfo*. These vehicles are usually privately owned and operated to serve the interests of the owner/operator, with intense competition among drivers. Worsening congestion and ever-increasing travel demand in the large cities means more vehicles on the road. Economic growth, including expanding manufacturing and service industries, is also increasing demand for freight transport. As a result, the reference scenario projects passenger and freight transport amounts to increase nine-fold between 2010 and 2035.

Road Transport in the Base Year

Nigeria's vehicle fleet is undergoing a slow evolution as vehicle emissions controls and import regulations come into force. Euro II standards (FGG 2011) were adopted at the end of 2011 for all new and imported vehicles. The import of two-stroke motorcycles was banned then, although import of large numbers of these high-polluting two-wheelers prior to the ban means that they are widespread in many parts of the country.

The existing vehicle fleet is made up of aging, high-polluting vehicles, with the majority imported from western countries only when they approach the end of their economic life. Cars up to 8 years old can be imported, as can trucks younger than 15 years and buses less than 10 years old. Poor routine maintenance and the harsh environment mean that the condition of these vehicles deteriorates quickly. However, the high costs of import and weak vehicle testing provide the incentive to extend the life of the existing fleet beyond the age and the operating conditions that might be considered desirable. The average age of commercial vehicles is estimated at over 20 years, and many private vehicles are kept on the road to ages that would be considered unserviceable elsewhere.

Fuel subsidies until recently kept the price of gasoline well below market levels (around 65 naira/liter) while diesel is close to international prices (currently 170 naira/liter). This has had clear effects on fleet composition: the proportion of private vehicles that run on diesel is negligible; commercial vehicle owners also have been opting to run petrol (or petroleum gas–powered) vehicles wherever possible. Hence the majority of small and medium size *danfo* minibuses run on petrol; even half of the large buses and coaches run on petrol. The higher price of diesel has resulted in far fewer heavy trucks and buses running on the more efficient diesel than would be expected if both fuels were similarly priced.

Information on Nigeria's vehicle fleet and usage is sparse. Data from official sources have been complemented by detailed fieldwork conducted by the World Bank in Lagos in 2006 and a targeted vehicle population survey conducted at four locations in Nigeria in 2012 specifically for the present study, to better understand the composition, characteristics, and activity of Nigeria's vehicle fleet. These data provided a basis for disaggregating by vehicle type and technology within the broad vehicle classifications reflected in the vehicle registration statistics (see table 7.1).

Private vehicle activity levels in Nigeria are very high; but commercial vehicle utilization is low compared to other parts of the developing world due to the combination of poor roads and vehicle condition. The 2012 survey and UITP/UATP report (UITP/UATP 2010) provide indications on average annual mileages

Table 7.1 Vehicle Fleet Estimates for 2010 Based on Vehicle Population Data

Vehicle type	*Vehicle class*	*% of total vehicles*	*Vehicle numbers*
Motorcycle	Two-wheeler	38.32	3,322,888
Saloon (sedan)/station wagon	Car	53.63	4,650,509
Van, pick-up and kitcar (also known as "component car")	LCV goods	1.11	96,314
Lorry/truck	HCV truck	1.35	117,424
Minibus	LCV goods	5.32	460,987
Omnibus (large bus)	HCV coach	0.12	10,687
Tanker	HCV truck	0.01	1,055
Highway tractor (tractor trailer, 18-wheeler)	HCV truck	0.01	1,121
Trailer	HCV truck	0.04	3,232
Tipper	HCV truck	0.08	7,257

Sources: Estimate based on State Licensing Authority vehicle registration data (2005) uplifted and disaggregated by vehicle classification using Lagos State Newly Registered Motor Vehicles by Type of Vehicle and Year of Registration (1990–2005).
Note: LCV = Light commercial vehicle; HCV = Heavy commercial vehicle.

(table 7.2). These were reviewed against vehicle population and fuel sales data and adjusted to ensure that fuel consumption by fuel type broadly reflects the levels observed in fuel sales.

As indicated in figure 7.1, private car use accounts for by far the greatest share of vehicle activity, followed by motorcycles—both mainly for commercial activity—and then light goods vehicles, which includes the minibus (*danfo*). Public transport movements typically account for around one-third of vehicle activity in the large cities such as Lagos, with private cars representing a similar proportion. Taxis typically account for up to 15 percent of movement, with the remainder made up of motorcycles and movers of goods. This varies from city to city, with Kano, for example, having a much higher proportion of motorcycle activity.

Using the COPERT (Computer Program to Calculate Emissions from Road Traffic) fuel consumption factors included in the World Bank's EFFECT (Energy

Table 7.2 Base Year Vehicle Average Annual Mileage (2010)

Vehicle type	*Annual km*
Two-wheeler	7,000
Passenger car	17,000
LCV goods	30,000
Heavy duty urban bus	30,000
Heavy duty long-distance coach	45,000
HCV truck	33,500

Source: Estimate based on 2012 vehicle survey and UITP/UATP *Report on Statistical Indicators of Public Transport Performance in Africa*, April 2010, balanced against fuel sales data from World Bank Development Indicator Index.
Note: LCV = Light commercial vehicle; HCV = Heavy commercial vehicle.

Figure 7.1 Composition of Vehicle Fleet and Vehicle Uses

a. Vehicle fleet composition (percentage)

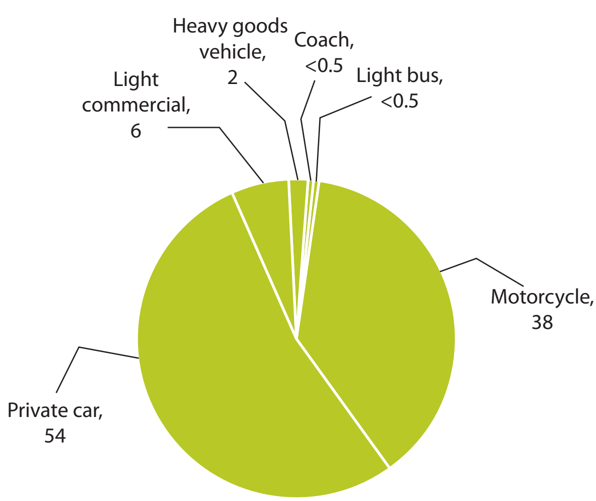

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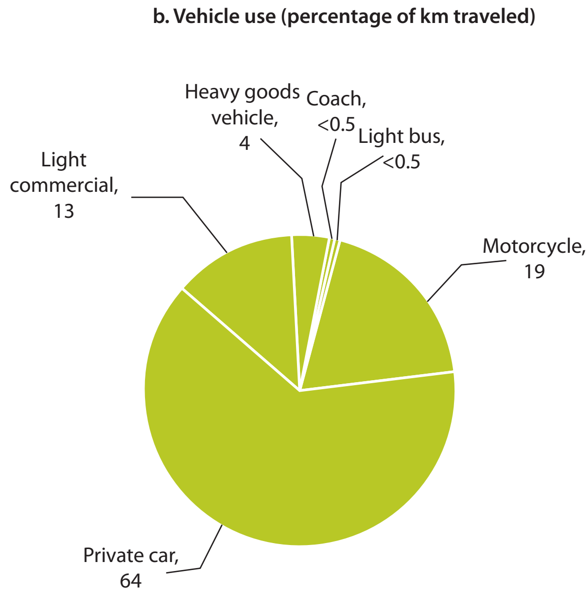
Figure 7.1 Composition of Vehicle Fleet and Vehicle Uses *(continued)*



Source: World Bank commissioned survey, 2012, based on State Licensing Authority vehicle registration data (SLA 2005).

Forecasting Framework and Emissions Consensus Tool) model for each of the vehicle subcategories used in the survey, estimates of total fuel consumption based on the baseline vehicle fleet and activity levels were made as shown in figure 7.2. This resulted in total emissions for the country of 27.6 million metric tons carbon dioxide equivalent (Mt CO_2e) in 2010.

Reference Scenario for Transport

Over the coming years, a number of cumulative factors can be expected to lead to increasing levels of greenhouse gas (GHG) emissions from the transport sector. These factors include population growth, development in manufacturing and services, increased per capita income, and vehicle fleet evolution.

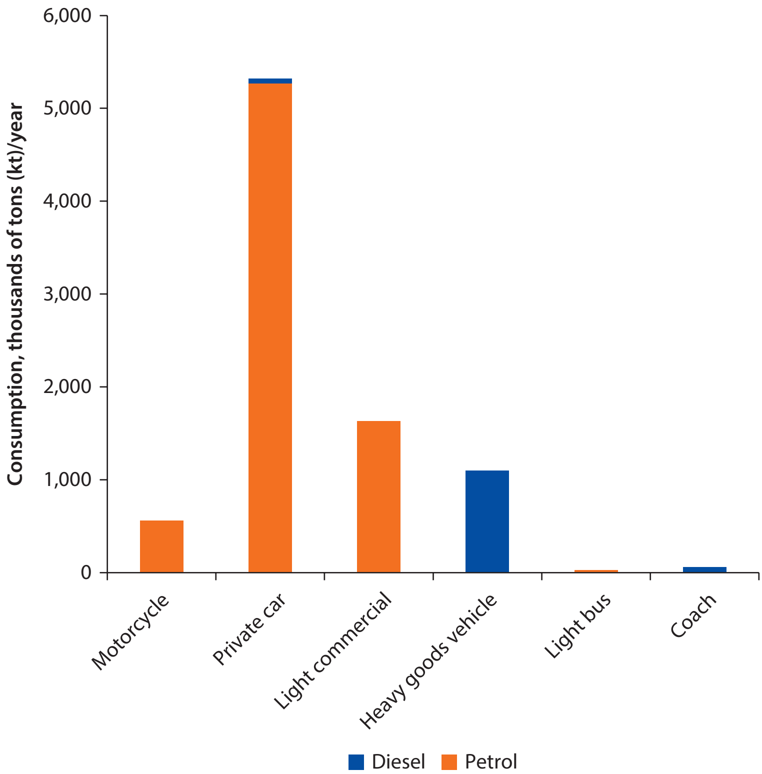
Population

Nigeria's growing population of young adults has direct relevance to the potential pool of future car owners. The increasing driving age population can be expected to have a direct impact on private vehicle ownership and usage, not only as a means of transport but for the social status it represents.

Manufacturing and Services

Economic growth drives both personal and commercial travel demand. It is equally true that the ability to move goods and people is a requisite to achieving economic growth. Therefore it is recognized that an efficient transport system is an essential element of a strongly performing economy.

Figure 7.2 Base Year Fuel Consumption by Vehicle and Fuel Type



Source: Calculated using vehicle fleet estimates with EFFECT model fuel consumption factors.

While the historically dominant oil and gas and agriculture sectors are likely to remain of significant importance to the Nigerian economy, future development is projected to shift the balance to manufacturing and services (as shown in table 7.3). These are more freight-intensive and so can be expected to lead to faster growth in freight demand.

Typically the elasticity of freight activity in relation to gross domestic product (GDP) is expected to be greater for developing counties. This is in contrast with industrialized countries, which have seen a decoupling of freight from economic growth, with elasticities falling below 1. For the purpose of freight forecasts, a conservative elasticity value of 1 has been adopted. This has been applied to commercial public transport vehicle growth and also to light goods vehicles.

However, to account for the increasing share that manufacturing and services will have in the Nigerian economy, and their greater freight intensity, growth in heavy goods vehicle numbers has been increased in proportion to the growth in these industries.

Car Ownership Levels

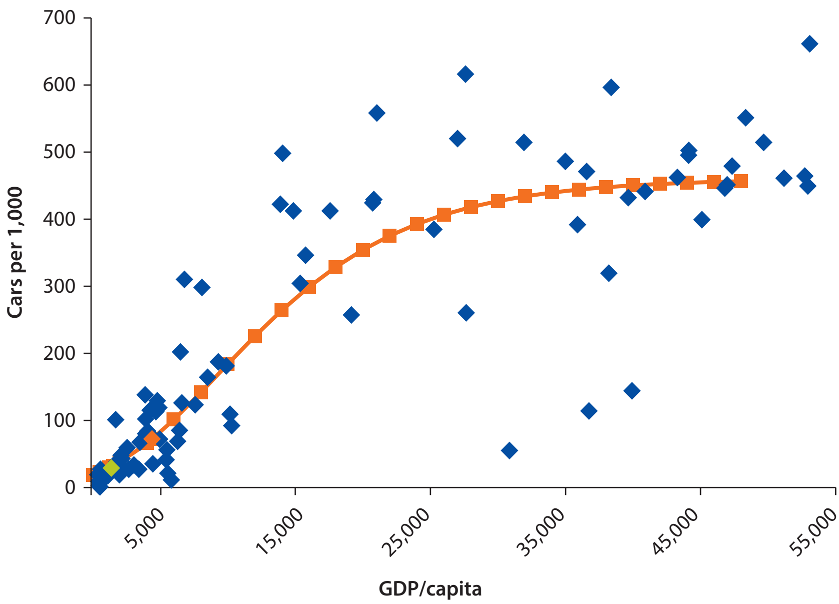
Cross-country evidence suggests a relationship between car ownership rates and income approximated by an S-shaped Gompertz curve; this reflects a slow

Table 7.3 Projected Macro-Sectoral Shares for Value-Added in Nigeria
percent

Year	*Agriculture*	*Manufacturing*	*Mining*	*Services*
2010	43	1	36	19
2015	32	5	33	29
2020	25	12	25	38
2025	23	17	21	39
2030	21	18	21	39
2035	21	19	21	39

Source: Elaborations on Vision 20: 2020 targets.

Figure 7.3 Car Ownership vs. Income in Various Countries (blue): Nigeria in 2010 (green) and 2035 (orange)



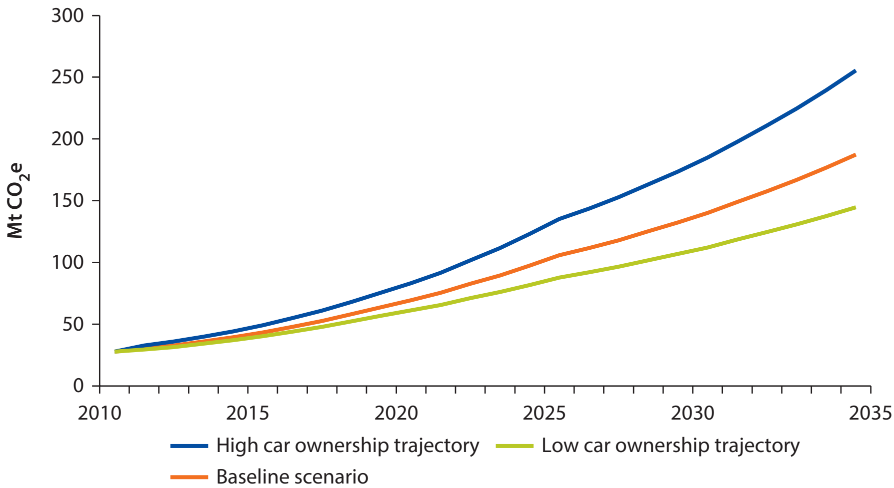
Source: World Bank 2010: World Development Indicators (GDP/Capita, Passenger Cars per 1,000 population).

increase in car ownership at lower incomes, after which car ownership increases rapidly before finally reaching saturation levels at around 450 cars per 1,000 population, under a "normal" European or Asian pattern of development.

Over the study period, the increase in GDP in Nigeria from US$1,222 in 2010 to $4,386/capita in 2035 is projected to result in car ownership increasing from 29 cars per 1,000 population in 2010 to 72 cars per 1,000 in 2035.

Factors other than income are also at play, as evidenced by the range of different car ownership levels observed at similar income levels in countries around the world (figure 7.3). For example, at the US$4,400/capita income projected for Nigeria in 2035, car ownership varies from 35 to 130 vehicles per 1,000

Figure 7.4 Effect of Low and High Car Ownership Trajectories on GHG emissions



Source: Modeled emissions based on different car ownership trajectories taken from World Bank 2010: World Development Indicators.

people. At 72 cars/1,000, Nigeria's projected car ownership level by 2035 would lie in the middle of this range. Alternative policy decisions could result in a different path for car ownership, probably in the range of 35 to 130 vehicles per thousand people. Correspondingly, there would be very different paths of overall vehicle emissions.

For example, maintaining gasoline subsidies and allowing the import of less-costly secondhand vehicles, together with a shortage of adequate public transport, would drastically increase car ownership rates. Conversely, high vehicle tariffs, coupled with good quality urban public transport, as well as adequate urban land use planning, could result in lower private vehicle ownership and use.

By 2035, the effect on emissions of different car ownership paths might result in a 75 percent emission increase, from 145 to 255Mt CO_2e/year (see figure 7.4).

Vehicle Fleet Evolution

To tackle pollution levels, the Federal Government of Nigeria (FGN) recently introduced regulation related to engine technology, prohibiting the import of two-stroke motorcycles and adopting Euro 2 standards as a minimum for all vehicles imported or sold from the end of 2011 (FGG 2011). Future regulatory tightening has been announced, with a move to Euro 3 in 2015 and then future emissions regulations forecast to track European standards with the current 15-year lag until the end of the modeled period. Thus, in the reference case, all new vehicles are expected to conform to Euro 5 as a minimum standard by 2035.

The reference case also assumes a slow removal of the gasoline subsidy, resulting in the proportion of diesel vehicles changing to a similar fraction as that of neighboring African countries and then developing along a similar trend to the

European Union (EU), but with a lag. By 2035, the reference case makes the assumption that 40 percent of cars imported to or bought in Nigeria are diesel. The proportion of diesel fuel used by road vehicles is predicted to reach 46 percent of sales in 2035.

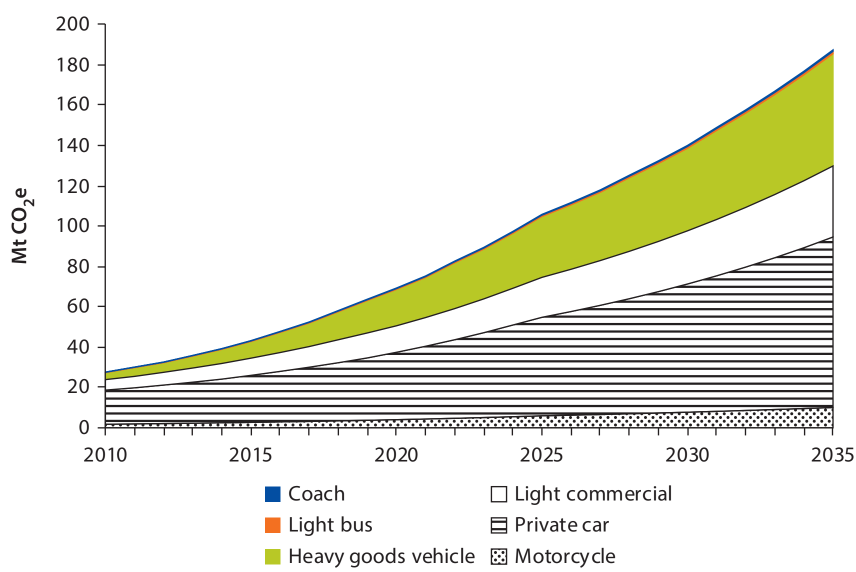
Fuel Consumption

Between 2010 and 2035, fuel consumption is projected to increase by 680 percent, driven by a five-fold increase in total vehicle kilometers driven. The disproportionate increase in fuel consumption is accounted for by the greater level of growth observed in the commercial vehicle fleet, which has higher average fuel consumption levels. This growth in the truck and bus fleet is due to the increasing importance of non-oil products in Nigeria's manufacturing industries, the expansion of the service sector due to rising incomes, and the removal of the gasoline subsidy that makes the use of heavy diesel-fueled vehicles more attractive. Diesel consumption accounts for 46 percent of the total fuel consumed in 2035 compared to 14 percent in 2010.

GHG Emissions

The resulting growth in CO_2e emissions levels are presented in figure 7.5. GHG emissions are forecast to increase significantly over the forecast period, driven by increasing population, economic activity, and wealth, reaching over 187 Mt by 2035. To put this into context, by 2035, emissions levels in Nigeria are projected to far exceed the level currently generated by the road transport sector across Sub-Saharan Africa as a whole (133 Mt in 2008).

Figure 7.5 CO_2e Emissions over the Study Period



Source: Modeled emissions based on vehicle fleet estimates and emissions factors from EFFECT model.

Low-Carbon Interventions for Transportation

The low-carbon scenario considers the scale of impact of potential mitigation measures on the growth in emissions. The options explored reflect a focus on the policy drivers and measures that can be implemented at the national level.

The study team defined the emissions reference case for road transport to enable estimation of the mitigation potential of several key interventions. However, due to time and budget limitations it was not possible to directly evaluate the marginal abatement cost (MAC) of each intervention. Instead, data and calculations from international experiences, suitably adapted to the Nigerian context, were used to develop indicative estimates of the MAC of the measures considered. Due to the importance of the expected future growth in GHG emissions from this sector, it would be valuable to conduct further work in this area.

Freight Rail Transport

With a decline in the state and operation of Nigeria's rail network since the 1980s, all but a very small fraction of freight is transported by road. Reinstatement of the rail network to its former operating capacity would permit the transfer of appropriate goods to the rail network, particularly aggregates, cement, and other heavy freight.

Taking into account historical freight tonnage statistics, the latest plans for the rail network, and efficiency levels achieved on the rail network in neighboring African countries, it can be argued that some bulk freight can be more efficiently transported by rail. Assuming an improved intensity of usage to around the level of Botswana (currently twice the level observed in Nigeria) would facilitate the carrying of 2,700 million ton-km, or 5.2 percent. If the rail network expansion outlined in the Vision 20: 2020 were implemented, the growth in the network would facilitate freight movement totaling 13 million ton-km (based on equivalent intensity of network use).

The impact of emissions reductions from increasing rail freight intensity would be relatively small, amounting to around a 0.6 percent reduction in overall emissions in 2020–30 but then tailing off to just 0.2 percent reduction by 2050. This is due to the inability of the rail network capacity to keep up with the growth in freight demand, so despite a significant increase in the physical volume of freight carried by rail, road-based freight growth is expected to continue to outstrip rail freight growth.

Under the scenario presented above, the scale of CO_2e reduction in the period 2010–35 could be expected to be on the order of 9.9 million tons of CO_2. However, a more detailed study is needed for a better estimate. Of course, transporting goods by rail does not eliminate emissions. The majority of the Nigerian rail network will remain non-electrified over the medium term, resulting in a certain level of emissions from the rail freight services. The scale of mitigation possible is constrained by the coverage of the rail network, which, even with the proposed expansion, would probably be inadequate to meet a rapidly growing demand for the transportation of goods. While rail might be able to carry 5 percent of freight by year 2015, the fraction falls as the total annual freight tonnage increases through the end of the study period (2035).

Freight Scheduling

Recognizing the likelihood that the majority of freight will be carried by road in the medium term, measures to increase the efficiency of freight movements through better logistical planning and fleet management are expected to prove most effective. Reducing empty running and rationalizing freight movements, with a move toward using larger freight vehicles, has been demonstrated to achieve significant savings in operating mileage and hence emissions levels. Efficiency savings of 20 percent in small and medium freight activity with 10 percent reduction in heavy freight kilometers has been assumed.

Cumulative emissions savings over the forecast period of this study at these assumed efficiency levels amount to 73.3 Mt CO_2 by 2035, demonstrating the sizeable abatement that can be achieved through measures aimed at improving the efficiency of the rapidly growing freight sector and the value of studying freight handling and transport in greater detail.

Driver Training

Training programs that teach drivers about the impact their driving has on vehicle wear and tear and operating costs has been shown to reap rewards during many pilot studies undertaken in the African region. Through less intensive acceleration and braking and maintaining a constant efficient speed, the training programs typically report reductions in fuel consumption of 20 percent or more. With this scale of potential improvement, enhanced driver training for even a small proportion of the goods vehicle drivers can reap strong rewards in terms of CO_2 reduction, lower costs, and also safety. A scenario has been developed for this study based on the following assumptions:

- Start of a training program covering 20 percent of heavy goods drivers in 2012 (representing 30,000 drivers);
- Achievement of a 20 percent improvement in fuel consumption levels for those drivers/vehicles following training; and
- Requirement of repeat training every 5 years for a similar proportion of drivers.

The overall impact over the projected period of such a scheme could allow 9.9 million tons of CO_2 to be saved.

More Efficient Private Vehicles

The average private vehicle on Nigeria's roads is 14 years old, does not comply with any Euro emissions standards, and as a result is outdated in terms of fuel efficiency and carbon emissions levels. Unlike Europe, Nigeria has no stated

CO_2 emissions standards for cars. The current average emissions level across the Nigerian private car fleet is estimated to be 214g CO_2/km. This is clearly far behind the standards being adopted in Europe, which are as follows:

- By 2015, an average 130g CO_2/km across fleet of new vehicle sales by manufacturer and
- By 2020, a target of 95g CO_2/km average across all vehicles sold.

Applying regulations in line with European emissions target levels with a lag of 15 years would mean that new and imported vehicles should on average emit only 130g CO_2/km by 2030. This could reduce average emissions levels for private cars to approximately 137g CO_2/km by 2035. The savings grow to 36 metric tons annually by 2035, with a total reduction in carbon emissions over the forecast period of 269 Mt CO_2. Not only does this represent one of the most effective policy levers to reduce local pollution and GHG emissions in a relatively short term, but it is also one of the few activities mainly controlled by the Federal Government of Nigeria and thus easier to implement than those under the control of multiple local stakeholders.

Public Transport

Public transport is currently the only form of available motorized transport for over three-quarters of travelers in the urban environment. While public transport typically alleviates urban congestion, the present public transport system consisting of small privately-owned minibuses, taxis, and motorcycle taxis is actually the source of much disruption, with undisciplined and erratic driving behavior (*danfos* regularly block two lanes of traffic while trying to board and alight passengers).

Nigeria has at least 10 cities with over 1 million population. Lagos estimates vary from 9 million to over 17 million. Until just a few years ago, it was the only megacity without any form of organized public transport. The sheer scale of people movement cannot adequately be served by an unplanned and unstructured public transport system.

A move to organized mass transit, whether rail, bus rapid transit (BRT), or conventional large bus operations, can significantly enhance the efficiency of transport operations, not only for public transport travelers but all highway users.

An organized mass transit scenario focuses initially on the migration to organized large bus operations because of its replicability in all major cities across Nigeria. Based on conservative assumptions, just under one-third of existing paratransit operations could be replaced by one-fifth of the number of large buses. The additional benefits and traffic reductions resulting from BRT along selected high-demand corridors are applicable on other routes and cities.

The introduction of large bus operations in the larger cities of Nigeria could reduce emissions levels by 0.4–0.5 percent per year. Over the projected period, these savings amount conservatively to 10.6 million tons of CO_2. Detailed studies on a city-by-city basis would be needed to better evaluate this change.

BRT is typically successfully implemented on corridors with passenger movements of over 3,000 per hour per direction. BRT enhances efficiency due to priority infrastructure, allowing more round trips by each larger-capacity vehicle, resulting in lower per-passenger CO_2 emissions.

Lagos has successfully implemented a BRT route on a key corridor from the mainland onto the island. The 22-kilometer route currently carries almost 200,000 passengers a day. Two additional routes are planned within the city.

Based on a target assumption of 30 percent of public transport trips by mass transit and a reduction of 75 percent of *danfo* trips, a reduction of 10.3 percent of light goods vehicle activity is forecast with an associated increase in large bus vehicle activity of 1.3 percent. This impact on emissions levels is conservatively estimated at 14.1 Mt CO_2 over the forecast period.

Extending the Use of CNG as a Transport Fuel

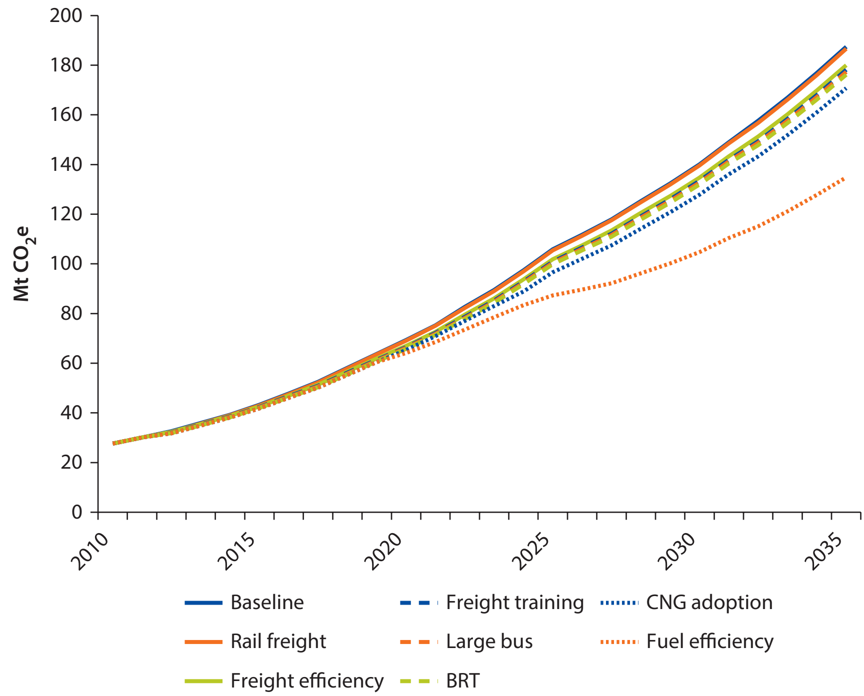
Although Nigeria is rich in natural gas, its use to fuel transportation in the form of compressed natural gas (CNG) is in its infancy, although widespread in many other countries. A trial commenced in 2010 in Edo State promoted by the Nigerian Independent Petroleum Company (NIPCO) in partnership with the Nigeria Gas Company (NGC). As a result of the program, as of 2012 there were six fueling stations, and another two under construction, to serve the state's large buses converted to CNG, and a fleet of 250 CNG taxis. NIPCO aims to roll out the concept and ultimately make CNG available at 5,000 stations across the country. Countries leading the way in the use of CNG include Pakistan, which currently has around 3,300 CNG fuelling stations countrywide and over 2.8 million CNG vehicles. As well as lowering fuel costs by up to 50 percent—particularly important in light of the gasoline subsidy reduction—the levels of GHG pollution can be significantly lower than with gasoline.

The low-carbon scenario of the current study considers the successful rollout of CNG to all of the new large bus vehicles introduced in the mass transit scenario set out above (existing bus vehicles are assumed to remain on standard technology), as well as adoption by 50 percent of the national taxi fleet and 15 percent of other private and commercial vehicles. The abatement of total emissions from road transport increases from 0.2 to 3 percent by 2035, resulting in total emission reduction over the forecast period of 53 Mt CO_2. Of course, to achieve these gains, good operational control and technology is essential, since the leakage of natural gas into the atmosphere can more than offset the GHG emissions advantage of consuming this fuel.

Impact of the Promotion of Low-Carbon Policies

As shown in figure 7.6, applying this combination of measures can achieve a reduction in emissions increasing from 0.88 Mt CO_2e in 2012 to over 50 Mt CO_2e in 2035. In total, this amounts to a reduction conservatively on the order of 452 Mt CO_2e over the 25-year study period.

Figure 7.6 Impact of Transport Sector Mitigation Measures on CO_2 Emissions Levels



Source: Modeled emissions based on vehicle fleet estimates and emissions factors from EFFECT model.

The major emissions savings are achieved through vehicular emissions regulations, followed by freight efficiency improvements and CNG adoption.

While these savings represent a significant reduction in absolute terms, they are not as sizeable in relative terms, which points to the need for further work on opportunities for a lower carbon development of Nigeria's road transport sector.

Recommendations for the Transport Sector

The sheer scale of demand for transport in Nigeria's major urban areas cannot adequately be served by an unplanned and unstructured public transport system. For freight, Vision 20: 2020 goals imply a growing importance for the manufacturing sector and service industries, which will drive an increasing demand for the movement of freight and goods. Evidently structural changes in land transport are needed to allow the country's development goals to be achieved.

The present study analysis is intended to frame the growing importance of the transport sector in terms of GHG emissions and initiate debate and discussion on the measures that need to be implemented to mitigate the impacts of the sector's growth. The limited scope of the transport study did not allow each of the involved factors to be evaluated in depth, and additional work will be needed to frame future policy decisions.

Recommendation: Strengthen and Coordinate Institutional Mandates at All Levels of Government

Actions other than adding more roads need to be taken to focus transport development along a more sustainable pathway. However, particularly in transport, these long-term planning processes need to recognize and integrate a wide spectrum of constituencies, including all levels of government, with careful attention to building ownership and consensus among key sectors, such as services and manufacturing, transport, and agriculture; civil society; and private-sector groups. The explosive growth in the demand for passenger mobility is centered in cities and requires a coordinated long-term consensus among local stakeholders, while technology choices and long-distance travel is mainly within the domain of the FGN and state governments.

Recommendation: Improve Transport Data

Policy Recommendation: Strengthen Nigeria-Specific Transport Data

To develop a low-carbon plan to reflect actual conditions in Nigeria, rather than using estimates adapted from other countries, it will be important to collect additional data to fill in critical gaps both at the national and local-area level. Detailed data on the vehicle fleet, vehicle activity, and the movement of goods and people need to be maintained and periodically updated to enable judicious policy decisions in a changing environment. It is virtually impossible to improve something that is not being measured, and the data currently available in this sector are particularly sparse.

Policy Recommendation: Give Priority to Infrastructure Development that Avoids Lock-In

As Nigeria's urban population increases, the infrastructure design and development decisions that will be taken over the coming years will directly affect the long-term sustainability of its cities. Infrastructure investments have a long life; design decisions made centuries ago are still evident in many European towns and cities. If cities develop around the needs of private motorization they will be "locked-in" to a high energy-consuming development trajectory that will be difficult to change at a later date.

Policy Recommendation: Evaluate the Costs of all Externalities of the Fuel Subsidy

Gasoline subsidies until recently have kept the price of gasoline well below market levels (around 65 naira/liter), in contrast to diesel, which is sold at close to market levels (currently 170 naira/liter). This has skewed the vehicle fleet toward small, inefficient vehicles, by making it more difficult for large diesel-fueled buses and trucks to compete. The anticipated eventual removal of the gasoline subsidy will narrow the cost differential with the cost of diesel and allow the Nigerian fleet to come into line with neighboring countries in terms of the mix between petrol and diesel vehicles. If the variable cost of private transport operation remains low due to subsidies, it will be difficult to promote the mass-transit and freight solutions needed to enable the country's development trajectory—including quality of life improvements.

Policy Recommendation: Actively Promote Formal Public Transport in All Cities

Maintaining present public transport shares in the face of exploding private vehicle ownership will be an impossible task unless a paradigm shift occurs in urban design and development. As more families become private transport owners (cars and two-wheelers), the challenge becomes one of providing them with alternatives to use for their routine daily travel.

Policy Recommendation: Give Priority to Efficient Freight Handling and Transport as Essential to Growth

Efficient freight movement is essential for the country to achieve its growth goals. This should include expansion of rail services, road infrastructure, vehicle technology, logistical planning, and fleet management. Significant savings (and a reduction in GHG emissions) can be achieved by leapfrogging to solutions with advantages demonstrated in more advanced countries. Making this happen needs direct investment from the FGN and creating the enabling environment that permits the private sector to adopt modern solutions.

Recommendation: Vehicle Technology

The combined impact of population growth and car ownership increases is expected to escalate the private car population from 4.7 million to over 20 million over the forecast period of the study. Evidently this would be catastrophic if all these were aging and high polluting vehicles near the end of their useful lives.

Therefore the recommendation is to track European standards with a 15-year lag. Over time, this lag should be reduced, and eventually eliminated, as Nigeria achieves its goal of becoming the world's 20th largest economy. The application of an effective vehicle inspection and maintenance system in major cities could have a major impact on lowering tailpipe and GHG emissions.

Alternative Fuels

Many countries, notably Pakistan and India, have successfully promoted the use of CNG as a transport fuel to combat air quality problems and reduce GHG emissions from this sector, while lowering operating costs. It is recommended that a detailed study be undertaken to identify urban areas suited to develop an infrastructure for deployment of a network of CNG filling stations.

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CHAPTER 8

Summary of Findings and Recommendations across Sectors

This chapter summarizes the key findings on emissions for the reference and low-carbon scenarios; and on benefits and costs of the mitigation options included in the latter. It provides general recommendations that cut across sectors for overcoming organizational and institutional barriers to reconcile growth with low-carbon development. (Chapters 4–7 contain more specific recommendations for each sector.)

Emissions across Sectors for the Reference Scenario

The reference scenario projects a doubling of emissions from the four sectors from 2010 to 2035 (figure 8.1). Over the same period, the population is projected to grow by 82 percent and the real gross domestic product (GDP) is projected to increase 6.5 times.

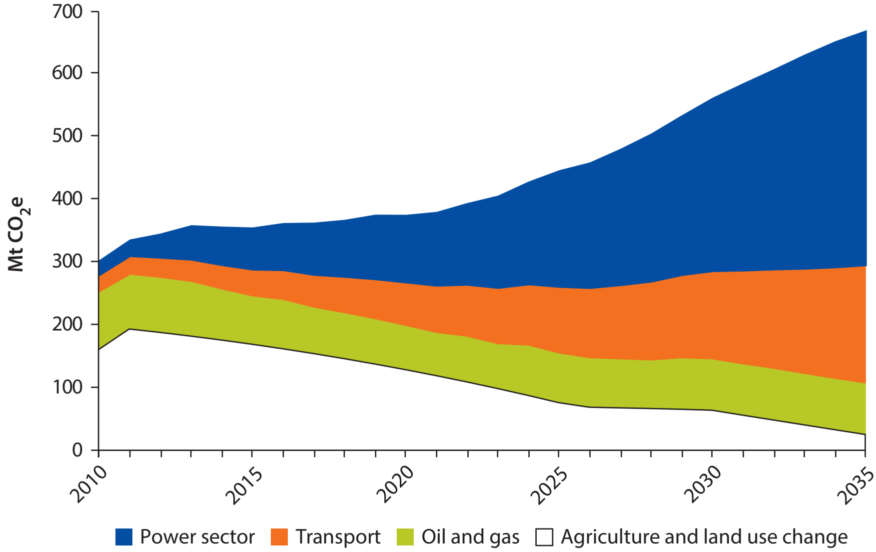
This doubling of greenhouse gas (GHG) emissions results from an important structural change: In 2010, over half of the nation's emissions originated from agriculture and land use change (53 percent), with oil and gas contributing 30 percent of the total. The power and road transport sectors contributed 8 percent and 9 percent, respectively.

By 2035, in the reference scenario, the mix is projected to be radically different: Agriculture, forestry, and land use change constitute only 4 percent of the total. Oil and gas drop from 30 to 12 percent. The power sector becomes the largest contributor at 56 percent, followed by road transport at 28 percent (figure 8.2).

The principal causes of these structural changes are as follows:

- For the agriculture sector, a dramatic reduction in net emissions is due to a slow-down in land use changes and to negative emissions from changes in annual, perennial, and wet rice crops (see figure 4.4).
- For the oil and gas sector, increased emissions from on-site gas combustion are counterbalanced by a reduction in emissions from flaring (figure 5.3).

Figure 8.1 Annual CO_2e Emissions in the Reference Scenario



Source: Calculations based on data sources listed in the chapter 3 references.

Figure 8.2 Reference Scenario: Sector Composition of GHG Emissions in 2010 and 2035
percent

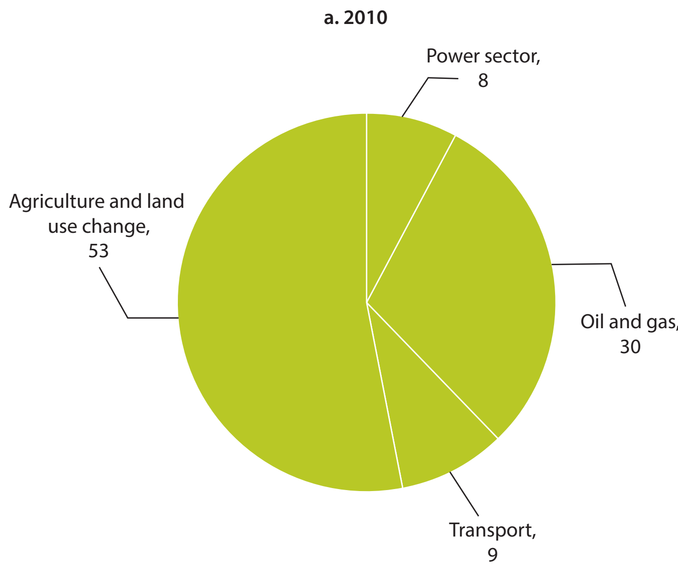


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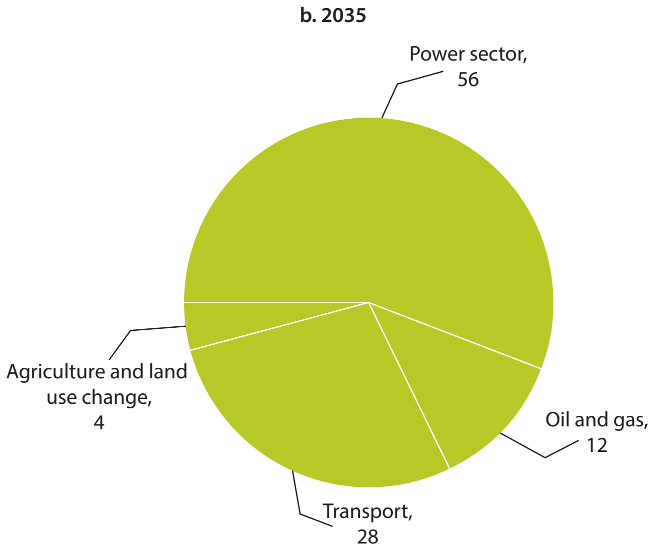
Figure 8.2 Reference Scenario: Sector Composition of GHG Emissions in 2010 and 2035 *(continued)*
percent



Source: Calculations based on data sources listed in the chapter 3 references.

- For the electricity and transport sectors, dramatic growth in emissions reflects growing electricity generation (figure 6.7) and volume of road transport (figure 7.5) as a result of increases in population and income per capita.

Emissions and Mitigation Potential for the Low-Carbon Scenario

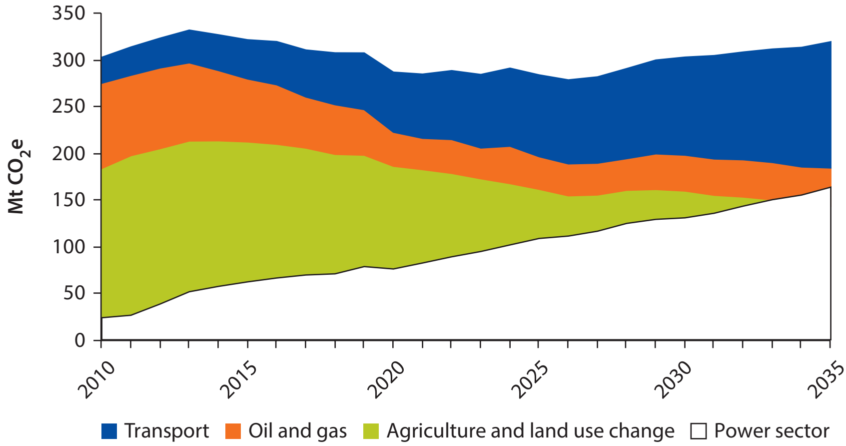
For each sector, the study team identified a set of low-carbon interventions (mitigation options.) As described chapter 3, interventions were evaluated according to a series of criteria, including the magnitude of potential emission reductions, as well as technical, economic, and institutional feasibility. The goal was to assess whether the different options can help reduce carbon emissions while meeting Nigeria's ambitious goals for economic development.

As result of this process, the teams selected some 30 options for inclusion in the low-carbon scenario. These measures would allow the Vision 20: 2020 development goals to be reached with minimal change in annual GHG emissions, increasing from 303 million metric tons carbon dioxide equivalent (Mt CO_2e/year) in 2010 to 320 Mt CO_2e in 2035 (figure 8.3).

The low-carbon scenario would result in a 50 percent reduction of emissions in the terminal year relative to the reference scenario. The reduction in cumulative emissions over the whole simulation period would be some 3.7 billion tons of CO_2e (table 8.1).

The largest contribution to the total mitigation potential comes from the power sector (some 1.9 billion tons), with smaller but significant contributions

Figure 8.3 Annual CO_2e Emissions in the Low-Carbon Scenario



Source: Calculations based on data sources listed in the chapter 3 references.

Table 8.1 Low-Carbon Scenario: End-Year Emissions and Cumulative Emissions Abatement by Sector

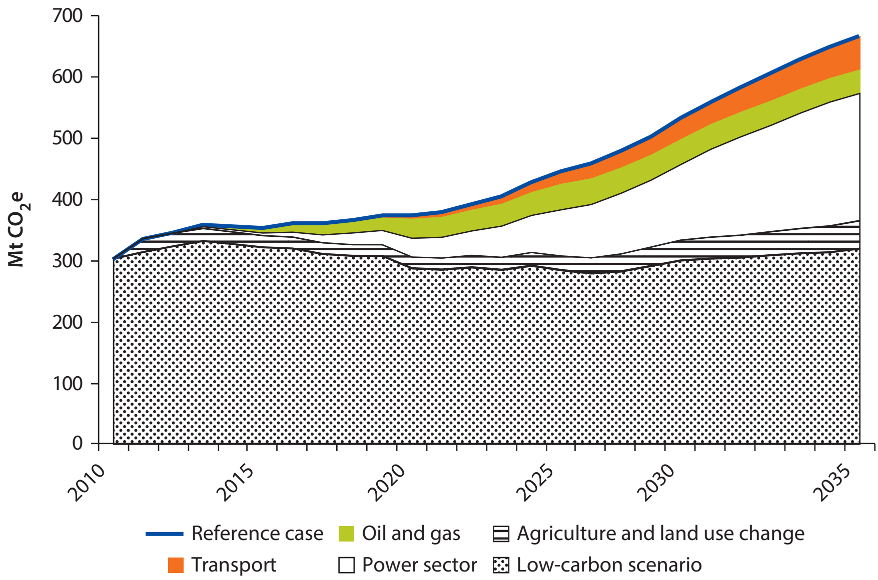
	GHG emissions, billion tons CO_2e/year in 2035		*Emissions reduction*
Sector	*Reference*	*Low-carbon*	*2010–35 billion tons CO_2e*
Power sector	0.37	0.16	1.92
Oil and gas sector	0.08	0.04	0.75
Road transport	0.19	0.13	0.45
Agriculture and LUC	0.03	−0.02	0.65
Total	0.67	0.31	3.77

Source: Calculations based on data sources listed in the chapter 3 references.
Note: LUC = land use change.

from oil and gas (0.7 billion tons), agriculture (0.6 billion), and transport (0.5 billion tons). The differences over time between the emissions in the reference scenario and in the low-carbon scenario are shown in figure 8.4 as the "mitigation wedges," reducing emissions from the reference case (top blue line) to low-carbon case (dotted area at the bottom).

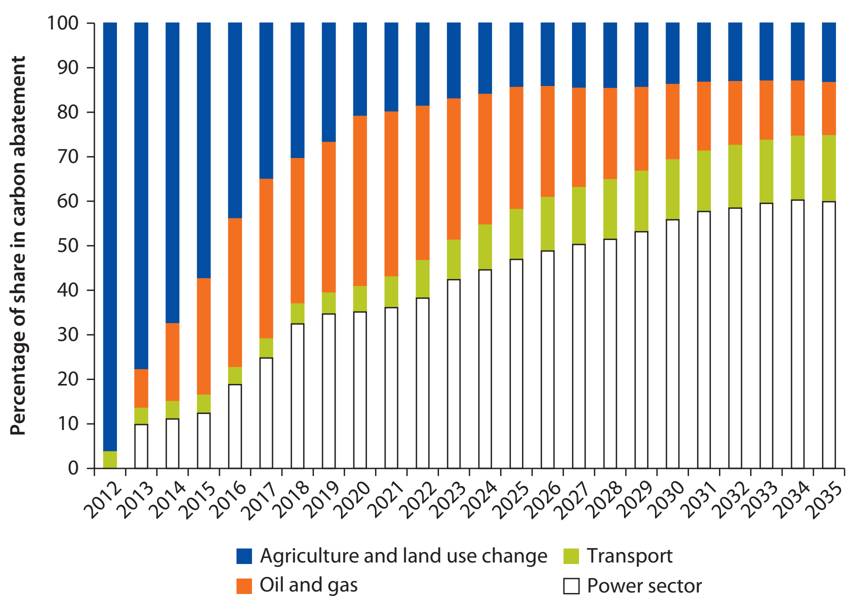
Sectors differ significantly in time distribution of their abatement potential (figure 8.5): Agriculture and land use account for the largest share of emissions abatement in the earlier years, when most of the land use changes might take place. In the middle of the period, the oil and gas sector provides considerable abatement opportunities. In the second part of the simulation period, land use changes slow down, and opportunities for expanding renewable energy (RE) generation increase. This reflects, in part, projections that costs of renewable technologies will become economically competitive with fossil fuel in terms of levelized cost. By the end of the period, the power sector offers 60 percent of the total abatement potential.

Figure 8.4 Mitigation Wedges for the Four Sectors



Source: Calculations based on data sources listed in the chapter 3 references.

Figure 8.5 Percent Shares by Sector of Mitigation Potential over Time

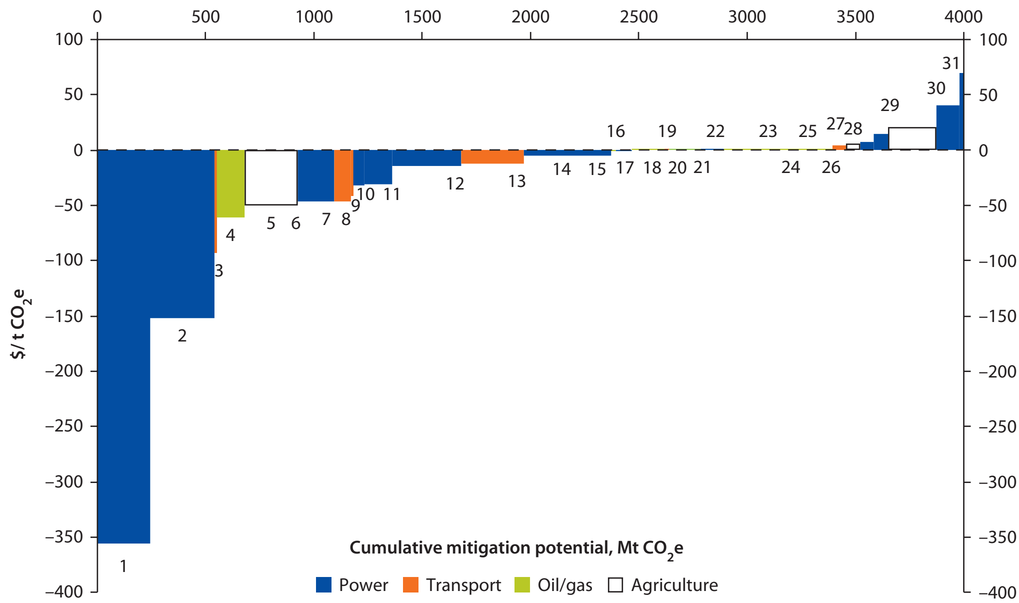


Source: Calculations based on data sources listed in the chapter 3 references.

Costs and Benefits of the Low-Carbon Scenario

Much of the low-carbon scenario appears economically attractive from Nigeria's point of view, even ignoring GHG abatement. Figure 8.6 shows the marginal abatement cost (MAC) of each intervention (in U.S. dollars per ton of carbon dioxide equivalent, \$/t CO_2e), plotted against the cumulated potential mitigation in Mt CO_2e from 2010 to 2035. The main interventions are ordered from lowest to highest MAC. Some 62 percent of the total mitigation potential

Figure 8.6 MAC for Nigeria (Selected Low-Carbon Interventions)



Code	Sector	Intervention	Mitigation potential (Mt CO_2e)	Average cost of mitigation (\$/t CO_2e)
1	P	EE lighting off-grid	233	–356
2	P	EE lighting on-grid	279	–152
3	T	Large bus	11	–93
4	O	Flaring	120	–61
5	A	Perennials	38	–50
6	A	Annuals	192	–49
7	P	Off-grid photovoltaics	158	–46
8	T	Freight efficiency improvements	73	–46
9	T	BRT	14	–41
10	P	Small hydro power	44	–32
11	P	Off-grid PV/diesel hybrid	124	–31
12	P	Gas combined cycle	300	–15
13	T	Fuel efficiency	269	–12
14	P	Expanded hydropower	382	–5
15	O	Glycol dehydration	19	–1

P = power; T = transport; A = agriculture; O = oil/gas

Code	Sector	Intervention	Mitigation potential (Mt CO_2e)	Average cost of mitigation (\$/t CO_2e)
16	P	Transmission	65	0
17	T	Rail freight	10	0
18	O	Crude storage	131	0
19	T	Freight training	22	0
20	A	Agroforestry	145	1
21	P	Concentrated solar power	92	1
22	A	SRI	3	1
23	O	Gas used for on-site powergen	388	2
24	O	Fugitives	88	2
25	T	CNG adoption	53	4
26	A	Livestock and pasturelands improvements	61	5
27	P	Solar PV (grid)	61	7
28	P	Biomass	64	15
29	A	Avoided deforestation	207	20
30	P	Wind turbines	104	41
31	P	Supercritical coal with CCS	17	70

Source: Calculations based on data sources listed in the chapter 3 references.

(2.3 gigatons [Gt] CO_2e) can be achieved at negative cost—that is, at a net social benefit. An additional 25 percent or 0.9 Gt CO_2e has a MAC of $5/t CO_2e or less. The remaining 14 percent (0.5 Gt CO_2e) has MAC values in excess of $5/ton. The average MAC of all 31 interventions (weighted by abatement potential) is a net social benefit of $42/t CO_2e.

Reviewing interventions using MAC shows that the benefits of the low-carbon scenario vary by sector: in power and transport, interventions with more than 80 percent of the abatement potential have net social benefits (Table 8.2). In agriculture, the corresponding share is over 35 percent; however in agriculture, and oil/gas, a significant share of total mitigation potential can be attractive for a relatively modest carbon price of US$5/t CO_2e or less; this is about 80% of the total the case of oil and gas.

Emissions abatement often requires higher capital expenditures, with lower fuel and operating costs over time, resulting in substantial long-run national benefits. In the agriculture sector, an additional public investment over the study period of $7 billion (0.04 percent of GDP) would result in additional cash flow to farmers and landowners of $37.3 billion (0.23 percent of GDP) while reducing GHG emissions by 646 Mt CO_2e.

For the oil and gas sector, a capital expenditure over the study period of $17 billion (0.11 percent of GDP) would generate net revenue (gross revenues minus gross expenditures) of $42 billion (0.26 percent of GDP). In the power sector, the capital expenditure of $118 billion (0.7 percent of GDP) is projected to reduce net expenditures (capital, fuel, and operating) by $225 billion (1.4 percent of GDP) (table 8.3).

In the transport sector, further work is required to quantify the public and private expenditures and savings. They will include important health benefits from reduced pollution (particularly in urban areas), reduced traffic congestion leading to time savings in travel and improved quality of life, and increased productivity and competitiveness in the manufacturing and service sectors.

In summary, there is the potential of abating some 3.7 billion tons of GHG emissions (CO_2e) with a net financial benefit close to 1.9 percent of GDP, over the study period—provided that Nigeria can find ways to overcome the significant institutional and financial barriers to adopting a low-carbon development pathway.

Table 8.2 Shares of Sector Mitigation Potential by Class of Marginal Abatement Cost

	Marginal abatement cost			
Sector	*Negative (%)*	*< \$5/t CO_2e*	*> \$5/t CO_2e*	*Total (%)*
Agriculture	36	23	41	100
Oil and gas	19	81	0	100
Power	82	5	13	100
Transport	81	19	0	100
Total	62	25	14	100

Source: Calculations based on data sources listed in the chapter 3 references.

Table 8.3 National Costs and Benefits of the Low-Carbon Scenario

	National costs			National benefits			Cumulative GHG abatement
Sector	*Indicator*	*US$Billion 2010–35*	*% of GDP*	*Indicator*	*US$Billion 2010–35*	*% of GDP*	*2010–35, Billion tons CO_2e*
Agriculture	Cumulative public additional capital expenditure	7	0.04	Net social additional cash flow	37	0.23	0.65
Oil and gas	Cumulative additional capital expenditure	17	0.10	Net additional cash flow	42	0.26	0.75
Power	Cumulative capital additional expenditure	118	0.72	Savings on cumulative capital, operating and fuel expenditure	225	1.41	1.92
Transport	Additional public capital expenditure	(a)	(a)	Reduced congestion, improved air quality, etc.	(a)	(a)	0.45
Total		142	0.85		304	1.90	3.77

Source: Calculations based on data sources listed in the chapter 3 references.
Note: (a) = Values not quantified.

Uncertainties and Sensitivity Analysis

A long-term analysis of this type, with a horizon of almost 25 years, inevitably faces large uncertainties. The study conducted a number of sensitivity analyses to evaluate whether findings are robust to key assumptions. For example, in the power sector, cost projections for renewable energy technologies—such as photovoltaics (PVs), concentrating solar power, and wind—suggest that some already are (or will soon be) competitive with fossil fuel technologies for off-grid generation compared to diesel generators, and most will reach grid-parity by the last decade of analysis. What if these projections are too optimistic?

Chapter 6 summarizes the result[1] of comparing the low-carbon scenario with a "delayed low-carbon scenario" that delays adoption of renewables by 5–10 years in case of slower learning curves and/or lower prices for fossil fuel. This scenario ends up with almost the same technology mix by 2035 with a 56 percent reduction in emissions from power relative to the reference scenario, although the cumulative emissions savings over the study period are reduced from 40 percent to 23 percent. The cost of the delayed low-carbon scenario is similar. This implies that the main conclusions for the low-carbon scenario for power are relatively robust to these changes, although the adoption of some options would be delayed.

A key assumption is relevant to all sectors is the future economic growth rates in Nigeria: Changing GDP growth from the "high growth" scenario down to the "medium growth" scenario, or up to the Vision 20: 2020 scenario, results in major changes to GDP by 2035. Under these scenarios, GDP increases by a factor of 2, moving from the medium growth scenario to the Vision 20: 2020 scenario (see chapter 3 for details). For the power sector, such changes to

GDP, and hence income per capita, would have correspondingly large effects on the demand for electricity and hence on emissions from electricity generation. In each case, however, the same types of low-carbon technologies and mitigation options would make sense for the same reasons. Their unit costs and benefits per megawatt (MW) or megawatt-hour (MWh) are not much affected by the speed of GDP growth. Hence, the same findings apply in terms of which options to select, when they become cost effective, what percentage mix of generation technologies to choose, and what institutional changes would be necessary to overcome barriers to adoption. The only thing that would change depending on the GDP growth scenario considered would be absolute quantities of new capacity to install and emissions produced. The percentage reduction in emission from the reference scenario to low-carbon scenario would be the same, at 56 percent. (For details see chapter 6 for a sensitivity analysis of the effects of GDP growth on emissions.)

Similarly, for the agriculture sector, most options are attractive for economic as well as environmental reasons, and recommendations should be robust to changes in GDP growth rates. The evolution of Nigeria's oil and gas sector is perhaps more dependent on the actual size of reserves and the global prices of oil and gas than on Nigeria's GDP growth. However, conversely, the size and revenues of the oil and gas sector (which is a major source of national revenues), will have a major influence on Nigeria's GDP growth. It might also affect the feasibility of Federal Government of Nigeria (FGN)-financed expenditures on capital-intensive low-carbon options.

Recommendations: Reconciling Growth with Low-Carbon Development

This final section summarizes general barriers to reconciling growth with low-carbon development and makes recommendations on how to overcome those barriers. These recommendations apply to all four sectors. They complement and extend the sector-specific recommendations presented at the end of each chapters 4–7.

While possible and often economically attractive, low-carbon development is by no means easy, in Nigeria or elsewhere. Barriers, including information needs, technologies, institutions, regulations, and financing, stand in the way of making low-carbon development a reality. But in many cases, barriers to low-carbon options are similar to barriers to conventional development. For example, problems of inadequate information also plague the monitoring of many "core business" indicators; in the power sector, data on off-grid generation is very scant; in transport, information on the volume, composition, age, and technology mix of the vehicular fleet is largely inadequate. These factors make it difficult to evaluate complementarities or trade-offs between mitigation and development objectives.

Barriers to financing are of particular significance for low-carbon development. Many low-carbon technologies feature higher upfront costs and delayed benefits, compared to the higher carbon technology they displace. This applies to most RE and to several conservation agriculture practices. Although their net benefits are often larger in the longer term than the reference technology, they are penalized by financial markets biased in favor of short-term returns.

Even for measures that do not require significant upfront funding, such as energy efficiency (EE) and load management, a mechanism is needed to promote adoption by the private and public sectors. This mechanism could acquire demand-side resources (EE and load management) and allow a utility or a government agency to purchase energy savings and/or demand reductions at an agreed rate in cents per kilowatt-hour (kWh) based on verified savings.

Recommendation: Strengthen the Overall Governance Framework

Nigeria is a party to the UN Framework Convention on Climate Change (UNFCCC), has ratified the Kyoto Protocol, and adheres to the Copenhagen and Cancun Accords, and to the Durban Platform. Nigeria in 2003 submitted its first national communication to the UNFCCC, but has not yet finalized the second one (FGN 2003). On the domestic front, the Federal Ministry of the Environment (FME) has taken a number of steps to move forward the climate agenda, including establishing an inter-ministerial committee for climate change as well as a special climate change unit inside the ministry, recently upgraded to a regular department of the ministry.

To consolidate these reforms, the Nigerian National Assembly passed a bill to establish a National Climate Change Commission to coordinate national policies on climate change, which is awaiting the president's approval (National Assembly of the Federal Republic of Nigeria 2010). However, the legislature's initiative can be interpreted as recognition of the fact that low-carbon, climate-resilient development requires institutions with the ability to make and implement decisions across multiple sectors.

The technical leadership exerted so far by the FME could be made more effective by charging a body that has a cross-sector policy mandate with the task to define policies for low-carbon, climate-resilient development, which require the concurrence of several line agencies. Such a role could be played by the existing Economic Management Team (EMT) of the FGN; or by the proposed National Climate Change Commission if it comes into being.

Recommendation: Improve Data Collection and Analysis

Relevant ministries, departments, and agencies (MDAs) in collaboration with the National Bureau of Statistics (NBS) should define action plans (with specific targets and milestones) to improve the quantity and quality of data required to design, monitor, and evaluate sector development policies. In many cases, data required for the ordinary development of the power, agriculture, transport, and oil and gas sectors will also be useful to evaluate synergies or trade-offs with low-carbon development. In addition, the action plans should also contain provisions for measuring and monitoring emissions of GHG, as such data will most likely be instrumental for accessing international climate finance.

Recommendation: Integrate Low-Carbon Objectives into Regular Sector Development Plans and Processes

Recent experiences in developing countries such as China (box 8.1) point to the key role of integrating low-carbon objectives and activities into regular sector strategies and planning processes, including the identification of targets and the definition of an array of policies to achieve them.

Box 8.1 The Experience of China with Scaling Up Renewable Energy

In China, coal is the dominant contributor—about 70 percent—to the country's energy supply. But with steadily rising prices and the impacts of coal on the environment and health and climate change, the Chinese government is pursuing renewable energy (RE) sources. In 2009, installed RE capacity reached 55 GW of small hydropower (the largest in the world), 22.68 GW of wind power (and rising), 4 GW for biomass, and 300 megawatts-peak (MWp) of solar photovoltaic (PV).

It was mainly the Renewable Energy Law, enacted in February 2005, and effective in January 2006, that set the stage for RE scale-up to meet China's surging electricity demand. The 2007 Renewable Energy Medium- and Long-Term Development Plan (Renewable Energy Plan), specified the country's commitment to increasing the share of RE to 15 percent of the 2020 primary energy supply. The government is increasing the targets of renewable electricity from 360 GW generating 1,490 terawatt-hours (TWh) to 500 GW generating 1,820 TWh (including large hydropower).

Established at the national level, the RE target eventually worked its way down to the provinces, through the 10th (2001–05) and 11th (2006–10) Five-Year Plans, and to individual energy-production entities, mainly through mandated RE shares.

The national target was ambitious for all technologies with special focus on wind and biomass, achieving the following:

- **Wind:** 5 GW installed and 12,300 GWh generated in 2010, and 30 GW installed and 73,800 GWh generated in 2020.
- **Biomass:** 5.5 GW installed and 27,280 GWh generated in 2010, and 30 GW installed and 148,800 GWh generated in 2020.
- **Small hydropower:** 50 GW installed and 205,000 GWh generated in 2010, and 75 GW installed and 307,500 GWh generated in 2020.
- **Solar PV:** 0.3 GW installed and 474 GWh generated in 2010, and 1.8 GW installed and 2,844 GWh generated in 2020.

The key to China's success is a wide and diverse mix of approaches, pragmatically combining three different policy instruments:

- Wind concessions, with a strict though unofficial price ceiling (however, developers benefited from compensatory subsidies per kilowatt-hour generated when bid prices failed to provide them with adequate returns);

box continues next page

Box 8.1 The Experience of China with Scaling Up Renewable Energy *(continued)*

- Feed-in prices for biomass and lately for wind; and
- RE obligations on generators, provinces, and grid companies.

These measures were supported by a clearly articulated political will and a strong domestic market that contributes to the growth of local wind power equipment manufacturing. Despite some problems, such as the difficulty of managing the multiplication of the projects at the national level and the different project approval standards applied at the local level, technical problems or fiscal disadvantages, the achievements made are impressive and unprecedented. They provide a successful example of the incentives needed for the development of RE.

Sources: World Bank/ESMAP 2011; WRI 2011.

Rather than relegate them to ad-hoc projects supported by international financiers, the government should integrate low-carbon development into mainstream policies and programs. Promoting this development should include the definition of objectives and the accountabilities to accomplish them. Based on the findings of this book, specific targets (for a time horizon of 2015–20) that the FGN might consider are as follows:

- As part of the Agricultural Transformation Agenda (ATA), bring up to 1 million hectares under sustainable land management practices, which can at the same time raise yields, increase climate resilience, and reduce net carbon emissions.
- Achieve a share of 20 percent of grid-based power generated by RE sources, 50 percent of total gas powered generation coming from combined-cycle gas turbines (CCGTs), and 20 percent of all off-grid supply being generated by renewables and hybrid systems.
- Provide 40 percent of urban mass transit in the 10–15 largest cities by formal bus services using large urban buses and bus rapid transit (BRT).
- Reduce the associated gas flared in joint venture (JV) operations by 80 percent compared to current levels and maintain the fraction of associated gas flared in production sharing contract (PSC) operations at 5 percent.

Sector-specific options, such as regulatory reforms and financial incentive schemes, can be found in the recommendations at the end of each of the sector-specific chapters (4–7).

Recommendation: Mobilize Resources for Climate Action

Addressing the financial barriers that most often prevent adoption of clean technologies is key to promoting low-carbon development. The creation or scaling up of instruments to mobilize financial resources *domestically* is important. Most of these instruments are sector-specific and thus discussed in the preceding chapters.

This section addresses two key areas related to the mobilization of resources from *international sources*: carbon markets, including the Clean Development

Mechanism (CDM), and the "nationally appropriate mitigation actions" (NAMAs), as a conduit to help developing countries articulate low-carbon priorities that could be supported by a variety of international climate finance instruments.

Carbon Markets and the Clean Development Mechanism (CDM)

Carbon markets encompass a variety of arrangements where assets that result in reduction of carbon emissions are traded for a price. One of the most important systems is the CDM, established under the Kyoto Protocol in 1997 and operational since 2001 (see box 8.2).

Box 8.2 Carbon Finance: A Brief Overview

Clean Development Mechanism (CDM)

With more than 3,800 projects registered in developing countries, the Clean Development Mechanism (CDM), established under the Kyoto Protocol in 1997 and operational since 2001, has exceeded all expectations. However, over two-thirds of all the registered projects, and over three-quarters of all issued certified emissions reductions (CERs), originate from a handful of countries. Africa's share still represents only about 2 percent of projects registered under the CDM. Despite being the most populous country in Africa (158 million people) and the third economy in size, just after South Africa and the Arab Republic of Egypt, Nigeria ranks poorly in the use of the CDM, both at the global and African levels. As of February 2012, Nigeria had only seven registered CDM projects, which have issued approximately 17,650 kCER almost equal to the emissions savings of the 40 registered projects in South Africa. There are another 16 projects in the validation process; however, fewer projects are entering the CDM pipeline as a result of the falling market prices for CERs.

Programs of Activities (PoAs)

In addition to stand-alone CDM projects, Nigeria has four programs of activities (PoAs) registered, which promote efficient cook stoves. Under this new instrument, Nigeria is lagging behind its peers, with a similar situation as CDM projects: South Africa has 37 PoAs in the pipeline and Kenya 11, out of a total of 85 in the whole African continent.

Overall, Nigeria appears to be at a disadvantage compared to the African average. Nigeria has only 6 percent of the overall CDM projects and only 2 percent of PoAs. In terms of issued CERs, Nigeria has achieved 20% of the CERs issued to Africa due to two large gas utilization projects. However, Africa has received only 3.6% of total global CERs. Even using GDP as a criterion instead of population, it is clear that Nigeria has underused its CDM possibilities.

Looking Ahead: New Instruments to Access Carbon Finance

Important CDM reforms are under way to expand the scope of the mechanism, improve process efficiency, and increase regional distribution. At the same time, the focus of the international negotiations is shifting toward new market-based instruments. Their design is expected to start taking shape under the international negotiations in the near future. However, the full-fledged development of these instruments will likely take several years.

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Box 8.2 Carbon Finance: A Brief Overview *(continued)*

Under the current market slow-down and given the European Union decision to prohibit new-project CERs beyond 2013 under the EU (European Union) Emissions Trading System (ETS) unless they are from least-developed countries, the demand for CERs may remain limited. In this environment, the reformed and expanded CDM program will be an important basis for the development of new instruments—such as the new market-based mechanism (NMM) agreed at the 17th Conference of the Parties to the UNFCCC (COP17), which could be particularly relevant for Nigeria.

The current project-by-project approach has clear limitations in the context of sector-wide transformation and is not well-adapted to deal with multi-level and multi-actor initiatives. Under new rules, adopting a higher level of aggregation for baseline setting and monitoring could allow more flexibility and efficiency. This could potentially facilitate monitoring and verification and foster the uptake of activities in sectors such as transport, which has been affected by high data requirements.

The current set of CDM rules excludes from financing eligibility a range of projects (in RE, forestry, agriculture) that can make important contributions to global mitigation efforts. In addition, the CDM is a mechanism based on results (that is, payment is made only when emissions are avoided, that is, year by year), and therefore does not provide the upfront financing that is needed to support the typically high investment costs of low-carbon technologies. In line with much of Africa, Nigeria has benefited little to date from CDM opportunities.

As discussed in box 8.2, there is an active debate on the reform of CDM and the identification of additional market-based mechanisms more relevant for developing countries. The findings of this study indicate that Nigeria has the potential to prevent carbon emissions of as much as 3.7 Gt CO_2e over 25 years. Even if just a fraction of that could be turned into assets tradable in the carbon markets of the future, the revenue potential could be significant. This suggests that it would be worthwhile for Nigeria to monitor closely ongoing international discussions on carbon markets. The rest of this section summarizes prospects for carbon market evolution in the sectors of interest for Nigeria.

CDMs and Gas Flaring Reduction

Historically, the project-by-project approach under the CDM has been a poor fit to the multi-sectoral nature of gas flaring reductions issue in Nigeria. A more streamlined CDM with more standardized approaches could bring interesting new opportunities to reduce CDM-related uncertainties. Carbon-based instruments need to allow for different levels of aggregation, applicable to clusters of fields with relevant infrastructure. A different approach for baseline setting and additionality demonstration is needed. This would allow reducing regulatory risks of carbon revenues. New carbon market mechanisms now being developed are moving in this direction.

CDMs and the Power Sector

In the power sector too, the current project-by-project approach shows clear limitation for sector-wide intervention. The deployment of RE and EE strategy at the national level requires intervention at multiple levels, from public intervention, private sector involvement, and incentives at the user level.

Given Nigeria's priority to expand the capacity of the national grid and expand energy services, it is essential that new crediting instruments have the flexibility to consider alternatives baseline scenarios, rather than the historical level. The reference level for crediting (baseline) under the existing mechanism has been disadvantageous for countries facing unmet demand, such as limited power generation capacity. Suppressed demand has recently been recognized under the CDM, but it is not yet fully integrated into existing methodologies for calculating carbon credits. Moving toward new crediting instruments, it is clear that challenges remain for the application of this concept to different accounting rules that are more aggregated and potentially based on inventory data for the sector.

CDMs in Agriculture and Forestry

The experience with developing land use, land use change, and forestry (LULUCF) projects under the CDM has proved challenging. The main barriers include the nonpermanence of credits in the LULUCF sector, limitation of scope to afforestation and reforestation (A/F), and the extensive monitoring requirements.

The experience with temporary crediting adopted for LULUCF mitigation activities under the CDM highlights the dampening effect of temporary credits on investments in emission removal activities. To address the problem, it is important to have uniform crediting and accounting procedures, so as to ensure that credits are fungible across sectors. In the case of LULUCF, this requires addressing the issue of nonpermanence. An important step in this direction has been made at the 17th Conference of the Parties (COP) of the UNFCCC, when the Subsidiary Body for Scientific and Technological Advice (SBSTA) was requested to review alternatives approaches to resolve the problem.

The Durban COP gave mandate to SBSTA to address two additional barriers to LULUCF-related carbon markets. First, SBSTA was tasked to review possible expansion of eligible activities (currently limited to A/F), to include wetlands and croplands. While an extension of eligible activities is unlikely to be of significance for the second commitment period of the Kyoto Protocol, the modalities and procedures that would be defined could serve for future crediting instruments. Second, SBSTA was also requested to consider approaches for more inclusive, and activity-based, approaches to accounting. Such a shift could potentially result in simplified monitoring requirements, thereby addressing another key obstacle that has hampered the uptake of LULUCF projects throughout the life of the CDM.

Recommendation: Formulate Nigeria's Position on the Reform of Carbon Markets

The previous discussion suggests that Nigeria has much at stake in the evolution of carbon markets. In recognition of this, the Ministry of Environment in partnership with the Ministry of Finance, and in consultation with relevant MDAs, could formulate a carbon-market position paper for submission to UNFCCC negotiations and other relevant forums. Such a paper would discuss how the CDM, and carbon markets more generally, should be reformed to enable Nigeria to turn as much as possible of the mitigation potential identified in this book into carbon revenues. It could also identify priorities for programs of activities (PoAs) to promote the sale of carbon assets on a programmatic, or sector-wide basis, rather than project-by-project.

Nigeria's Nationally Appropriate Mitigation Actions (NAMAs)

In the context of the UN Climate Change Convention (UNFCCC) and in particular of the Copenhagen Accord and Cancun Agreement, NAMAs refer to a set of policies and actions each country undertakes as part of a commitment to reduce GHG emissions. NAMAs recognize that different countries may take different nationally appropriate actions, taking into account equity considerations and the principle of differentiated responsibilities and capabilities. The concept of NAMAs also emphasizes financial assistance from developed countries to assist developing countries in their efforts to reduce GHG emissions.

As of May 2012, 44 developing country parties have presented their NAMAs to the UNFCCC. Of the pledges published by the UNFCCC secretariat in Bonn in Germany, three African nations' were prominent: Ethiopia listed 75 projects, including a new rail line to be powered by renewable energy. The Central African Republic declared that it would expand its forests to cover a quarter of its territory. Côte d'Ivoire listed a plan for more hydropower, RE, and forest management. Nigeria has developed, but not yet finalized, its own NAMA document (see box 8.3).

Box 8.3 Nigeria's Progress toward Nationally Appropriate Mitigation Actions (NAMAs)

Nigeria is in the process of defining its NAMA framework. The FGN considers them a good tool to target more strategic, long-term measures that are unlikely to be funded through carbon market mechanisms, which tend to focus on short-term emission impacts. Nigeria seeks to make NAMAs the standard framework of mitigation finance using the following criteria:

- "Bankable" programs or scalable projects
- Official endorsement by the Nigerian government
- Significant positive sustainable development impacts
- Robust monitoring, reporting, and verification (MRV) (ex-ante/ex-post)

box continues next page

Box 8.3 Nigeria's Progress toward Nationally Appropriate Mitigation Actions (NAMAs) *(continued)*

- Appropriate cost-effectiveness
- Efficient co-funding arrangements through national budget
- Adopting international high-quality standards for NAMAs, including the presence of a strong, transparent, trustworthy framework
- Simplifying co-financing arrangements for NAMAs to spread risks and achieve an adequate scale
- Making full use of decades of experience with project finance by commercial, multilateral, bilateral, and national development banks
- Focusing resources to activities where there is a financing gap to fill; and a demonstrated value added
- Improving coordination and transparency: create a sound NAMA oversight and climate finance registry

Examples of Potential Nigerian NAMAs

The following are examples of NAMAs identified for development in Nigeria:

- Expanding urban bus transport in Lagos City
- Supporting renewable electricity production through a feed-in tariff
- Promoting energy-efficient appliances in the residential and public sector: refrigeration appliances, air conditioners, lighting (compact fluorescent lamps [CFLs] and LEDs), electric motors and fans, heating appliances
- Promoting energy efficiency (EE) in the industrial sector: energy demand-side management and the developing building codes
- Reducing carbon and ozone emissions and waste from commerce and industry, including avoidance of gas flaring in the oil and gas sector, the fugitive emissions of ozone depleting substances, and end-of-life management of appliances
- Managing agricultural, municipal, and industrial waste

Additional proposed mitigation measures in Nigeria include the *Green Wall Sahara Project* (that entails the planting of trees); the *Save 80 Fuel-Efficient Wood Stove* (a UNFCCC-registered CDM project that seeks to save 80 percent of firewood, reduce emissions, and curb desertification); a switch from the conventional lighting to the solar lighting with energy-saving bulbs; determination of the carbon footprint of productive facilities; and creation of an *International Green Hall of Fame* (as an incentive to reward individuals and corporate bodies to reduce their carbon footprint).

Source: Federal Ministry of Environment 2011.

Recommendation: Articulate Nigeria's Vision for Low-Carbon Development by Finalizing the NAMAs

The document defining Nigeria's NAMAs could be a natural vehicle to accomplish the following goals: (1) articulate Nigeria's overall vision and strategy on low-carbon development, (2) define an internal consensus among stakeholders on priority policies and investment for climate action, and (3) better position the country in international discussions on climate agreements and climate finance.

Completion of the Nigeria NAMA document should be accelerated, supported by the findings in this book. The resulting priorities should be endorsed at the highest level of decision making in the FGN to ensure policy relevance and concrete follow-up.

Note

1. This scenario reduced cumulative emissions through 2035 by 40% relative to the reference scenario, compared to a 43% reduction due to the original low-carbon scenario. It cost about the same as the original low-carbon scenario and slightly more than the base case. This implies substantial robustness to key uncertainties of the main findings of the analysis.

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green press INITIATIVE

The Federal Government of Nigeria has adopted an ambitious strategy to make the nation the world's 20th largest economy by 2020. Sustaining such a rapid pace of growth will entail an expansion of activity in many sectors, including those with high carbon emissions per unit of output. In the absence of sound policies to accompany economic growth with efforts to reduce its carbon footprint, emissions of greenhouse gases could more than double in the next two decades, with negative consequences on the local and global environment.

Over the course of two years, the World Bank has worked closely with the Federal Government of Nigeria as well as with representatives of academia, the private sector, and civil society to produce the first comprehensive low-carbon development study for Nigeria.

Low-Carbon Development: Opportunities for Nigeria presents the final results of that detailed analytical effort. Focused on four key sectors—agriculture and land use, oil and gas, power, and transport—the analysis shows that low-carbon development can be an attractive and viable proposition for Nigeria, not only because it would position the country as a leader in the global fight against climate change, but also because, more importantly, it would generate significant local benefits. These include cheaper and more diversified provision of electricity; more efficient operation of the oil and gas industry; more productive and climate-resilient agriculture; and better transport services, resulting in fuel economies, better air quality, and reduced congestion. Taken together, these measures will assist in the overall fight to end poverty and build shared prosperity.

Low-Carbon Development: Opportunities for Nigeria identifies a number of specific actions that Nigeria can undertake—such as enhanced governance for climate action, integration of climate consideration in the Agriculture Transformation Agenda, promotion of energy-efficiency programs, scale-up of low-carbon technologies in power generation, accelerated reduction of gas flaring, and enhanced fuel efficiency in transport—to move toward a model of development that reduces carbon emissions while at the same time spurring the broad-based economic growth needed to end poverty.

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FAO — Fiat Panis

ESMAP — Energy Sector Management Assistance Program

THE WORLD BANK

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