2010

Brazil Low-carbon
Country Case Study

Lead Author
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Sustainable Development Department of the Latin
America and Caribbean Region

The World Bank

The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank that assists low- and middle-income countries to increase know how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth.

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This data corresponds to a disaggregation by state of the results presented for the entire country.
The data by state is available in an electronic file in the CD attached with the main report.

Foreword

In order to mitigate the impacts of climate change, the world must drastically reduce global GHG emissions in the coming decades. According to the IPCC, to prevent the global mean temperature from rising over 3oC, atmospheric GHG concentrations must be stabilized at 550 ppm. By 2030, this will require countries to reduce annual global emissions from 60 GtCO2e to less than 30 GtCO2e. At the same time, industrialized countries' emissions are expected to stabilize around 22 GtCO2e per year, with the rest of the world responsible for the remaining 38 GtCO2e. Therefore, it is clear that developed countries alone cannot sufficiently reduce their emissions to stabilize global GHG concentrations. It will be necessary for emerging economies to shift toward a low carbon development path in to reduce global GHG concentrations on the required scale.

Without Brazil playing a prominent role, it is difficult to envisage an effective solution at the global level, given its importance in setting political agendas. To date, Brazil has lead many key domestic and international initiatives to reduce greenhouse gas emissions. First, Brazil has implemented innovative policies to reduce emissions from deforestation, land use and land use changes (LULUCF), which, until recently, accounted for around 20% of global emissions. Second, in the energy sector, Brazil has accumulated unprecedented experience in renewable energy, particularly bioenergy and, as a result, Brazil's per capita fossil fuel-based emissions are significantly lower than those in other countries. Third, on December 29, 2009 the Brazilian Parliament adopted a National Climate Change Policy, which includes an ambitious voluntary national GHG reduction target for 2020. Furthermore, on the international level, Brazil has for decades been a key participant in developing agreements to tackle the climate change challenge. In June 1992, the country hosted the United Nations Conference on Environment and Development, also known as the Rio Earth Summit. The Clean Development Mechanism of the Kyoto Protocol was also a Brazilian proposal.

The Brazil Low Carbon Study aims to support Brazil's continued efforts to foster development while reducing GHG emissions. The World Bank Group has always been committed to supporting growth in developing countries, and in October 2008, it adopted a Strategic Framework on Climate Change and Development (SFCCD) to integrate climate change into the development agenda without compromising growth and poverty reduction efforts. Within the context of the SFCCD, the World Bank has undertaken a series of initiatives to support climate change mitigation within country-led development processes. One of these initiatives has been to coordinate several low-carbon growth studies through close interactions with its longstanding partners. This study is the result of that initiative.

In order to build upon the best available knowledge, the study process emphasized a consultative, iterative approach that involved extensive participation by Brazilian experts and government representatives. In particular, this study adheres to the government's development plans, exploring options to achieve the same development goals while reducing emissions in four main areas – LULUCF, energy, transport, and waste management. However, it does not stop at establishing a list of low-carbon technical options. It builds understanding of the current dynamics that drive emissions in these sectors and examines the necessary conditions for these

low-carbon options to be effectively scaled-up in place of conventional ones. By doing so, the study provides technical and analytical elements for exploring possible emissions reductions through 2030, going beyond the 2020 voluntary commitments announced by the Government.

Many developing countries have already indicated their commitment to addressing climate change by declaring their willingness to implement Nationally Appropriate Mitigation Actions (NAMAs), which in many cases will require external financial support. Brazil has demonstrated a growing interest in helping other developing countries to move along sustainable development paths through increased South-South cooperation. It is our hope that both the tools and the findings of this study will be of use to Brazil and other countries as they seek to move towards low-carbon development paths.

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Acronyms and Abbreviations

ABRELPE — Brazilian Association of Public Cleaning and Special Waste Companies (Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais)

ANFAVEA — National Association of Motor Vehicle Manufacturers (Associação Nacional dos Fabricantes de Veículos Automotores)

ANEEL — National Agency for Electric Energy (Agencia Nacional de Energia Elétrica)

ANP — National Agency of Petroleum, Natural Gas, and Biofuels (Agência Nacional do Petróleo, Gás Natural, e Biocombustíveis)

ARPA — Amazon Region Protected Areas Program

BDMG — Minas Gerais Development Bank

BEN — National Energy Balance

BLUM — Brazil Land Use Model

BNDES — National Bank of Economic and Social Development (Banco Nacional de Desenvolvimento Econômico e Social)

BRT — Bus Rapid Transit

CAN — National Confederation of Agriculture and Livestock

CBERS — China-Brazil Earth Resources Satellites

CCC — Fuel Consumption Account (Conta de Consumo de Combustíveis)

CCS — Socio-environmental Commitment Register

CDE — Energy Development Account (Conta de Desenvolvimento Energético)

CDM — Clean Development Mechanism

CEAF — Center for Alternative Energy Strengthening (Centro de Energias Alternativas de Fortaleza)

CEIF — Clean Energy Investment Framework

CEPEL — Research Center for Electrical Energy (Centro de Pesquisas de Energia Elétrica)

CER — Certified Emissions Reduction

CETESB — São Paulo State Waste Management Agency (Companhia de Tecnologia de Saneamento Ambiental)

CFL — Compact Fluorescent Lamp

CGEE — Center for Strategic Management and Studies

CH_4 — Methane

CIDE — Contribution on Intervention in the Economic Domain (Contribuição de Intervenção no Domínio Econômico)

CMN — National Monetary Council (Conselho Monetário Nacional)

CNG — Compressed Natural Gas

CONAB — National Crop Supply Agency

CONPET — National Program for the Rationalization of the Use of Oil and Natural Gas Derivatives (Programa Nacional de Racionalização do Uso dos Derivados de Petróleo e Gás Natural)

CO_2 — Carbon Dioxide

COPPE — Post-graduate Engineering Programs Coordination

CPTEC — Center for Weather Forecasts and Climate Studies

CSR	Remote Sensing Center
CTEnerg	Sector Energy Fund of the Ministry of Science and Technology (Fundo Sectorial de Ciência e Tecnologia para Energia)
CT-Petro	Oil and Natural Gas Sector Fund of the Ministry of Science and Technology (Fundo Sectorial de Ciência e Tecnologia para Petróleo e Gás)
CU	Conservation Unit
DEGRAD	Mapping of Forest Degradation in the Brazilian Amazon
DETER	Detection System for Deforestation in Real Time
EGO	Environment for Geoprocessing Objects
EIA	Energy Information Administration
EMBRAPA	Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agrícola)
EPE	Energy Planning Company (Empresa de Planejamento Energético)
ESCO	Energy Efficiency Service Company
FAPRI	Food and Agricultural Policy Research Institute
FDI	Foreign Direct Investment
FGEE	Guarantee Fund for Electric Energy Projects
FGTS	Social Security (Fundo de Garantia do Tempo de Serviço)
FINAME-Agricola	Agency for the Acquisition of Machines and Equipment (Agência de Financiamentos para Aquisição de Máquinas e Equipamentos)
FINEM	Equipment and Machinery Financing (Financiadora de Equipamentos e Máquinas)
FINEP	Agency for the Funding of Projects and Studies (Financiadora de Estudos e Projetos)
FNP	FINEP Consulting & Trade (FINEP Consultoria & Comércio)
FUNAI	National Foundation for Indigenous People
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GNP	Gross National Product
GTL	Gas-To-Liquid
GTZ	German Technical Cooperation Agency
HFC	Hydrofluorocarbon
IAEA	International Atomic Energy Agency
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis)
IBGE	Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística)
IBP	Potential Biomass Index
ICMBio	Chico Mendes Institute of Biodiversity Conservation (Instituto Chico Mendes de Conservação da Biodiversidade)
ICONE	Institute for International Trade Negotiations
IEA	International Energy Agency
IGP-DI	General Price Index-Domestic Availability (Índice Geral de Preços-Disponibilidade Interna)
INPE	National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais)
INT	National Technological Institute (Instituto Nacional de Tecnologia)
I-O	Input-Output
IPAM	Amazon Institute for Environmental Research (Instituto de Pesquisa Ambiental da Amazonia)

IPCC	Intergovernmental Panel on Climate Change
IPI	Industrial Products Tax
IRR	Internal Rate of Return
KfW	German Development Bank
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land-Use Change, and Forestry
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MCT	Ministry of Science and Technology (Ministério de Ciência e Tecnologia)
MELP	Long-term Expansion Model
MEPS	Minimum Energy Performance Standard
MIPE	Integrated Energy Planning Model
MMA	Ministry of the Environment (Ministério do Meio Ambiente)
MME	Ministry of Mines and Energy (Ministério de Minas e Energia)
M-Ref	Refining Study Model
MSR	Residential Energy Demand Projection Model
MT	Ministry of Transport (Ministério dos Transportes)
N	Nitrogen
NAPCC	National Action Plan on Climate Change
NIPE	Interdisciplinary Center for Strategic Planning
NPV	Net Present Value (Valor Presente Líquido)
NRC	National Research Council
N_2O	Nitrous Oxide
OECD	Organisation for Economic Co-operation and Development
PAC	Government Accelerated Growth Plan
PAS	Sustainable Amazon Program
PFC	Perfluorocarbon
PLANSAB	National Sanitation Plan (Plano Nacional de Saneamento Básico)
PME	Monthly Employment Survey
PNE	National Energy Plan (Plano Nacional de Energia)
PNLT	National Logistics and Transport Plan (Plano Nacional de Logistica e Transporte)
PNMC	National Plan on Climate Change (Plano Nacional sobre Mudança do Clima)
PPA	Permanent Preservation Area
PPCDAM	Plan of Action for the Prevention and Control of Deforestation in the Legal Amazon (Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal)
PPP	Public-Private Partnership
PROALCOOL	National Alcohol Program
PROBIO	Project for the Conservation and Sustainable Use of Brazilian Biological Diversity
PROCEL	National Electrical Energy Conservation Program (Programa de Combate ao Desperdício de Energia Elétrica)
PRODES	Amazon Deforestation Monitoring Program (Programa de Cálculo do Desflorestamento da Amazônia)
PRODUSA	Programa de Estímulo a Produção Agropecuária Sustentável)
PROESCO	Support Program for Energy Efficiency Projects (Programa de Apoio a Projetos de Eficiência Energética)

PROINFA	Incentive Program for Alternative Electric Energy Sources (Programa de Incentivo às Fontes Alternativas)
PROLAPEC	Agriculture-Livestock Integration Program (Programa de Integração Lavoura-Pecuária)
PRONAF	National Program for the Strengthening of Family Agriculture (Programa Nacional de Fortalecimento da Agricultura Familiar)
PROPASTO	National Program for Recuperation of Degraded Pastures
PROPFLORA	Program for Commercial Planting and Recovery of Forests (Programa de Plantio Comercial e Recuperação de Florestas)
R&D	Research and Development
REDD	Reducing Emissions from Deforestation and Degradation
RGR	Global Reversion Reserve (Reserva Global de Reversão)
RSU	Urban Solid Residues (Residuos Sólidos Urbanos)
SAE	Secretariat of Strategic Affairs (Secretaria de Assuntos Estratégicos)
SFB	Brazilian Forest Service
SF_6	Sulfur Hexafluoride
UFMG	Federal University of Minas Gerais (Universidade Federal de Minas Gerais)
UFRJ	Federal University of Rio de Janeiro
UNFCCC	United Nations Framework Convention on Climate Change
UNICAMP	State University of Campinas
USP	University of São Paulo
WTI	West Text Intermediate

Units of Measure

Ce	Carbon Equivalent
CO_2e	Carbon Dioxide Equivalent
ETE	Sewage Treatment Plant
gCO_2e	Grams of Carbon Dioxide Equivalent
Gt	Billions of Tons
Gt CO_2e	Billion Tons of Carbon Dioxide Equivalent
GW	Gigawatt
GWh	Gigawatt Hour
ha	Hectare
kg	Kilogram
km	Kilometer
km^2	Square Kilometer
kW	Kilowatt
m	Meter
m^3	Cubic Meters
Mt	Millions of Tons
Mt CO_2e	Million Tons of Carbon Dioxide Equivalent
MW	Megawatt
MWh	Megawatt Hour
ppm	Particles per Million
tCO_2e	Tons of Carbon Dioxide Equivalent
TWh	Terawatt Hour

Currency Exchange

1 US Dollar (US$) = 2.20 Brazilian Real (R$)

Executive Summary

Brazil's commitment to combat climate change had already begun when the country hosted the United Nations Conference on Environment and Development, also known as the Rio Earth Summit, in June 1992. The resulting United Nations Framework Convention on Climate Change (UNFCCC) led to the creation of the Kyoto Protocol. Today, Brazil remains strongly committed to voluntarily reducing its carbon emissions. On December 1, 2008 President Luiz Inácio Lula da Silva launched the National Plan on Climate Change (PNMC), based on work of the Interministerial Committee on Climate Change, in collaboration with the Brazilian Forum on Climate Change and civil society organizations. The PNMC calls for a 70-percent reduction in deforestation by 2017, a particularly noteworthy goal given that Brazil has the world's second largest block of remaining native forest. On December 29, 2009 the Brazilian Parliament adopted Law 12.187, which institutes the National Climate Change Policy of Brazil and set a voluntary national greenhouse gas reduction target of between 36.1% and 38.9% of projected emissions by 2020.

As the world's largest tropical country, Brazil is unique in its greenhouse gas (GHG) emissions profile. **In prior decades, the availability of large volumes of land suitable for crop cultivation and pasture helped to transform agriculture and livestock into key sectors for sustaining the country's economic growth**. In the past decade alone, these two sectors accounted for an average of 25 percent of national GDP. The steady expansion of crop land and pasture has also required the conversion of more native land, **making land-use change the country's main source of GHG emissions today. At the same time, Brazil has used the abundant natural resources of its vast territory to explore and develop low-carbon renewable energy.**

Currently, per capita fossil fuel–based emissions in Brazil are much lower than those in other countries,[1] owing to the large role of renewable-energy sources for electricity and fuels. Hydropower represents more than three-fourths of installed electricity generation capacity, while ethanol substitutes for two-fifths of gasoline fuel. **Without the historically large investments in renewable energy, Brazil's current energy matrix would be far more carbon intensive. If Brazil's energy matrix reflected the worldwide average, energy-sector emissions would presumably be twice as high and total national emissions 17 percent greater. The energy and transport sectors in Brazil are, thus, already widely based on low-carbon alternatives and current efforts to keep the energy matrix clean must be acknowledged. However, the maintenance of a low-carbon development path in Brazil will continue to require larger investments in low-carbon options and additional measures to reduce emissions in the Brazilian energy sector may require increased efforts.**

Yet Brazil used to be one of the largest GHG emitters from deforestation and would probably continue to be so if not for the government's recent adoption of a series of measures to protect the forest. Although drastically reduced in recent years, deforestation could continue to be a potentially large emission source in the future. Exacerbating this outlook are expected growth in carbon-intensive sources of electric power, accelerated use of diesel-based transport, and a larger volume of methane (CH_4) emissions from expanded landfill development.

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1   Fossil fuel–based emissions amount to about 1.9 tCO_2 per year per capita or less than one-fifth of the OECD country average.

At the same time, Brazil is likely to suffer significantly from the adverse effects of climate change. Some advanced models suggest that much of the eastern part of the Brazilian Amazon region could be converted into a savannah-like ecosystem before the end of this century. A phenomenon known as the Amazon dieback, combined with the shorter-term effects of deforestation by fires, could reduce rainfall in the Central-West and Northeast regions, resulting in smaller crop yields and less available water for hydropower-based electricity[2]. Urgent solutions are thus needed to reduce Brazil's vulnerability to climate change **and to enable the implementation of adaptation actions in the country**.

Like many other developing countries, Brazil faces the dual challenge of encouraging development and reducing GHG emissions. President Lula echoed this concern in his introduction to the National Plan, stating that actions to avoid future GHG emissions should not adversely affect the development rights of the poor, who have done nothing to generate the problem. Efforts to mitigate GHG emissions should not add to the cost of development, but there are strong reasons to shift toward a low-carbon economy. Low-carbon alternatives would offer important development co-benefits, ranging from reduced congestion and air pollution in urban transport areas to better waste management, jobs creation and costs savings for industry, and biodiversity conservation. Countries that pursue low-carbon development are more likely to benefit from strategic and competitive advantages, such as the transfer of financial resources through the carbon market, new international financing instruments, and access to emerging global markets for low-carbon products. In the future this may create a competitive advantage for the production of goods and services, due to the lower emission indexes associated with the life cycle of products.

Study Overview

The overall aim of this study was to support Brazil's efforts to identify opportunities to reduce its emissions in ways that foster economic development. The primary objective was to provide the Brazilian government the technical inputs needed to assess the potential and conditions for low-carbon development in key emitting sectors.

To this end, the World Bank study adopted a programmatic approach in line with the Brazilian government's long-term development objectives, as follows: (i) anticipate the future evolution of Brazil's GHG emissions to establish a reference scenario; (ii) identify and quantify lower carbon-intensive options to mitigate emissions, as well as potential options for carbon uptake; (iii) assess the costs of these low-carbon options, identify barriers to their adoption, and explore measures to overcome them; and (iv) build a low-carbon emissions scenario that meets the same development expectations. The team also analyzed the macroeconomic effects of shifting from the reference scenario to the low-carbon one and the financing required.

To build on the best available knowledge and avoid duplicate effort, the study team undertook a broad consultative process, meeting with more than 70 recognized Brazilian experts, technicians, and government representatives covering most emitting sectors and surveying the copious literature available. This preparatory work informed the selection of four key areas with a large potential for low-carbon options: (i) land use, land-use change, and forestry (LULUCF), including deforestation; (ii) transport systems; (iii) energy production and use, particularly electricity and oil and gas; and (iv) solid and liquid urban waste.[3]

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2   "Assessment of the Risk of Amazon Dieback," World Bank, 2010.
3   Certain industrial sources of nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs), sulfur hexafluoride (SF_6), and other non-Kyoto GHG gases are not covered by this study. Without a recent

In order to estimate the emissions Brazil would generate in these four key areas over the study period, the study team defined a "reference scenario" that is later compared with the projected "low-carbon scenario". It is worth noting that the reference scenario is based on a different methodology than the one used by the Brazilian government in its national GHG inventory. In particular, having focused on these four areas, the reference scenario built by this study does not cover 100 percent of all emission sources of the country and therefore, should not be considered as a simulation of future national emissions inventories.

Since the objective of this study was not to simulate the future development of the Brazilian economy or to question the government's stated development objectives, this study has adhered, to the extent possible, to existing government plans to establish the reference scenario. Therefore, the 2030 National Energy Plan (PNE 2030), published by the Ministry of Mines and Energy (MME) in 2007, was adopted as the reference scenario for the energy sector. The study also took into account of Brazil's Government Accelerated Growth Plan (PAC) and the National Logistic and Transport Plan (PNLT), launched in 2007, and other policies and measures in other sectors that were already published by the time the reference scenario was established[4]. Where long term planning publications were unavailable, the team built its own reference scenarios, using sector models developed or adapted for the project, consistent with the main assumptions of the PNE 2030. Key interfaces (e.g., determining the land needed for solid and liquid biofuels production in the transport and energy sectors) were addressed jointly by the teams in charge of these sectors and the land-use modeling.

Reference-scenario results for these main areas show that deforestation remains the key driver of Brazil's future GHG emissions through 2030. Modeling results indicate that, after a slight decrease in 2009–11, deforestation emissions are expected to stabilize at an annual rate of about 400–500 Mt CO_2. Even so, the relative share declines to about 30 percent as emissions from the energy, transport, and waste-management sectors continue to grow. Since transport and energy consumption are both functions of economic growth, certain subsectors dependent on fossil fuels (e.g., urban bus systems or thermal power generation and industrial processes) have high emissions growth; for subsectors that depend on energy forms with a lower carbon intensity (e.g., bioethanol-powered vehicles or hydropower-generated electricity), levels of emission remain relatively stable. An annex of maps and an electronic database detail the results of the study by state.

Land Use and Land-use Change: Toward a New Dynamic

Despite its significant decline in the past four years, deforestation remains Brazil's largest source of carbon emissions, representing about two-fifths of national gross emissions (2008). Over the past 15 years, deforestation has contributed to reducing Brazil's

complete inventory, it is not possible to determine precisely the share of other sources in the national GHG balance. However, based on the first Brazil National Communication (1994), it is expected that they would not exceed 5 percent of total Kyoto GHG emissions. Not all agriculture activities were taken into account when estimating emissions from that sector; crops taken into account in the calculation of the emissions from agriculture represent around 80% of the total crop area.

4 As a result of the methodology used to establish this reference scenario, it differs from the projections of national and sectoral emissions officially announced by the Brazilian Government in 2009 along with the voluntary commitment to reduce emissions, which are reflected in law Law 12.187. The difference between the reference scenario defined in this study and the one established by the Brazilian government on the basis of past trends reflects the positive impact on emission reductions of the policies already adopted at the time this study's reference scenario was established. Notably, the reference scenario was defined before the elaboration of the National Plan on Climate Change (PNMC) and the adoption of Law 12.187, which institutes the National Climate Change Policy of Brazil and set a voluntary national greenhouse gas reduction target.

carbon stock by about 6 billion metric tons, the equivalent of two-thirds of annual global emissions.[5] Without the Brazilian government's recent forest protection efforts, the current emissions pattern from deforestation would be significantly higher.[6] The drivers of deforestation occur at multiple levels. In the Amazon and Cerrado regions, for example, the spatial dynamics of agricultural and livestock expansion, new roads, and immigration determine the pattern of deforestation. At a national or international scale, broader market forces affecting the meat and crop sectors drive deforestation.

Agricultural production and livestock activities also produce direct emissions, together accounting for one-fourth of national gross emissions. Agricultural emissions mainly result from the use of fertilizer and mineralization of nitrogen (N) in the soil, cultivation of wetland irrigated rice, the burning of sugar cane, and use of fossil fuel–powered agricultural equipment. Livestock emissions result mainly from the digestive process of beef cattle, which releases of methane (CH_4) into the atmosphere.

Models and Reference-scenario Results

To estimate future demand for land and LULUCF emissions, the study developed two complementary models: i) Brazilian Land Use Model (BLUM) and (ii) Simulate Brazil (SIM Brazil). BLUM is an econometric model that estimates the allocation of land area and measures changes in land use resulting from supply-and-demand dynamics for major competing activities.[7] SIM Brazil, a geo-referenced spatialization model, estimates future land use over time under various scenarios. SIM Brazil does not alter BLUM data; it finds a place for land-use activities, taking into account such criteria as agricultural aptitude, distance to roads, urban attraction, cost of transport to ports, declivity, and distance to converted areas. SIM Brazil works at a definition level of 1 km^2, making it possible to generate detailed maps and tables.

Under the reference scenario, about 17 million ha of additional land are required to accommodate the expansion of all activities over the 2006–30 period. In Brazil as a whole, the total area allocated to productive uses, estimated at 257 million ha in 2008, is expected to grow 7 percent—to about 276 million ha—in 2030; 24 percent of that growth is expected to occur in the Amazon region. In 2030, as in 2008, pastures are expected to occupy most of this area (205 million ha in 2008 and 207 million in 2030). Growth of this total amount over time makes it necessary to convert native vegetation to productive use, which mainly occurs in frontier regions, the Amazon region, and, on a smaller scale, in Maranhão, Piaui, Tocantin, and Bahia.

To estimate the corresponding balance of annual emissions and carbon uptake over the next 20-year period, these and related models calculated land use and land-use change for each 1-km^2 plot at several levels.[8] Results showed that land-use change via deforestation accounts for the largest share of annual LULUCF emissions—up to 533 Mt CO_2e by 2030. Direct annual emissions from land use only (agriculture and livestock) increase over the period, with an average annual rate of 346 Mt CO_2e. Carbon uptake offsets less than 1 percent of gross LULUCF emissions, sequestering 29 Mt CO_2e in 2010, down to 20 Mt CO_2e in 2030. Over the 20-year period, LULUCF gross emissions increase one-fourth, reaching 916 Mt CO_2e by 2030. **The**

5   From 1970 to 2007, the Amazon lost about 18 percent of its original forest cover; over the past 15 years, the Cerrado lost 20 percent of its original area, while the Atlantic Forest, which had been largely deforested earlier, lost 8 percent.

6   After peaking at 27,000 km^2 in 2004, deforestation rates have declined substantially, falling to 11,200 km^2 in 2007, the second lowest historical rate recorded by the PRODES deforestation observation program (INPE 2008).

7   These include six key crops (soybean, corn, cotton, rice, bean, and sugar cane), pasture, and production forests; the model also projects demand for various kinds of meat and corresponding needs for chaff and corn.

8   Microregion, state, and country.

net balance between land use, land-use change, and carbon uptake results in increased emissions, which reach about 895 Mt CO$_2$e annually by 2030[9].

Low-carbon Options for Emissions Mitigation

Avoiding deforestation offers by far the largest opportunity for GHG mitigation in Brazil. Under the resulting low-carbon scenario, avoided emissions from deforestation would amount to about 6.2 Gt CO$_2$e over the 2010–30 period, or more than 295 Mt CO$_2$e per year.

Brazil has developed forest-protection policies and projects to counter the progression of pressure at the frontier and is experienced in economic activities compatible with forest sustainability. **Shifting to a low-carbon scenario that ensures growth of agriculture and the meat industry—both important to the Brazilian economy—would also require acting on the primary cause of deforestation: demand for more land for agriculture and livestock.**

To drastically reduce deforestation, this study proposed a dual strategy: (i) eliminate the structural causes of deforestation and (ii) protect the forest from illegal attempts to cut. Eliminating the structural causes of deforestation would require a dramatic increase in productivity per hectare. **Increasing livestock productivity could free up large quantities of pasture.** This option is technically possible since Brazil's livestock productivity is generally low and existing feedlots and crop-livestock systems could be scaled up; use of more intensive production systems could trigger higher economic returns and a net gain for the sector economy (chapter 7). **The potential to release and recover degraded pasture is enough to accommodate the most ambitious growth scenario.**

The combination of reducing pasture area and protecting forests can lead to a sharp decline in deforestation emissions. This was demonstrated in 2004–07, when new forest-protection efforts, combined with a slight contraction in the livestock sector and resultant pasture area,[10] led to a 60-percent reduction in deforestation (from 27,000 km^2 to 11,200 km^2). **Such a rapid reduction resulted from deforestation and its associated emissions being related to the *marginal expansion* of land for agriculture and livestock activities,[11] without which there would be no need to convert additional native vegetation and incidentally generate GHG emissions. If the effort to reduce pasture area and protect forests were neglected, emissions from deforestation would resume immediately. To protect against illegal cuts, the forest should be further protected against fraudulent interests.** The Brazilian government has made considerable efforts in this area, particularly under the 2004 Plan of Action for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM).

Model-based projections indicate that, under the new land-use dynamic, deforestation would be reduced by more than two-thirds (68 percent) in 2030, compared to *projected* levels in the reference scenario; in the Atlantic Forest, the reduction would be about 90 percent, while the Amazon region and Cerrado would see reductions of 68 percent and 64 percent,

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9 When calculating national carbon inventories, some countries consider the contribution of natural regrowth towards carbon uptake; therefore, although this study does not compute this contribution in the carbon balance of LULUCF activities, it would be fair to add that information for comparison purposes. If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 109MtCO2 per year, thus reducing the net emissions.

10 The 2005–07 period witnessed the first decline in herd size (from 207 million to 201 million head), following a decade-long increase, together with a slight contraction in pasture area (from 210 million to 207 million ha).

11 Unlike other sectors, whose energy-based emissions are usually proportional to the *full size* of the sector activity, emissions from deforestation are related only to the *marginal* expansion of agriculture and livestock activities.

respectively. **Accordingly, in 2030, annual emissions from deforestation would be reduced nearly 63 percent (from about 530 Mt CO_2 to 190 Mt CO_2) compared to the *projected* reference scenario. In the Amazon, the level of deforestation would fall quickly to about 17 percent of the historic annual average of 19,500 km² *observed* in the recent past, thus complying with the PNMC goal of reducing deforestation in the Amazon region by 72% by 2017**[12].

The study also proposed ways to reduce direct emissions from agricultural production and livestock activities. For agriculture, the study proposed an accelerated dissemination of zero-tillage cultivation. Compared to conventional farming systems, zero-tillage involves far fewer operations and can thus reduce emissions caused by altering soil carbon stock and using equipment powered by fossil fuels. Done effectively, zero-tillage cultivation can help control soil temperature, improve soil structure, increase soil water-storage capacity, reduce soil loss, and enhance the nutrient retention of plants. For these reasons, expansion of zero-tillage cultivation is accelerated in the low-carbon scenario, reaching 100 percent by 2015 and delivering 356 Mt CO_2e of avoided emissions over the 2010–30 period.

To lower direct emissions from beef-cattle farming, the study proposed shifting to more intensive meat-production systems, as mentioned above. **It also proposed genetic-improvement options to reduce CH_4, including improved forage for herbivores and genetically superior bulls**, which have a shorter life cycle. The study projects that the combination of improved forage and bulls, along with increased productivity, would reduce direct livestock emissions from 272 to 240 Mt CO_2 per year by 2030; that is, maintain them close to the 2008 .

The study also explored two major carbon uptake options: (i) recovery of native forests and (ii) production forests for the iron and steel industry . For forest recovery, the low-carbon scenario considered compliance with legal actions for mandatory reconstitution, in accordance with the laws of riparian forests and legal reserves.[13] In this sense, the low-carbon scenario engendered a "Legal Scenario." Using these defined areas for reforestation, the study modeled their potential for CO_2 removal.[14] Results showed that the Legal Scenario has a high carbon-uptake potential: a cumulative total of 2.9 Gt CO_2e over the 20-year period or about 140 Mt CO_2e per year on average[15]. For production forests, the reference scenario assumed that the thermo-reduction process would be based on coke (66 percent), non-renewable plant charcoal (24 percent), and renewable plant charcoal (10 percent). The low-carbon scenario assumed total substitution of non-renewable plant charcoal by 2017 and use of renewable plant charcoal for up to 46 percent of total production of iron and steel ballast by 2030; the volume of sequestered emissions would total 377 Mt CO_2 in 2030, 62 Mt CO_2 more than in the reference scenario.

A New Dynamic for Land Use

Building a low-carbon scenario for land use involves more than adding emissions reductions associated with mitigation opportunities; it must also avoid the potential for carbon leakage. For example, increasing forest recovery leads to carbon uptake, but it also

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12   Over the 1996–2995 period, the historical rate of deforestation in the Amazon region was 1.95 million ha per year, according to the PNMC.

13   In areas with optimal conditions, forest recovery can remove 100 tC per ha on average in the Amazon Region. (Saatchi, 2007). In the reference scenario, its contribution is limited in terms of quantity.

14   The study model used meteorological and climatic variables (e.g., rainfall, dry season, and temperature) and edaphic (soil and topography) variables to estimate potential biomass.

15   If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 112MtCO2 per year on average.

reduces the land area otherwise available for expanding agriculture and livestock activities. This, in turn, could provoke an excess in demand for land use, which could generate deforestation, inducing a lower net balance of carbon uptake. To avoid a carbon leakage, ways must be found to reduce the global land demand for other activities, while maintaining the same level of products supply found in the reference scenario.

In the low-carbon scenario, the amount of additional land required for emissions mitigation and carbon uptake totals more than 53 million ha. Of that amount, more than 44 million ha—over twice the land expansion projected under the reference scenario—is for forest recovery. Together with the additional land required under the reference scenario, the total volume of additional land required is more than 70 million ha, more than twice the total amount of land planted with soybean (21.3 million ha) and sugar cane (8.2 million ha) in 2008 or more than twice the area of soybean projected for 2030 in the reference scenario (30.6 million ha) (table 1).

Table 1: Summary of Additional Land Needs in the Reference and Low-carbon Scenarios

Scenario	Additional land needed (2006–30)
Reference Scenario: additional volume of land required for the expansion of agriculture and livestock activities	*Expansion of agriculture and livestock production to meet the needs anticipated in 2030:* → *16.8 million ha*
Low-carbon scenario: additional volume of land required for mitigation measures	Elimination of non-renewable charcoal in 2017 and the participation of 46% of renewable planted charcoal for iron and steel production in 2030: → *2.7 million ha*
	Expansion of sugar cane to increase gasoline substitution with ethanol to 80% in the domestic market and supply 10% of estimated global demand to achieve an average worldwide gasoline mixture of 20% ethanol by 2030: → *6.4 million ha*
	Restoration of the environmental liability of "legal reserves" of forests, calculated at 44.3 million ha in 2030. → *44.3 million ha*
Total	*70.4 million additional hectares*

To increase livestock productivity to the level needed to release the required volume of pasture, the low-carbon scenario considered three options: (i) promote recovery of degraded pasture, (ii) stimulate the adoption of productive systems with feedlots for finishing, and (iii) encourage the adoption of crop-livestock systems. The increased carrying capacity that results from recovery of degraded areas, combined with more intensive integrated crop-livestock systems and feedlots for finishing are reflected in an accentuated reduction in demand for land, projected at about 138 million ha in the low-carbon scenario, versus 207 million ha in the reference scenario, for the year 2030. The difference would be enough to absorb the demand for additional land associated with both expanded agriculture and livestock activities in the reference scenario and expanded mitigation and carbon uptake in the low-carbon scenario.
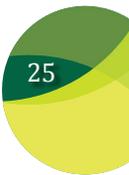
Energy: Sustaining a Green Energy Matrix

The intensity of GHG emissions in Brazil's energy sector is comparatively low by international standards, owing to the significant role of renewable energy in the national energy matrix. Renewable energy accounts for nearly half of Brazil's domestic energy supply—more than three-quarters of it provided by hydroelectricity (MME 2007). In 2005, the country's energy sector accounted for just 1.2 percent of the world's 27 Gt CO_2, of fossil-fuel emissions, corresponding to an annual average per capita of 1.77 tCO_2, significantly less than annual global (4.22 tCO_2) and OECD-country (11.02 tCO_2) per-capita averages (IEA 2007). In 2010, emissions from energy production and consumption, excluding transport, represented about one-fifth of national emissions.

Reference Scenario: 97-percent Increase in Emissions

The PNE 2030, on which the sector reference scenario is based, reflects recent sector policies and basic market tendencies and features, including the dynamics of incorporating technology and the evolution of supply and demand[16]. The view toward long-term technical and economic consistency renders the PNE 2030 an important tool for creating the energy-sector reference scenario; however, for circumstantial reasons, (i.e. adverse hydrological conditions), Brazil's higher use of thermoelectric power in recent years was anticipated by the PNE 2030. If this were to continue over a longer term, the Brazilian grid's average emissions factor would be greater than that projected by the MME in 2007. If hydroelectricity proves substantially less than predicted, the reference scenario considered in this study would prove conservative.

Although the PNE 2030 assumes greater use of renewable energy sources over the 2010–30 study period, Brazil's energy matrix should result in higher emissions over time under the reference scenario. For 2030, the projected emissions figure, excluding fuels for transport, is just over 458 Mt CO_2, representing a 97-percent increase or more than one-fourth of national emissions. Cumulative sector emissions are estimated at 7.6 Gt CO_2 over the 20-year period.

Low-carbon Mitigation Potential: Less Than 20 Percent

To develop the low-carbon scenario, the study analyzed mitigation options for energy efficiency and fuel switching in industry, refining and gas-to-liquid (GTL), wind-energy generation and bagasse cogeneration, and high-efficiency appliances.[17] Since most of Brazil's main remaining large-hydropower potential will have been fully exploited by 2030 (PNE 2030), the study assumed no further opportunities to significantly reduce emissions via hydropower expansion beyond what was established in the reference scenario. Beyond options to reduce domestic emissions, the study considered two opportunities to reduce emissions abroad: (i) hydro-complementarity (to reduce CO_2 emissions of energy sectors in Brazil and Venezuela) and

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16   The reference scenario adopted in this study, the PNE2030, differs from the emissions projections for the energy sector officially announced by the Brazilian Government in 2009 along with the voluntary commitment to reduce emissions, which are reflected in law Law 12.187. The difference between the reference scenario defined in this study and the one established by the Brazilian government on the basis of past trends reflects the positive impact on emission reductions of the policies already adopted in the PNE2030.

17   To avoid double counting, this study considered emissions reductions from vehicular fuel switching as transport-sector emissions reduction.

(ii) large-scale ethanol exports (to reduce fossil-fuel emissions of transport sectors worldwide).

Over the 2010–30 period, cumulative emissions reductions would amount to 1.8 Gt CO$_2$ or less than 25 percent of cumulative emissions of the sector in the reference scenario.[18] If all of the proposed low-carbon mitigation options were implemented, annual energy-sector emissions would be reduced by 35 percent in the year 2030.[19] Not surprisingly, the industrial sector, which still relies heavily on fossil fuels, would account for 75 percent of 2030 reductions (68 Mt CO$_2$ per year), followed by renewable charcoal for the steel industry (31 percent) and biomass cogeneration (9 percent). **Even so, energy-sector emissions under the low-carbon scenario would remain about 28 percent higher in 2030 than in 2008.**

Scaled-up Ethanol Exports: One-third Increase in Mitigation Potential

Brazil's success with bio-ethanol offers an opportunity to reduce global emissions by increasing ethanol exports. It terms of emissions, social costs, and economic production costs, ethanol from sugar in Brazil is superior to alternatives in others countries, reflecting a significant comparative advantage to serve the growing international demand for low-carbon vehicle fuels. Reducing or eliminating the high trade barriers and enormous subsidies currently in place in many countries would produce economic benefits for both Brazil and its trade partners, and reduce GHG emissions. While the size of such exports depends on counterfactual assumptions, this study adopted a target of 70 billion liters by 2030—57 billion more than in the PNE 2030 reference scenario and slightly more than 2 percent of estimated global gasoline consumption for that year (equal to 10 percent of bio-ethanol demand to reach an average target of 20 percent ethanol blend in gasoline worldwide). This target corresponds to the lower bound of a recent study on the feasibility of scaled-up ethanol production for export.[20]

The added emissions reductions achieved via ethanol exports would reach 73 Mt CO$_2$ per year in 2030 and would amount to 667 Mt CO$_2$ over the 2010–30 period or about one-third of the total reduction in energy emissions. The additional ethanol would require increasing the area planted to sugar cane by 6.4 million ha in 2030 (from 12.7 to 19.1 million ha), still less than the current area planted to soybean (22.7 million ha in 2006) and one-tenth the current pasture area (210 million ha).[21] As explained above, it is assumed that, as long as the proposed goals for increasing livestock-raising productivity are met, sugar-cane expansion would not result in deforestation, either directly or indirectly through pasture expansion, and sugar-cane production would not occur on conservation lands.

Transport: Modal Shifts and Fuel Switching

Brazil's **transport sector has a lower carbon intensity compared to that of other countries because of the widespread use of ethanol as a fuel for vehicles.** Still, the transport sector accounts for more than half of the country's total fossil-fuel consumption. In 2008, the sector emissions were about 149 Mt CO$_2$e, representing 12 percent of national emissions.

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18 Excluding 667 Mt CO$_2$ of avoided emissions from ethanol exports and 28 Mt CO$_2$ from the transmission line between Venezuela and Brazil.

19 In 2030, annual emissions would be reduced from 458 to 297 Mt CO$_2$ (excluding transport) or from 735 to 480 Mt CO$_2$ (including transport); that is, an annual reduction similar to Argentina's emissions in 2000.

20 NIPE/UNICAMP report for CGEE/MCT, Campinas, December 2007.

21 The measures proposed to reduce deforestation under the low-carbon scenario considered the added land required for planting sugar-cane for ethanol export to avoid carbon leakage.

Urban transport accounts for about 51 percent of direct sector emissions in 2008. The main causes are increased use of private cars, congestion, and inefficient mass transport systems. **The study revealed that a modal shift to Bus Rapid Transit (BRT) and Metro plus traffic management measures have a potential to reduce urban emissions by about 26 percent in 2030**; however, policy, coordination, and financing issues often prevent their implementation. The country's more than 5,000 municipalities administer their own transit and transport systems, making it difficult to mobilize resources where needed. In addition, mass transport systems are capital-intensive.

For regional transport, the study revealed a potential for reducing emissions by about 9 percent in 2030 via modal shifts for both passenger and freight transport. Simulations showed that expanding the high-speed passenger train between São Paulo and Rio de Janeiro, for example, can attract passengers from higher emitting transport modes (e.g., planes, cars, and buses). For freight transport, shifting from road- to water- and rail-based transport can reduce emissions significantly. Obstacles to making the shift include inadequate infrastructure for efficient inter-modal transfer and lack of coordination among public institutions.

Without bio-ethanol, which already contributes to the transport sector's low carbon intensity, 2030 transport emissions would be nearly 32 percent more than in the reference scenario and more than twice as much as current emissions. Because of the increase in flex-fuels vehicles and fuel switching from gasoline to bio-ethanol, emissions from light-duty vehicles are expected to stabilize over the next 25 years, despite a projected rise in the number of kilometers traveled. **Under the low-carbon scenario, this fuel switch could be further increased from 60 to 80 percent in 2030, thus delivering half of the emissions reductions in 2030 and more than one-third of the total emissions reductions targeted for the transport sector over the period (nearly 176 Mt CO_2).** The key challenge is to ensure that market price signals are aligned with that objective. Because of volatile oil prices, an appropriate financial mechanism would be needed to absorb price shocks and maintain ethanol's attractiveness for vehicle owners.

Implementing the low-carbon scenario would mean reducing increased emissions of the transport sector from almost 65percent to less than 17%(from 149 Mt CO_2 in 2008 to 174Mt CO_2 instead of 245 Mt CO_2 per year in 2030). Total avoided emissions would amount to nearly 524Mt CO_2 over the 2010-2030 period, or about 35 Mt CO_2 per year on average, roughly equivalent to the combined emissions of Uruguay and El Salvador.

Waste Management: Leverage of Financial Resources

Brazil's waste-management sector has a history of underinvestment and little private-sector participation. This situation can be attributed, in part, to a lack of long-term planning, insufficient allocated funds, and lack of incentives. Both solid and liquid waste management face a high level of institutional complexity and decentralization, making it more difficult to leverage the required financial resources. **As of 2008, sector emissions were relatively limited, at 62 Mt CO_2e, representing 4.7 percent of national emissions**.

In modern landfills, where fermentation is anaerobic, methane (CH_4) is released into the atmosphere; emissions increase as waste collection and disposal sites continue to expand. Under the reference scenario, the CH_4 generated is a powerful end-of-pipe GHG, which is not necessarily destroyed. **The emissions are quickly boosted and could increase more than 50 percent over the study period as ever greater numbers of people begin to benefit from solid and**

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liquid waste-collection services. But given that CH_4 can easily be destroyed, incentives created by the carbon market under the low-carbon scenario could encourage participation in projects designed to destroy landfill gases. To meet the waste-management sector's challenges, it is imperative that the appropriate capacitation is developed in the municipalities with respect to long-term planning and project development capabilities, expanded awareness of and capacity to use the existing legal structure, regulations and procedures, and improving access to the available financing resources. In particular, inter-municipal and regional consortia should be created to handle waste treatment, and public-private partnerships (PPPs) should be developed via concessions under long-term contracts.

Implementing the low-carbon scenario would reduce annual sector emissions by 80 percent (from 99 Mt CO_2e to 19 Mt CO_2e in 2030). Over the 2010–30 period, total avoided emissions would equal 1,317 Mt CO_2 or an average of 63 Mt CO_2 per year, comparable to the annual emissions of Paraguay.

Economic Analysis of Mitigation Options

To inform the Brazilian government and larger society of the economic costs involved in shifting to a low-carbon development pathway, the study team conducted an economic analysis to determine the financial conditions under which the proposed mitigation and carbon uptake options might be implemented. The economic analysis was also used to select the mitigation options that could be retained in a low-carbon scenario. **Two complementary levels of economic analysis were undertaken: (i) a microeconomic assessment of the options considered from both social and private-sector perspectives and (ii) a macroeconomic assessment of the impacts of these options**, either individually or collectively, on the national economy using an input-output (I-O) model.

The social approach provided a cross-sectoral comparison of the cost-effectiveness of the mitigation and carbon uptake options considered for the overall society. For that purpose, a marginal abatement cost (MAC) was calculated for each measure using a social discount rate of 8 percent. Results were sorted by increasing value and plotted in a single graph, known as the marginal abatement cost curve (MACC), which permits a quick reading of how the various measures compare in terms of cost and volume of GHG emissions.

The private-sector approach explored the conditions under which the proposed measures would become attractive to individual project developers. It corresponds to the same principle underlying the cap-and-trade approach adopted in the Kyoto Protocol: providing additional revenues to economic agents who opt for carbon-intensive solutions that are less intensive than those in the baseline. This approach aims at estimating the minimum economic incentive—the "break-even carbon price"—that should be provided for the proposed mitigation measure to become attractive. This approach is based on the expected rates of return from real economic agents in the considered sectors, as observed by the major financing institutions consulted in Brazil.

Because the rates of return expected by the private sector are generally higher than the social discount rate, the break-even carbon price is usually higher than the MAC. In certain cases, the MAC is negative and the break-even carbon price is positive (e.g., cogeneration from sugar-cane, measures to prevent deforestation, fuel substitution with natural gas, electric lighting and motors or GTL), which helps one to understand why a measure with a negative MAC is not automatically implemented. Most mitigation and carbon uptake options presume an incentive to become attractive, with the exception of energy efficiency measures.
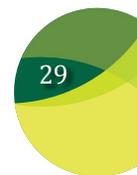
The total volume of incentives needed over the study period would amount to US$445 billion or US$21billion per year on average. .

The incentive for the measures proposed to avoid deforestation-related emissions is estimated at about US$34 billion over the period, equivalent to US$1.6 billion per year and US$6 per tCO_2 (including forest protection costs of $24 billion over the period). For 80 percent of the mitigation and carbon uptake potential under the low-carbon scenario—that is, more than 9 Gt CO_2—the required level of incentives is US$6 per tCO_2e or less.

The economic incentive to be provided is not necessarily through the sale of carbon credits. Other incentives, such as capital subsidies for low-carbon technologies, investment financing conditions, tax credits, regulations, or other instruments can sometimes be more effective in making the low-carbon option preferable to project developers.

The macroeconomic effects of the mitigation options considered were estimated individually and collectively, with the incremental impact of the low-carbon scenario calculated in comparison to the reference scenario using a simple Input-Output (IO) modeling. While results should be viewed with caution, used only to suggest the magnitude of the impact, the IO-based simulation indicates that **investment under the low-carbon scenario is not expected to negatively affect economic growth. Rather, both GDP and employment might improve slightly, owing to economy-wide spillover from the low-carbon investment**. It is estimated that GDP could increase 0.5 percent per year on average over the 2010–30 period, while employment could increase an average of 1.13 percent annually over the same period.

Based on this two-level economic analysis, the study selected the mitigation and carbon uptake options retained for a low-carbon scenario for Brazil over the 2010–30 period. The criteria adopted were that the MAC, which represents the social perspective usually adopted in government planning exercises, should not exceed US$50, except for the options triggered more by large expected co-benefits and their positive macroeconomic impacts, which would balance the higher MAC. This is typically the case for most of the measures proposed by the transport and waste sectors.

A National Low-carbon Scenario

The low-carbon scenario constructed for Brazil under this study is an aggregate of the low-carbon scenarios developed for each of the four sectors considered in this study. In each sector, the most significant opportunities to mitigate and sequester GHGs were analyzed, while less promising or fully exploited options in the reference scenario were not further considered. In short, this national low-carbon scenario is derived from a bottom-up, technology-driven simulation for single subsectors (e.g., energy conservation in the industry or landfill gas collection and destruction), based on in-depth technical and economic assessments of feasible options in the Brazilian context, and sector-level optimization for two of the four main sectors (land use and transport).

This national low-carbon scenario has been built in a coordinated way to ensure full consistency among the four main sectors considered. To ensure transparency, the methods and results were presented and discussed on various occasions with a range of government representatives.[22] **But this low-carbon scenario is not presumed to have explored all possible mitigation options or represent a preferred recommended mix. This scenario,**

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22   Three seminars were held over the past several years (September 14–16, 2007; April 30, 2008; and March 19, 2009) to present and discuss the study methodology, intermediate results, and near-final results with representatives of 10 ministries. Sectoral teams also interacted on various occasions with technical-area and public-agency representatives.

which simulates the combined result of all the options retained under this study, should be considered modular—as a menu of options—and not prescriptive, especially since the political economy between sectors or regions may differ significantly, making certain mitigation options that at first appear more expensive easier to harvest than others that initially appear more attractive economically.

    This low-carbon scenario represents a 37-percent reduction in gross GHG emissions compared to the reference scenario over the 2010–30 period. The total cumulative emissions reduction over the period amounts to more than 11.1 Gt CO_2e, equal to approximately 37 percent of the cumulative emissions observed under the reference scenario. Projected gross emissions in 2030 are 40 percent lower under the low-carbon scenario (1,023 Mt CO_2e per year) compared to the reference scenario (1,718 Mt CO_2e per year) and 20 percent lower than in 2008 (1,288 Mt CO_2e per year) (table 2, figure 1). In addition, forest plantations and recovery of legal reserves will sequestrate the equivalent of 16 percent of reference-scenario emissions in 2030 (213 Mt CO_2e per year)[23].

Table 2: Comparison of Emissions Distribution among Sectors in the
Reference and Low-carbon Scenarios, 2008–30

Sector	Reference scenario, 2008		Reference scenario, 2030		Low-carbon scenario, 2030	
	Mt CO_2e	%	MT CO_2e	%	Mt CO_2e	%
Energy	232	18	458	27	297	29
Transport	149	12	245	14	174	17
Waste	62	5	99	6	18	2
Deforestation	536	42	533	31	196	19
Livestock	237	18	272	16	249	24
Agriculture	72	6	111	6	89	9
Total	**1.288**	**100**	**1.718**	**100**	**1.023**	**100**
Carbon uptake	(29)	(2)	(21)	(1)	(213)	(21)

    The two areas where the proposed low-carbon scenario succeeds most in reducing net emissions are reducing deforestation and increasing carbon uptake. The main drivers are (i) reduction of total land area needed, via significant gains in livestock productivity, to accommodate expanded agriculture and meat production and (ii) restoration of legal forest reserves and production forests for producing renewable charcoal for the steel industry. By 2017, the proposed low-carbon scenario would reduce deforestation by more than 80 percent compared to the 1996–2005 average, thereby ensuring compliance with the Brazilian government's December 2008 commitment.

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23   If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 112MtCO2 per year on average, thus reducing the net emissions.

Figure 1: GHG Mitigation Wedges in the Low-carbon Scenario, 2008–30

In the low-carbon scenario, the chart shows:

- Reference Scenario *(Does not reflect Brazilian historical GHG Emissions)*
- Low Carbon Scenario

Legend:
- Wind
- Sugarcane cogeneration
- Energy Conservation Residential (Elec)
- Energy Conservation Commercial/Industrial (Elec)
- Refineries
- Gas to liquid (GTL)
- Energy Conservation – Industry (fossil fuels)
- Regional Transport
- Urban Transport
- Landfill and wastewater treatment methane destruction
- Reduction of deforestation and livestock
- Scaling up no tillage cropping
- Reforestation
- Referência
- Ethanol exports displacing gasoline
- Estimated Level of Emissions in 2010

In the energy and transport sectors, it is more difficult to reduce emissions since they are already low by international standards, owing mainly to hydroelectricity for power generation and bioethanol as a fuel substitute for gasoline in the current energy matrix. As a result, these sectors' relative share of national emissions increases more in the low-carbon scenario than in the reference scenario.

Assessment of Financing Needs

Implementing the low-carbon scenario options would require more than twice the volume of financing needed for the alternatives in the reference scenario—about US$725 billion in real terms versus US$336 billion over the 2010–30 period. The per-sector distribution is **US$344 billion for energy, $157 billion for land use and land-use change, $141 billion for transport, and $84 billion for waste management**.

An average of US$20 billion in added annual investment would be required. This would represent less than 10 percent of the annual $250 billion in national investments in 2008 (at approximately 19 percent of GDP[24]), or less than half of the $42 billion in loan disbursements by the BNDES and two-thirds of the US$30 billion in FDI in Brazil during 2008. These requirements also compare well with Brazil's Government Accelerated Growth Plan (PAC), which anticipated spending $504 billion in 2007–10.

To implement the reference and low-carbon scenarios, both public and private investments are necessary. Under either scenario, the transport and waste sectors require more private-sector investments than today, while the energy sector continues to benefit from significant public sector participation; potential implementation of new rules or modification of existing ones may favor better use of resources (such as GTL). For the land-use sector, reducing emissions from deforestation continues to require public-sector intervention, albeit in the form of special funds, such as the Amazon Fund, and legal enforcement; while increased livestock productivity relies on better access to both public- and private-sector financing. Similarly, restoration of forests via compliance with the Legal Reserve Law requires public-sector

enforcement and potentially greater private-sector participation.

To mobilize the private investment, incentives would be required to turn the low carbon options attractive when compared with more conventional options. Transport mitigation options would require the greatest amount of average annual incentives at approximately $9 billion, followed by energy at $7 billion, waste at $3 billion and LULUCF at $2.2 billion. However, most of energy efficiency measures would not require incentives.

Few of Brazil's many economic financing mechanisms and instruments currently in place target climate change–related activities. Non-climate financing mechanisms might be applicable to low-carbon options, as they would to reference-scenario alternatives. However, their availability, reach, configuration, and scale may be limited, especially when applied to unconventional alternatives. Although the overall costs may not appear exorbitant for implementing a low-carbon development scenario, the available resources for implementing mitigation activities at the site-specific level may not be as easily identifiable or sufficient, or financing mechanisms may not be appropriately defined for such options. **Thus, specific financing instruments and new sources that promote implementation of the proposed mitigation activities would be required.**

Meeting the Challenge of the Low-carbon Scenario

Implementing the proposed low-carbon scenario requires tackling a variety of challenges in each of the four areas considered. The combined strategy of releasing pasture and protecting forests to reduce deforestation to 83 percent of historically observed levels involves five major challenges. **First, productive livestock systems are far more capital-intensive, both at the investment stage and in terms of working capital.** Having farmers shift to these systems would require offering them a large volume of attractive financing far beyond current lending levels. Thus, a large volume of financial incentives, along with more flexible lending criteria, would be needed to make such financing viable for both farmers and the banking system. A first attempt to estimate the volume of incentives required indicates an order of magnitude of US$1.6 billion per year, or US$34 billion during the period. **Second, these systems require higher qualifications than traditional extensive farming**, which is used to move on to new areas as soon as pasture productivity has degraded, eventually converting more native vegetation into pasture. Therefore, the financing effort should be accompanied by intensive development of extension services.

A third challenge is preventing a rebound effect: The higher profitability of needing less land to produce the same volume of meat might trigger an incentive to produce more meat and eventually convert more native forest into pasture. Such a risk is especially high in areas where new roads have been opened or paved. Therefore, the incentive provided should be selective, especially in the Amazon region. It should be given only when it is clearly established, based on valid and geo-referenced land ownership title, that the project will include neither conversion of native vegetation nor areas converted in recent years (e.g., less than 5 years).

Fourth, several attractive options in the low-carbon scenario to mitigate emissions or increase carbon uptake amplify the requirement of freeing up pasture to prevent carbon leakage. For example, while replanting the forest to comply with the Legal Reserve Law would remove a large amount of carbon dioxide (CO_2) from the atmosphere, this area would no longer be available for other activities. The equivalent additional amount of pasture would need to be freed up; otherwise, a portion of production would have to be reduced or more native forest

would eventually be destroyed elsewhere. **A more flexible legal obligation regarding forest reserves would make the goal of accommodating all agriculture, livestock and forestry activities without deforestation less difficult, but it might also mean less carbon uptake.**

For urban transport, the major challenge is not technological, although some efficiency gains can still result from technology innovations. Mass-transport technologies, non-motorized transport options, and demand management measures are all available and road-tested. **Rather, the main challenge centers on a lack of financing and need for more institutional coordination.** For example, Brazil's more than 5,000 municipalities independently administer their transit and transport systems, making it difficult to harmonize nationwide plans and policies. In addition, mass transport systems in urban areas are capital-intensive, which prevents many municipalities from implementing them. One way to overcome the limited investment capacity of the public sector is to promote PPPs.

For regional transport, meeting the freight transport targets under the low-carbon scenario requires better integration and partnerships among rail concessionaires and between concessionaires and government, including regulatory authorities. The various transport modes are generally operated privately; thus, their efficient integration requires new infrastructure and terminals, calling for more coordination of and support from public authorities. Regarding the Amazon region, the opening of new roads in Amazon forests can lead to increased deforestation and thus emissions. For policies involving intermodal-transfer projects to succeed and mitigate negative impacts, there must be adequate planning, appropriate allocation of resources, as well as measures to facilitate the financing of the large investments required to build and adapt the needed infrastructure.

Regarding further substitution of gasoline by bio-ethanol, the key challenge is how to ensure that market price signals are aligned with this objective. Most new cars produced in Brazil are flex-fuel vehicles, which, by definition, can switch continuously from gasoline to ethanol and vice-versa. Market price signals are key determinants of ethanol's high market share. Because of the high volatility of oil prices, a financial mechanism would need to be designed and implemented to absorb price shocks and maintain the attractiveness of ethanol for vehicle owners.

For the energy sector, the main challenges to emissions mitigation involve not only implementation of the measures proposed in the low-carbon scenario; certain assumptions that underpin the reference scenario also require significant efforts. In the low-carbon scenario, the energy sector's low carbon intensity results, in large part, from the already low carbon intensity of the reference scenario for that sector. The PNE 2030 projects that hydroelectricity will represent more than 70 percent of power generation in 2030, which implies increasing hydropower generation capacity at a pace not yet observed.

The participation of hydro-energy at new energy auctions has been limited by the environmental licensing process. As a result, the participation of fuel oil, diesel, and even coal-based power plants, which often face less difficulty in obtaining environmental licenses, has increased. Measures to improve the efficiency of the environmental licensing process for hydropower generation could include (i) ensuring that the design of electricity-sector plans, programs, and policies take social and environmental factors into account, along with economic, financial, and technical factors; (ii) promoting and establishing mechanisms to resolve disputes among players in the licensing process; (iii) preparing an operations guide, which defines the approaches used during the process; and (iv) building technical capacity and upgrading and

diversifying the professional skills of environmental agencies.[25]

Harnessing the mitigation potential of energy efficiency under the low-carbon scenario requires fully exploring the options offered by the existing framework. Progress, albeit slow, has been made in implementing the energy efficiency law, and several available mechanisms promoting energy efficiency address the needs of all consumer groups (e.g., PROCEL, CONPET, and EPE planned auctions). These initiatives offer the possibility of creating a sustainable energy-efficiency market. Key problems to address are: (i) price distortions that introduce disincentives for energy conservation and (ii) separation of the energy-efficiency efforts of power and oil-and-gas institutions. Better institutional coordination might be achieved via a committee responsible for the development of both programs.

For bagasse cogeneration and wind energy, the main barrier to implementation is the cost of interconnecting with the sometimes distant or capacity-constrained sub-transmission grid. If this cost continues to be fully borne by the respective sugar mills and wind-farm developers, the contribution of cogeneration and wind energy will likely remain low, resulting in the entry of more fossil fuel–based alternatives. The key question is how to finance the required grid. An ambitious smart-grid development program would help to optimize the exploration of this promising but distributed low-carbon generation potential.

With regard to the waste sector, **both solid and liquid waste management face a high level of institutional complexity and decentralization, making it more difficult to leverage the large amount of required financial resources.** Scaling up appropriate collection, treatment and disposal, together with emissions avoidance, would require more inter-municipal coordination, clear regulationsand PPPs, along with a continuation of carbon-based incentives to destroy or use landfill gas.

Final Remarks

Brazil harbors large opportunities for GHG emissions mitigation and carbon uptake.. This positions the country as one of the key players to tackle the challenge posed by global climate change. This study has demonstrated that a series of mitigation and carbon uptake measures are technically feasible and that promising efforts are already under way. **Yet implementing these proposed measures would require large volumes of investment and incentives, which may exceed a strictly national response and require international financial support. Moreover, for Brazil to harvest the full range of opportunities to mitigate GHG emissions, market mechanisms would not be sufficient. Public policies and planning would be pivotal, with management of land competition and forest protection at the center.**

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25   See "Environmental Licensing for Hydroelectric Projects in Brazil: A Contribution to the Debate," Summary Report. World Bank Country Management Unit, March 28, 2008.
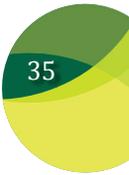
Chapter 1
Introduction

The urgent need to combat global climate change has been firmly established. An overwhelming body of scientific evidence, including the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) and a recent review on the economics of climate change led by Nicholas Stern (Stern 2007), underscore the severe risks to the natural world and global economy. According to Stern, how we decide to live over the next 20–30 years—how we treat forests, generate and use energy, and organize transport—will determine whether the risks of global climate change can remain manageable (Stern 2009).

1.1 Managing Risk: Target Levels

Failure to hold greenhouse gas (GHG) concentrations below certain levels would carry great risk to our planet. Recent studies have put forward various target levels, all of which would need emissions to peak soon. The IPCC (2007) concluded that stabilizing GHG concentrations at 550 particles per million (ppm)—the level at which it may be possible to hold the rise in global mean temperature under 3°C above pre-industrial levels[26]—would require concentrations to peak not later than 2030 and then fall drastically by 2050; in this scenario, the IPCC estimates global emissions would need to be reduced to about 29 Gt CO_2e by 2030.

Another recent study, conducted by the United Nations Framework Convention on Climate Change (UNFCCC), projects emissions to 61.5 Gt CO_2e by 2030. In this scenario, annual emissions from Annex I (industrialized) countries would grow from 21 Gt CO_2e to just 22.1 Gt CO_2e by 2030,[27] while the bulk of global emissions—50–70 percent of the emissions-mitigation potential—would come from non-Annex I (developing) countries. Despite the range of uncertainty, it is clear that developing countries have a vital role to play in shaping international policies and actions to cut emissions to the required scale.

1.2 The Brazilian Context: Key Role of Forests and Other Sectors

Without Brazil playing a prominent role, it is difficult to imagine an effective solution to stabilizing GHG concentrations to the required scale. The Amazon rainforest, which covers more than half the country, is a reservoir of about 100 billion tons of carbon, sequestering more than 10 times the amount of carbon emitted globally each year. Given Brazil's large forested areas—second only to those of Indonesia—it is perhaps not surprising to discover that most of the world's emissions from deforestation come from these two countries.

At the same time, Brazil is likely to suffer from the adverse effects of climate change. Some advanced models suggest that much of the eastern part of the Brazilian Amazon region could be converted into a savannah-like ecosystem before the end of this century. This phenomenon, known as the Amazon dieback, combined with the shorter-term effects of deforestation by fires, could reduce rainfall in the Central-West and Northeast regions, resulting in smaller crop yields and less water available for hydropower-based electricity.[28]

As the world's largest tropical country, Brazil is unique in its GHG emissions profile. In prior decades, the availability of large volume of land suitable for cultivating crops and pasture helped to transform agriculture and livestock into key sectors for sustaining the country's economic growth. In the past decade alone, these two sectors accounted for an average of 25 percent of national GDP. The steady expansion of crop lands and pasture has also required the

26 Or about 2.5°C above the level of the early 2000s.
27 Details are available at http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php
28 "Assessment of the Risk of Amazon Dieback," World Bank, 2010.

conversion of more native land, making land-use change the country's main source of GHG emissions today. At the same time, Brazil has used the abundant natural resources of its large territory to explore and develop renewable energy, having built numerous large hydropower plants and scaled up bio-ethanol production as a gasoline substitute, which, in turn, account for the low carbon intensity of its energy matrix.

Apart from land use, land-use change, and forestry (LULUCF), Brazil accounts for only 2.3 percent of global GHG emissions; but until a few years ago, that percentage used to rise another 3 percent when considering LULUCF.[29] Indeed, the LULUCF sector is pivotal, accounting for about two-thirds of Brazil's gross CO_2e emissions (2008), two-thirds of that amount represented by deforestation alone. By contrast, Brazil's energy sector has a per-capita carbon intensity of only 1.9 tCO_2 per year—about half the global average and less than one-fifth the average for OECD countries. Were it not for Brazil's previous large investments in renewable energy, the country's current energy matrix would be far more carbon intensive, with presumably twice the amount of energy-sector emissions and national emissions 17 percent higher.

Four sectors are key contributors to Brazil's GHG emissions. First and most important is LULUCF, which covers the forestry dimensions described above. In addition, there are three other major emitting sectors: (i) energy, (ii) transport, and (iii) waste management. In 2008, the respective emissions contributions of these three sectors were 18, 14, and 5 percent. While waste management's contribution was low in 2008, it has increased more than 60 percent over the past two decades.

1.3 A National Commitment To Combat Climate Change

Climate change has long been a vital part of Brazil's national agenda. In June 1992, Brazil hosted the United Nations Conference on Environment and Development, known as the Rio Earth Summit, which resulted in an agreement on the UNFCCC and, in turn, the Kyoto Protocol. Since then, Brazil has played an active role in the international dialogue on climate change. In 2007, the Brazilian government created the Secretariat for Climate Change within its Ministry of Environment. The following year, President Luiz Inácio Lula da Silva launched the National Plan on Climate Change (PNMC),[30] which put the issue at the forefront of the national agenda. On December 29, 2009 the Brazilian Parliament adopted Law 12.187, which institutes the National Climate Change Policy of Brazil and set a voluntary national greenhouse gas reduction target of between 36.1% and 38.9% of projected emissions by 2020.

Like other developing countries, Brazil faces the dual challenge of encouraging development while reducing GHG emissions. President Lula echoed this concern in his introduction to the PNMC, stating that actions to avoid future GHG emissions should not adversely affect the development rights of the poor, who have done nothing to generate the problem. Recognizing the need for a low-carbon pathway to growth, Brazil has chosen to benefit from the Clean Development Mechanism (CDM), an innovative financial mechanism, originally proposed by Brazil, which is defined in Article 12 of the Kyoto Protocol.[31] To date, Brazil has initiated more than 300 projects under the CDM.

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29   Aligning the methods used for carbon removal accounting in Brazil with those of other countries may affect these percentages.

30   The PNMC is based on work of the Interministerial Committee on Climate Change and its Executive Group, in collaboration with the Brazilian Forum on Climate Change and civil society organizations.

31   The CDM allows non-Annex I countries to host project activities that reduce GHG emissions. These emission reductions can be certified and acquired by Annex I countries to comply with their emissions-reduction commitments under the Kyoto Protocol.

1.4 Study Objective and Approach

To support Brazil's integrated effort to reduce GHG emissions and promote long-term economic development, this study aimed to build a transparent and internally consistent low-carbon scenario that the Brazilian government could use as a tool to assess the inputs required to forge a low-carbon pathway to growth.[32]

1.4.1 Method Overview

The study team analyzed opportunities in each of the four sectors identified (table 1.1). The team constructed the reference scenario to the year 2030 based on current projections and available modeling exercises for each of the sectors. For the energy and transport sectors, the team built on existing long-term national and citywide plans.[33] Because no similar plans were available for the LULUCF and waste-management sectors, new models and sets of equations were developed, consistent with the macroeconomic and demographic projections of the energy and transport sectors to the year 2030.[34] For the LULUCF sector, the team used two complementary models: (i) Brazil Land Use Model (BLUM), an econometric model to project future land use for crops, developed by the Institute for International Trade Negotiations (ICONE) and (ii) SIM Brazil, a georeferenced spatialization model to allocate land use to specific sites and years, developed by the Remote Sensing Center (CSR) of the Federal University of Minas Gerais (UFMG). For the waste-management sector, the team worked with the São Paulo State Waste Management Agency (CETESB) to develop sets of equations for modeling disposal.

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Table 1.1: Summary of Study Method, by Sector

Step[*]	LULUCF	Energy	Transport	Waste
1. Build the reference scenario	Project land use and land-use change (consistent with projected liquid and solid biofuels) (develop geospatially explicit, land-use modeling), deforestation (adapt existing modeling), and emissions.	Project energy demand (consistent with demand from other sectors) (using MAED projections); optimized energy-supply mix (using MESSAGE projections); and emissions.	Project regional and urban transport demands, transport modes shares for regional and urban transport (using TRANSCAD modeling), fuel mix for transport modes, and emissions (using adaptatition of COPERT modeling).	Project waste and effluent production, carbon content and methane (CH_4) potential, waste and effluent disposal mix, and emissions.

2. Explore mitigation and carbon uptake options	Analyze options to reduce deforestation pressure and protect forests, mitigate emissions from agriculture and livestock, and sequester carbon; conduct an economic (abatement cost) analysis of the proposed options.	Analyze options to manage demand and reduce carbon intensity of supply; conduct an economic analysis (abatement cost) of the proposed options.	Analyze options to improve regional transport efficiency and scale up low-carbon interurban modes; improve urban transport efficiency and scale up low-carbon urban modes; and switch to biofuels. Conduct an economic analysis (abatement cost) of the proposed options.	Analyze options to reduce waste and effluent production and scale up collection and low-carbon disposal modes; conduct an economic analysis (abatement cost) of the proposed options.
3. Assess the feasibility of the options identified	Identify barriers that limit or prevent implementation of the options analyzed, environmental and economic co-benefits, and measures to overcome the barriers.	Identify barriers that limit implementation of the energy-demand management and emissions-mitigation options analyzed, environmental and economic co-benefits, and measures to overcome the barriers.	Identify barriers that limit implementation of regional and urban transport efficiency and low-carbon modes, environmental and economic co-benefits, and measures to overcome the barriers.	Identify barriers that limit implementation of waste and effluent production reduction and low-carbon waste and effluents disposal modes, environmental and economic co-benefits, and measures to overcome the barriers.
4. Build the low-carbon scenario	Project new land use and land-use changes (including added land needed for mitigation and carbon uptake options), estimate reduced deforestation, and project reduced emissions.	Revise energy demand (including new fuel mix from transport); define new and internally consistent, low-carbon energy mix for energy supply; and project reduced emissions.	Project new transport demand (consistent with new land use), new modal distribution for regional and urban transport, new fuel mix, and reduced emissions.	Project new waste and effluent production, new carbon content and CH_4 potential, new waste and effluents disposal-mode mix, and reduced emissions.

The study team then explored mitigation and carbon uptake options. For each sector, relevant subsectors were screened to identify the main technical options for reducing GHGs to 2030; it ranked these options for incremental costs and compared them with the reference-scenario options. The team adapted the "wedge" concept developed by Pacala and Socolow (2004), which scales up a single area or technology to achieve significant reductions in GHG emissions that can be deducted from the reference scenario. Because of the systemic nature of emissions in the LULUCF and transport sectors, the team found that a pure wedge approach was not appropriate and developed a specific modeling approach[35]. For the LULUCF sector, the team analyzed the country's potential for large carbon removal and avoidance of GHG emissions in other countries via scaled-up ethanol exports.

To determine the feasibility of the mitigation and carbon uptake options identified, the study team assessed the added costs faced by technical options in the low-carbon scenario and compared them to those in the reference scenario. For low-carbon options that were more cost-effective in theory, the team identified the major barriers preventing their adoption and proposed measures to overcome them. Since many of the proposed options were either not cost-effective or would face financing difficulties, the team assessed the volume of support required to ensure their funding or competitiveness.

The final step was to build the low-carbon scenario aggregated from the diversified findings of the sectors and subsectors. To ensure consistency of mitigation and carbon uptake estimates, including avoidance of conflict or double counting, the study team built an indicative low-carbon scenario: The scenario developed is not a projection of Brazil's full GHG emissions inventory, and does not pretend to capture 100 percent of all sources of GHG emissions.[36] Indeed, to the extent possible, the team developed and used modeling tools to allow for building other low-carbon scenarios in a modular manner.[37] In addition to analyzing the potential trade-offs that such a low-carbon scenario may incur in terms of sector-level sustainability, the team investigated the potential macroeconomic impacts of shifting from the reference scenario to the low-carbon one (table 1.1).

1.4.2 A Consultative and Iterative Process

The study emphasized two important dimensions. First, to the extent possible, it relied on existing literature and studies so as to effectively leverage the wealth of existing information. Second, the process emphasized a consultative, iterative approach that involved extensive discussions and give-and-take with experts in the field and Brazilian government representatives (Annex B). The team conducted an extensive literature survey and, through a broad consultative process, met with more than 70 recognized Brazilian experts, technicians, and government representatives. The consultative process, combined with the World Bank's extensive knowledge of Brazilian institutions, enabled the team to build partnerships with centers of excellence recognized for their national and international expertise in these sectors.

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35 Possible feedback effects of climate change impacts on mitigation and carbon removal opportunities could not be integrated in the modeling at this stage.

36 For example, industrial sources of nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs), sulfur hexaflouride (SF_6), and other non-Kyoto GHG gases are not accounted for here. In the absence of a recent complete inventory, it is not possible to determine precisely the share of other sources in the national GHG balance. However, based on the first Brazil National Communication (1994), it is expected that they would not exceed 5 percent of total Kyoto GHG emissions.

37 Given the many possible combinations and that removal of certain barriers, particularly those related to incremental costs and financing, may or may not be possible, this low-carbon scenario should be considered as one among others that could also be simulated.

1.5 Structure of This Report

Chapters 2 through 6 describe the study results for the four sectors analyzed. Results for the LULUCF sector are divided into two chapters: Chapter 2 presents the reference-scenario results, while chapter 3 describes the low-carbon scenario. Chapters 4 through 6 describe the reference and low-carbon scenarios for the energy, transport, and waste sectors, respectively; while chapter 7 provides the economic analysis for the various mitigation and carbon uptake options used to build them. Chapter 8 presents the national reference scenario and proposed low-carbon scenario, based on the aggregate results from the four sectors. An annex of maps and an electronic database detail the results of the study by state. Chapter 9 then assesses the financing needs of the proposed low-carbon scenario. Finally, chapter 10 outlines the main challenges to its implementation.
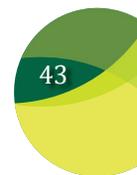
Chapter 2
Land Use, Land-use Change, and Forestry: Reference Scenario

Brazil's forests represent an enormous carbon stock. The Amazon, a reservoir of about 47 billion tons of carbon[38], permanently sequesters more than 5 times the amount emitted globally each year. At the same time, in 2000, Brazil was the world's second largest emitter of carbon dioxide (CO_2) resulting from deforestation—often driven by the need to convert land for agricultural production and livestock pasture[39].

Not surprisingly, the land use, land-use change, and forestry (LULUCF) sector accounts for more than two-thirds of Brazil's gross CO_2e emissions; of this amount, approximately two-thirds results from deforestation, with the remainder from agricultural production and livestock activities. Conversion of forest land to other land uses results in GHG emissions from soils,, while the digestive process of ruminants results in methane (CH_4) emissions. A key sector challenge is identifying opportunities to curb the net balance of GHG emissions from deforestation and foster economic growth.

This chapter describes the background and development of the LULUCF reference scenario. Section 2.1 explains how LULUCF affects GHG emissions. Section 2.2 outlines the integrated modeling approach used and estimates future land use for agricultural production and livestock activities and projected land-use change from deforestation. Section 2.3 then estimates GHG emissions from these activities, as well as potential carbon uptake. Finally, section 2.4 presents the emissions results for the reference scenario.

2.1 Effects of Land Use and Land-use Change on Emissions

There are three main ways through which land use and land-use change contribute to carbon emissions: (i) conversion of forest land to other land uses (agriculture, grassland, settlements, etc.), (ii) agricultural production, and (iii) livestock activities. In addition, the carbon uptake via reforestation activities affects net GHG levels.

2.1.1 Deforestation

According to the results of this study, in 2008, deforestation accounted for 40 percent of Brazil's gross emissions. When the forest biomass is destroyed, mainly by fire and decomposition, carbon is emitted into the atmosphere. Brazil has been converting forested areas at a rapid pace (approximately 420,000 km² over the past 20 years). The Amazon lost approximately 18 percent of its original forest cover between 1970 and 2007; the Cerrado lost about 20 percent of its original area between 1990 and 2005, while the Atlantic Forest lost approximately 8 percent over the same period (INPE 2009). Between 1990 and 2005, Brazil's carbon stock was reduced by 6 billion metric tons, largely as the result of deforestation[40]. This amount is equivalent to one year of global emissions, if all sources are combined.

Since peaking at 27,772 km² during the 2004-2005 period, Brazil's deforestation rates have declined sharply to 11,200 km² in 2007, the second lowest annual historical rate estimated by the deforestation assessment program (PRODES) since the year 1988, according to INPE (2008)[41]. This decrease continued in the following years. This drop reflects, in part, the higher valued Brazilian currency, the Real (R$), compared to the U.S. Dollar (US$), which has made export-based

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38   Phillips et alii, 2009: "Drought Sensitivity of the Amazon Rainforest" in *Science.*
39   Erin C. Myers Madeira: "Policies to Reduce Emissions from Deforestation and Degradation (redd) in Developing Countries", RFF, December 2008.
40   National Plan for Climate Change, p.67
41   11,030 km² in 1990.

production less profitable. Implementation of the Plan of Action for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM), improved enforcement of environmental laws via increased monitoring capacity, and more rigorous conservation policies for the Amazon rainforest have all contributed to this reduction.[42]

While the spatial dynamics of livestock and agricultural expansion in the Amazon determine the pattern of deforestation at the regional level, deforestation is also affected by broader dynamics. National and international market forces drive the development of Brazil's meat and crop sectors. Depending on price trends, an array of agricultural and livestock activities compete for land. Many geographical studies have shown that the resulting spatial dynamics are national in scale. Over the past three decades, **the soybean cultivation has progressed** more than 1,500 km from south to north (de Gouvello, 1999).

Recent geo-statistical analysis shows that livestock activities are the primary reason for the conversion of forest areas, followed by the expansion of agricultural production as the main drivers of deforestation. Other contributing phenomena include migration, opening of paved roads, and land speculation (Soares-Filho et al. 2009).

2.1.2 Agricultural Production

GHG emissions from agricultural production are caused mainly by changes in soil carbon stocks, and to a lesser extent by fertilizers and residues, cultivation of wetland irrigated rice, burning of agricultural residues, and use of fossil fuels to power agricultural operations. According to the results of this study, in 2008, direct emissions from agriculture accounted for about 6 percent of gross national emissions. Variation in soil carbon stock corresponds to the loss of organic matter in the soil as a result of a particular land use.

2.1.3 Livestock Activities

The main source of livestock emissions in Brazil is methane (CH_4) from the digestive process of ruminants. According to the results of this study, in 2008, direct emissions from livestock activities accounted for about 18 percent of gross national emissions. Livestock emissions are related predominantly to beef-cattle farming. According to the Initial National Communication to the United Nations Framework Convention to Climate Change, in 1994 the methane emissions from the beef-cattle subsector were responsible for more than four-fifths of the total amount of enteric emissions caused by Brazilian livestock. Thus, this study emphasized emissions from and mitigation alternatives for this subsector.

2.1.4 Forestry-based Carbon Uptake

Apart from GHG emissions sources associated with land use and land-use change trees remove CO_2 from the atmosphere and store it in the trunk, branches, leaves, flowers and fruits, counteracting part of the emissions from LULUCF.[43] In Brazil, carbon uptake takes place mainly in natural re-growth of degraded forests and production forests. In accordance with the results of this study, in 2008, it was estimated that forestry-based carbon removal offset about 4 percent of national gross emissions.

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42   In 2003–07, for example, 148 protected areas were created, covering 640,000 km².
43   For annual crops, increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year – thus there is no net accumulation of biomass carbon stocks. (IPCC GPG, page 3.71)

2.2 Modeling Land Use and Land-use Change

This section focuses on the emissions modeling and results for the LULUCF reference scenario. Section 2.2.1 highlights the economic and geospatial modeling approach used to establish the model. Section 2.2.2 presents the modeling results for projected land use from agricultural production and livestock activities. Finally, section 2.2.3 estimates land-use change from deforestation.

2.2.1 Economic and Geospatial Models

Exploring options for mitigating deforestation emissions first requires projecting future deforestation, which, in turn, requires simulating future land use and land-use change. To establish the reference scenario, the study developed two models: i) Brazilian Land Use Model (BLUM) (box 1) and (ii) Simulate Brazil (SIM Brazil) (box 2). These complementary models were used sequentially. The BLUM projected land use and land-use change through 2030. SIM Brazil then allocated this land use and land-use change to specific locations and years.

Box 2.1: Projecting Land Use for Crops to 2030: BLUM

The Brazilian Land Use Model (BLUM), a partial equilibrium econometric model developed by the Institute for International Trade Negotiations (ICONE), operates at two levels: (i) supply and demand of final crops and (ii) land allocation for agricultural products, pasture, and production forests. Supply and demand are calculated simultaneously, in accordance with the microeconomic principle of market balance, whereby offer equals demand for each product. This balance occurs when there is a price that leads to the convergence between supply and demand during the same period of time. The main parameters are demand income and price elasticity, supply price elasticity and cross-elasticity.

Land allocation for every crop in each region was estimated using two explanatory variables (i) regional profitability of the considered crop and (ii) regional profitability of competing crops. Regions that showed higher expected returns for particular products had larger areas allocated to them. Estimating the quantity of land allocated to pasture depended on (i) amount of land used for agricultural crops and (ii) expected herd evolution. Projections to 2030 were obtained for six large regions, all of which were divided into micro-regions created by the Brazilian Institute of Geography and Statistics (IBGE).

Simulate Brazil (SIM Brazil) is a georeferenced spatialization model structured and implemented according to the Environment for Geoprocessing Objects (EGO) Dynamic, an integrated software platform. Developed by the Remote Sensing Center (CSR) of the Cartography Department at the University of Minas Gerais (UFMG), SIM Brazil operates at two spatial levels: (i) IBGE micro-region and (ii) raster of 1-km2 resolution. The model creates favorability maps for crop allocation via such criteria as agricultural aptitude (Assad and Pinto 2008), distance to roads, urban attraction, cost of transport to ports, declivity, and distance to converted areas. For each micro-region, the model allocates the land-use activities projected by BLUM at a level of 1 km2, using agricultural aptitude as a basis for each crop modeled and estimated production cost factors according to infrastructure proxis and distance to consumer markets.

When available land in a given micro-region is insufficient, SIM Brazil reallocates the distribution to neighboring regions, creating an overspill effect. In this way, calculated rates of agricultural expansion are accounted for. Three main sequences were constructed: (i) calculation of land available for expansion, (ii) simulation of land-use change, and (iii) estimation of resulting carbon emissions.

2.2.2 Projected Land Use: Agriculture and Livestock

Modeling results project 7 percent growth (about 16.8 million ha) in land allocated to agricultural production and livestock activities from 2006 to 2030 (table 2.1). Of the six major regions studied, it is estimated that the Amazon will have the highest growth rate, at 24 percent; livestock pasture is expected to account for the largest share. These results suggest that it will be necessary to convert native vegetation for productive uses (mainly in the frontier regions, Amazon, and, to a lesser extent, in MAPITO and Bahia).

Table 2.1: Projected expansion of land used for agricultural production and livestock activities for selected years in the period 2006–30 (millions of ha)

Region	2006	2008	2018	2030
South	34.17	33.56	33.61	34.24
Southeast	54.84	53.52	53.75	53.96
Center-West (Cerrado)	61.78	61.09	61.84	62.99
Northern Amazon	56.64	57.70	61.83	70.40
Northeastern Coast	14.57	14.62	14.91	15.23
MAPITO and Bahia	37.30	36.82	37.68	39.30
Total	259.28	257.30	263.62	276.13

Source: ICONE.

Growth in productive land use is expected in Brazil's frontier regions as a result of two phenomena: (i) increased demand for meat and significant growth in herd size, principally in the Amazon (44 percent) and, to a lesser extent in MAPITO and Bahia (13 percent) and (ii) expansion of crop production, especially in MAPITO. Expected growth in herd size and pasture in these regions may be an indirect effect of increased crop production in pasture areas of the south-

central regions. The study model projects that growth of grazing land in Northern Amazon, where livestock productivity is lower, will exceed the loss of pasture land in the other five regions as a result of competition with agriculture and production forests (table 2.2).

Demand for soybean—Brazil's most important land-use crop, especially in the South and East Central regions, Triangle Mineiro, and parts of the states of Bahia, Piaui, and Maranhão—is expected to grow; land for soybean cultivation is expected to expand, and part of this expansion is projected on the Amazon frontier. Sugar-cane cultivation is expected to expand mainly in northeastern Paraná, Goiás, west-central São Paulo, Triangle Mineiro, Goiás, central Tocantins, Mato Grosso do Sul, and the Northeastern Coast. Expansion is also expected in the states of Bahia, Santa Catarina, Rio Grande do Sul, Rio de Janeiro, Espirito Santo, Piaui, Maranhão, and Mato Grosso. According to Assad (2008) and other data sources used to create favorability maps, sugar-cane cultivation is increasing in all states that show potential for its development. Corn cultivation, which is widely distributed throughout the territory, is expected to increase or remain stable in most states, except in Mato Grosso, where it will likely decline.

Table 2.2: Absolute Variation in Area Allocated, 2006–30 (thousands of ha)

Land use	South	South-east	Center-West (Cerrado)	Northern Amazon	North-eastern Coast	MAPITO and Bahia	Total Brazil
Cotton	(8)	(25)	270	12	8	297	555
Rice	206	(14)	(46)	5	20	42	213
Beans (1st harvest)	(195)	(122)	(39)	(101)	(122)	279	(300)
Beans (2nd harvest)	6	6	(2)	-	-	(212)	(201)
Corn (1st harvest)	(123)	169	330	(24)	205	103	660
Corn (2nd harvest)	632	(56)	1,344	328	-	28	2,276
Soybean	3,097	228	1,845	1,615	-	1,067	7,852
Sugar cane	809	3,111	1,093	(3)	235	1,275	6.520
Production forest	1,160	255	591	188	310	677	3,181
Pasture	(4,881)	(4,488)	(2,806)	12,074	11	(1,739)	(1,829)
Total	65	(884)	1,239	13,765	667	2,001	16,852

Values in parantheses represent negative values

With regard to pasture land, expansion in the Amazon, which to date has resulted mainly from conversion of forests, is expected to continue. Relatively stable pasture lands are projected for the states of Minas Gerais (except in the Triangle region), Bahia (except in the west), Ceara, Rio de Janeiro, parts of Rio Grande do Sul, much of Mato Grosso do Sul, as well as Sergipe, Alagoas, Pernambuco, Rio Grande do Norte, and Paraiba. By contrast, in central and southern Brazil, pasture expansion is expected to remain limited because of direct competition with agricultural production.

2.2.3 Expected Land-use Change: Deforestation

The study team combined the results of economic land-use modeling and geostatistical analysis to project the expected conversion of forest land to other land uses (deforestation).[44]

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[44]   The geostatistical analysis of deforestation reflects socioeconomic, demographic, and public-policy processes, which are usually less obvious than processes associated with direct conversion to meet crop and pasture demand for land.

The team used the EGO Dynamic platform to model deforestation and worked with three fixed variables (migration rates, protected areas, and infrastructure [including paved and non-paved roads]) and two others (areas occupied by crops and herd growth). Base data included the micro-regions map and tabular entries for protected areas, original forest area, crop and herd tables for the years studied, and road-density tables. A spatial lag regression that combined annual rates of crop and cattle expansion (calculated per micro-region), road-density tables, net migration rates, and protected areas was applied. Based on the regression results, the model calculated the net deforestation rate for each micro-region. In the Amazon region, estimated deforestation in the reference scenario was higher than land-use conversion projected by the economic modeling, reflecting the effect of variables other than agricultural expansion.

The expected annual rate of gross deforestation rate in the reference scenario is about 14,500–15,500 km² on average for the period 2010-2030. This range is lower than the annual historic average of 19,000 km² (1996–2005), but well above the targets outlined by Brazil's National Plan on Climate Change (PNMC) (figure 2.1).[45]

The Brazilian government aims to reduce deforestation rates by 72 percent or more (to about 5,300 km² by 2017). To make this ambitious target feasible, the government is implementing a series of measures, including the creation of a forest policy, the PPCDAM, which focuses on deforestation monitoring and control.

Figure 2.1: Evolution of Deforestation in the Reference Scenario, 2009–30
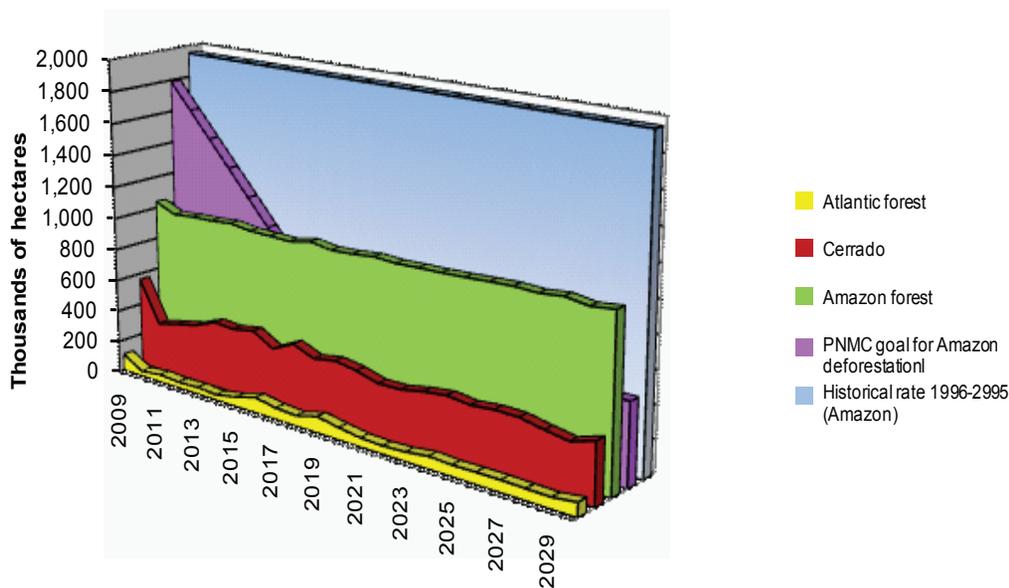
Source: UFMG (2009).

2.3 Estimating Emissions Balance for Land Use and Land-use Change

The projected land use and land-use change results, along with potential carbon uptake, constituted the basis to project future GHG emissions. The following subsections describe the key emission sources and uptake sinks, calculation methods, and total projected emissions over the period considered.

45   Modeling did not incorporate the potential effects of deforestation-reduction objectives in Brazil's PNMC. Compliance with forest codes and new laws on permanent preservation areas and legal reserves are considered in the context of a "Legal Scenario" (chapter 3).

2.3.1 Deforestation

The estimate of future emissions from conversion of forest land to other land uses was based in the methodologies provided in the Good Practice Guidance for Land Use, Land-use Change and Forestry of the Intergovernmental Panel on Climate Change (GPG/LULUCF) (IPCC, 2003).[46] Pasture carbon stock after conversion was subtracted from forest carbon stock before conversion. Because of biomass variation, an indicative carbon-stock map for the start of the period was built as a basis for that calculation (figure 2.2). Values varied between 0 and 276.5 tC per ha (biomass above and below ground), while the average pasture value was 4 tC per ha.[47] Total expected emissions from deforestation were 9.9 Gt CO_2e over the 2010–30 period, or 474 Mt CO_2e per year on average.

Figure 2.2: Map of Carbon Stock Used To Estimate Emissions from Deforestation

Carbon density
Ton of C/ hectare

High: 276.5

Low: 0

Non-linear scale

ANNUAL CHANGE IN LIVING BIOMASS (DIFFERENCE APPROACH)

$$\Delta B = (B_{t_2} - B_{t_1}) / (t_2 - t_1)$$

Where:

ΔB = annual change in living biomass, tonnes d. m. yr^{-1}

B_{t_2} = biomass at time t_2, tonnes d. m.

B_{t_1} = biomass at time t_1, tonnes d. m.
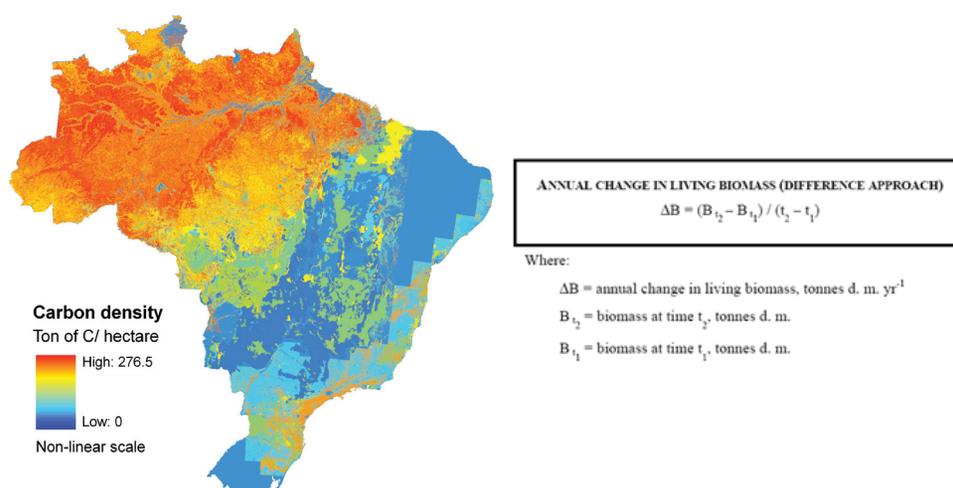
2.3.2 Livestock Activities

Ruminants emit CH_4 and nitrous oxide (N_2O) as a function of quantity of food ingested and quality of diet. In general, the more fibrous the food (for a given level of ingestion), the higher the quantity of CH_4 emitted; the higher the protein content—and thus the more nitrogen (N) execrated—the higher the quantity of N_2O emissions. The more food ingested, the higher the daily emissions of CH_4 and N_2O for a given diet per animal. However, increasing food intake also increases the animal's performance, thus shortening the animals' life cycle or lowering the number of calves necessary for the production of animals for slaughter, and eventually reducing CH_4 emissions per product unit and for total meat production.

To estimate the quantity of food ingested and CH_4 emissions, it is necessary to determine the animal's weight, physiological state, breed, and performance (weight gain, birth rate, and milk production). Since these characteristics are heterogeneous in the herd, it is good practice to categorize the herd and calculate the ingestion and emissions for each category (IPCC 2006).[48]

46   See IPCC (2003), "Good Practice Guidance for Land Use, Land-use Change, and Forestry;" Aavailable at www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html.

47   See Saatchi et al. (2007) for the Amazon region and (PROBIO-MMA 2007) for the rest of the country.

48   In this study, the herd was divided into nine categories of animals according to age (cows, bulls, heifers less than 1 year old, heifers 1–2 years old, bullocks 2–3 years old, bullocks less than 1 year old, young bulls 1–2 years old, young bulls 2–3 years old, and young bulls more than 3 years old.

The study team used a systemic approach to keep track of GHG emissions from beef-cattle farming. Prototypical farms were identified using various types of systems in a complete cycle (pre-stock, post-stock, finishing), which reflects levels of land use and animal productivity intensification. Four types of production systems were considered: (i) complete cycle on degraded pasture, (ii) complete cycle on extensive pasture, (iii) extensive cow-calf raising on pasture plus supplemented stocking and finishing in crop-livestock systems, and (iv) extensive cow-calf raising on pasture plus supplemented stocking and finishing in feedlots.

Prototypical farms were modeled to estimate the pasture-land needs of these production systems (figure 2.3); GHG emissions were calculated using inputs on projected meat demand and characteristics of each production system. Thus, the volume of livestock emissions is a function of the mix of production systems observed at the national level to meet the corresponding demand for meat.

Figure 2.3: Flowchart of Prototypical Farms
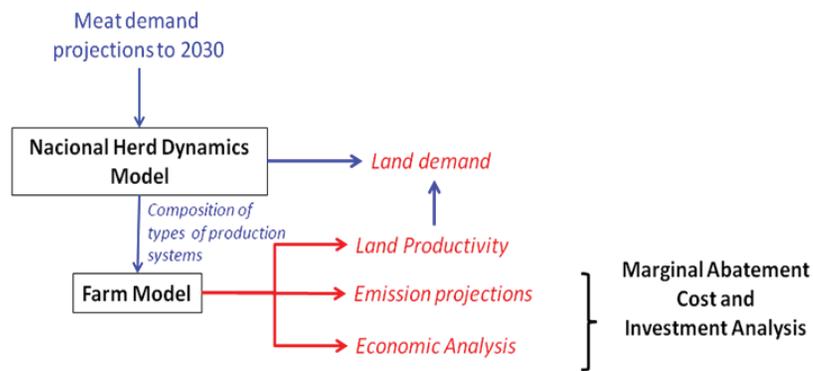
For each production system, herd composition, average weight, and performance were calculated based on typical zootechnical indices. The productivity of each prototypical farm, representing each of the four production systems, was thus calculated based on these indexes. The resulting figures may be considered as a basis for estimating the number of cattle confined (FNP 2008), average productivity estimated for the total production of carcasses (CNA 2009), and number of cattle (IBGE 2009) (table 2.3). Beef-production data generated by the land-use economic model were used to project the required herd size, composition, and distribution per production system to meet national demand.

Table 2.3: Area and Number of Cattle in Each Production System for the Reference-scenario Base Year (2008)

Production system	Area (millions of ha)	No. of cattle (millions of head)	Emissions (Mt CO_2e/ year)
Complete cycle on degraded pasture	59.53	22.38	26.94
Complete cycle on extensive pasture	132.18	155.51	171.36
Extensive cow-calf raising on pasture, plus supplemented stocking and finishing in crop-livestock systems	5.50	10.00	12.11
Extensive cow-calf raising on pasture, plus supplemented stocking and finishing in feedlots	8.18	14.88	18.94
Total	205.39.00	202.77.00	229.35

CH$_4$ and N$_2$O emissions were estimated based on animal weight, quality of diet, and performance for each production system according to tiered IPCC models (2006). Modifications considered estimates of dry-material ingestion for the NRC reverse calculation (2000) with a maintenance factor for Nelore zebus (predominant in Brazil) and the CH$_4$ equation described by Ellis et al. (2006).

According to this study's projections, annual livestock emissions will increase from 229 Mt CO$_2$e in 2008 to 272 Mt CO$_2$e in 2030. The cumulative total over the 2010–30 period is 5.2 Gt CO$_2$e.

2.3.3 Agricultural Production

Main GHG emissions sources related to agricultural production are (i) changes in soil carbon stocks, (ii) CH$_4$ from cultivation of irrigated rice and burning of crop residues, (iii) N$_2$O from fertilizers and manure management, and (iv) CO$_2$ from the use of fossil energy in agricultural operations. To estimate CO$_2$ equivalent emissions from changes in soil carbon stock, this study used the methodology in the GPG/LULUCF for changes in carbon stock in soils in cropland, which takes into account changes in the reference carbon stock (expected carbon stock in the type of soil under native vegetation) and its change due to management (e.g., tillage), land use (e.g. long-term cultivated, set aside), and inputs to soil (e.g. organic or mineral fertilizers). Associated emissions depend not only on the size of the area under use, as determined by the land-use economic model, but also on (i) carbon stock under native vegetation and (ii) carbon-stock changes in the soil, which vary by region and type of agricultural activity.

The study team estimated the carbon stock under native vegetation for regions defined by the different soil classes and vegetation. Using simplified soil and vegetation classifications, 30 soil x vegetation combinations were created; each was attributed a value of the soil carbon stock based on available published data and soil databases in the EMBRAPA Agrogas Network. Subsequently, the team created a map of the soil carbon stock under native vegetation.

Conventional soil-preparation systems used for cultivating grains generally lead to a reduction in soil carbon stock relative to native vegetation (Zinn et al. 2005; Fernside et al. 1998); by contrast, in a zero-tillage system, soil carbon stock is preserved or increased (Zinn et al. 2005; Cerri et al. 2007). The change factors for soil C stocks were estimated taking into account the GPG/LULUCF methodology where the default factor values for land use, management and input are available. Further, the estimated change factors were adjusted as a function of the literature available for Brazil. For example, the change factors for soybean-maize (for Central Brazil) or soybean-wheat (Southern region) crop sequences under conventional tillage were estimated to be 0.48 and 0.69, respectively, using the GPG default values. These change factors mean that after 20 years soils under soybean will present soil C stocks at 48% and 69% of the original content. Data obtained in Brazil suggests this could be even lower. Moreover, in the First National Communication of GHGs the change factor for crops was 0.43. Hence, the change factors were adjusted to 0.50 for the South and 0.40 for Central Brazil. . Factors considered for conventional planting suggest that soil use reduces carbon stocks to 44–63 percent of amounts under native vegetation; this range was observed in samplings done in Brazil (Zinn et al. 2005). Differences between regions and crops are due to the climate and residue-production features of crops.

The IPCC method was also used to estimate CH$_4$ emissions from the production of irrigated rice in southern Brazil and N$_2$O and CH$_4$ emissions from the burning of sugar-cane straw during harvest. According to data from INPE (2009), the proportion of sugar cane harvested without burning was 46.4 percent in 2006/2007 and 49.1 percent in the 2008/2009 harvest. This

proportion increased to 54.4 percent in the 2009/2010 harvest. In the reference scenario, it was assumed that the area harvested without burning would increase and stabilize at about 90 percent by 2020, except in the Northeastern Coast, where it would stabilize at about 40 percent.[49]

CH_4 emissions from the production of irrigated rice and the burning of sugar-cane straw are expected to total 434 Mt CO_2e over the next 20 years. About four-fifths of this amount is expected to result from the cultivation of wetland irrigated rice, mainly in the south. N_2O soil emissions from fertilizer and residues, as well as from the burning of sugar cane, add another 686 Mt CO_2e. The reference scenario projects that, by 2030, only about 3 percent of these N_2O emissions will result from the burning of sugar cane, while the remainder will result from the decomposition of harvest residues, especially those derived from soybean cultivation, which are richer in nitrogen (N) and from pastures with cattle.

From 2009 until 2030, it is estimated that about 55 percent of the N_2O emitted from residues (171 Mt CO_2e) will result from soybean cultivation. Fertilizer use will account for about 121 Mt CO_2e in soil emissions. But because production and transport of every 100 kg of N used in agriculture generates 450 kg CO_2e in fossil-energy emissions, the use of nitrogenous fertilizers would result in total emissions of 250 Mt CO_2e. Fossil-energy emissions associated with agricultural operations (e.g., diesel-powered equipment) are expected to reach 344 Mt CO_2e over the period (table 2.4).

Table 2.4: Emissions from Agricultural Production in the Reference Scenario

GHG emissions source	Mt O2e	% of total
Changes in soil carbon stock	585.2	28.6
Fertilizers, residues (including burning of sugar cane), and mineralization of nitrogen in the soil (N2O)	685.6	33.4
Cultivation of wetland irrigated rice and burning of sugar cane (CH4)	433.6	21.2
Use of fossil energy to power agricultural operations (CO2)	343.5	16.8
Total	2,048.0	100.0

2.36   In summary, GHG emissions resulting from agricultural production are expected to total about 2.0 Gt CO_2e, corresponding to about 102.4 Mt CO_2e per year (table 2.4). Slightly more than 40 percent of these emissions result from loss of organic material in the soil, caused mainly by the conversion of pasture land into farming areas in the Southeast, Center-West, and MAPITO and Bahia regions. The farming area under zero tillage is maintained at 77 percent of the area under corn (first harvest) and soybean cultivation and at just over 8 percent of the area under cultivation by other crops until 2030. The gradual elimination of sugar-cane burning is expected to lower annual emissions over this period.

2.3.4 Carbon Uptake

Brazil's potential opportunities for carbon uptake reside mainly in (i) forest recovery through afforestation or reforestation activities, or assisted natural regeneration and (ii) production forests. Forest recovery has a significant potential for carbon removal. For example, modeling results and data from the available literature indicate that plant-cover restoration for the riparian

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49   The areas utilized for sugar plantation in the states of Pernambuco and Alagoas have on average 70 percent and 30 percent respectively of declivitis above 12 percent, which incapacitates mechanized harvesting under current technology; manual cutting without burning in large scale becomes unviable.
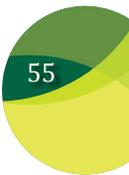
forests of São Paulo alone could result in the removal of about 400 Mt CO_2., while in the Amazon, the potential is even higher, given that climate conditions in much of this biome increase the carbon-absorption potential of growing forests.

However, in degraded ecosystems, such as abandoned pasture and cropland, the regeneration potential of arboreal species and secondary-succession species is impaired. Specific botanical obstacles include lack or inadequacy of seed banks, poor seed dispersal, competition with high-biomass graminae, herbivore predation, burning, and absence of pollinators. Therefore, in the reference scenario, native forest recovery, which accounts for the major share of carbon uptake by antropogenic activities, remains limited compared to the theoretical potential, at about 10.3 Mt CO_2 per year. If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 109MtCO2 per year.[50]

With regard to Brazil's production forests,[51] alternation of planting and harvesting generates an average carbon stock whose flow dynamic is determined by the cycle of the species cultivated; for example, the cycle for Eucalyptus species is about 21 years (three seven-year cycles). The average carbon stock of forest clusters is linked to the earmarked economic activity (e.g., iron and steel or pulp and paper production) and thus the risk that the economic activity will decline or end.[52]

This study focused on production forests of renewable plant charcoal for the iron and steel industry. Substitution for non-renewable plant charcoal or mining coal can result in increased carbon uptake without altering the supply and demand of the final products. This is not the case for other sectors, whose reforestation potential is confined to market growth of the end-use activity. Future projections for production forests using renewable plant charcoal were based on estimated annual growth in the iron and steel market over the study period (3.7 percent) and market participation of all thermo-reduction agents.

The reference scenario assumes a continuation of the current market situation. With regard to thermo-reduction participation, it assumes 66 percent based on mineral coke, 24 percent on non-renewable plant charcoal, and 10 percent on renewable plant charcoal. The reference scenario also assumes (i) continued lack of public policies and adequate sector financing; (ii) continuation of the current regulatory structure, which leaves room for the use of non-renewable plant charcoal; and (iii) low productivity development in terms of growing trees for wood and efficiency of the wood carbonization process.

Under the reference scenario, it is estimated that production forests can sequester 315 Mt CO_2e over the period analyzed.

2.4 Reference-scenario Emissions Results

Based on subsectoral analyses, the study team generated an integrated reference scenario for LULUCF. This reference scenario used the emissions calculation methods indicated above, which were integrated into the SIM Brazil model. Use of these models made it possible to generate maps and tables that registered annual emissions and carbon uptake over the study period, calculated for each 1-km^2 plot and integrated by micro-region, state, and country (figure 2.4).

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50   When calculating national carbon inventories, some countries consider the contribution of natural regrowth towards carbon uptake; therefore, although this study does not compute this contribution in the carbon balance of LULUCF activities, it would be fair to add that information for comparison purposes.
51   Brazil currently has about 5 million ha of production forests.
52   However, risks associated with extreme events, such as fires and pests, are ostensibly less, owing to the need to replant areas to compensate for the end-use activity.

Figure 2.4: Reference Scenario Results: Emissions from Land Use and Land-use Change, 2009–30
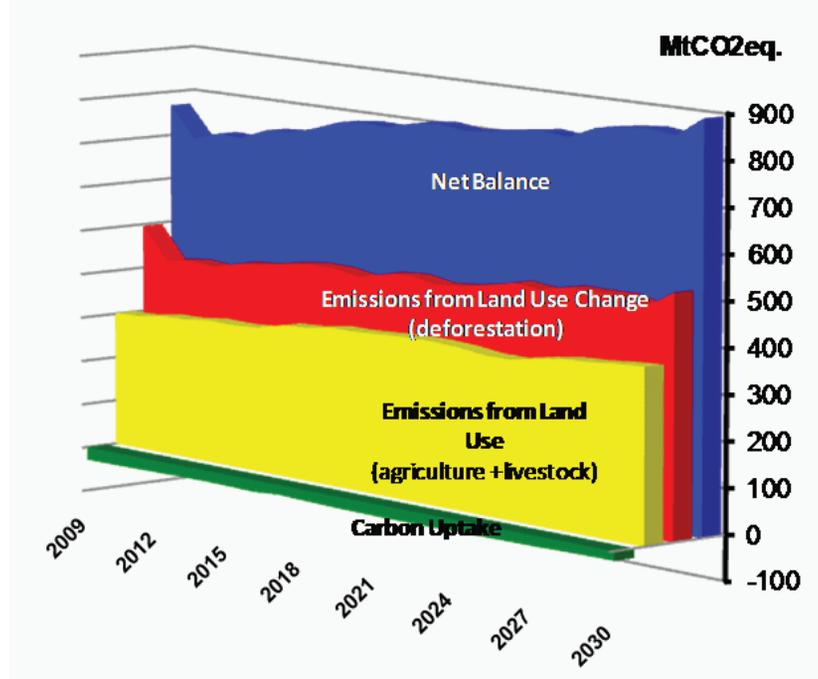
Emissions from land-use change via deforestation account for the largest single share of total emissions from LULUCF—up to 533 Mt CO_2e per year by 2030. Direct annual emissions from land use (agricultural production and livestock activities) increase over the period up to annual rate of 383 Mt CO_2e. The model shows a decrease in the annual rate of carbon uptake, from 28 Mt CO_2e in 2010 to 20 Mt CO_2e in 2030. For the entire period considered, the net balance between land use, land-use change, and carbon uptake results in increased emissions, reaching about 895 Mt CO_2e annually by 2030[53].

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53   When calculating national carbon inventories, some countries consider the contribution of natural regrowth towards carbon uptake; therefore, although this study does not compute this contribution in the carbon balance of LULUCF activities, it would be fair to add that information for comparison purposes. If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 109MtCO2 per year, thus reducing the net emissions.

Chapter 3
Land Use, Land-use Change, and Forestry: Toward a Low-carbon Scenario

Based on the projected evolution of LULUCF-sector emissions in the reference scenario (chapter 2), this study explored opportunities for reducing emissions and scaling up carbon uptake. Sections 3.1–3.3 identify the mitigation options for agricultural production, livestock activities, and deforestation, respectively; similarly, section 3.4 identifies options for forestry-related carbon uptake. Each of these four sections analyzes barriers to adopting the respective mitigation measures and explores ways to overcome them. Section 3.5 suggests how these mitigation options, taken together, can create a new land-use dynamic for Brazil. Section 3.6 offers added forest protection measures to further deepen and strengthen emission reductions. Finally, section 3.7 summarizes the integrated strategy for a low-carbon scenario.

3.1 Mitigation Options for Agricultural Production

Reduction in soil carbon stock accounts for more than two-fifths of direct emissions from agricultural production, as discussed in chapter 2, suggesting the need for mitigation efforts to adopt agricultural practices that reduce the conversion of soil carbon stock and mineral nitrogen (N) into carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4).

The study team identified acceleration of the dissemination of zero-tillage cultivation as the most promising option for reducing GHG emissions from agricultural production. Emissions in the low-carbon scenario, using more zero-tillage cultivation, were about 21 percent less than in the reference scenario, which used conventional farming systems (table 3.1). Zero-tillage farming can reduce soil loss by about three-fourths, resulting in a 20-percent increase in water infiltration. Other potential benefits include control of soil temperature, improved soil structure, increased water-storage capacity, and enhanced nutrient retention of plants. In wetland-irrigated-rice systems, zero-tillage has reduced CH_4 emissions by about 15 percent (Lima 2009). Total avoided emissions using zero-tillage could amount to 356 Mt CO_2e over the 2010–30 period (figure 3.1). For these reasons, zero-tillage cultivation is expanded to 100 percent by 2015 in the low-carbon scenario.

Despite Brazil's extensive experience with zero-tillage cultivation, switching from conventional to zero-tillage systems involves a range of cultural, technical, and financial hurdles:

- *Knowledge gap.* Myths about soil compaction, low-liming efficiency, and likelihood of pests and disease discourage small-scale farmers from attempting zero-tillage farming.

- *Lack of access to technology.* Small-scale farmers are responsible for an important part of grain production (e.g., beans and corn), but have little or no access to the technical assistance needed to adapt their production systems.

- *Upfront costs of conversion.* Initiating a zero-tillage system may involve acquiring machinery and larger quantities of inputs, and there is a lack of consensus on the economic advantages of zero tillage in all regions.

- *Research gap.* Although zero-tillage farming is practiced widely in southern Brazil, where the climate is mild, further research is needed for certain regions, e.g. northern and northwestern parts of the Paraná State and such regions as the Cerrados (e.g., research on plant cover for the period following the summer harvest to guarantee enough residue to cover the soil throughout the year).

- *Lack of infrastructure and marketing.* Brazilian farmers often face problems of produce storage and transport to markets. The higher value of soybeans precludes the storage of such crops as corn, a key option for summer rotation. Also, small farmers have no guarantee that alternative cereal crops will be purchased. The

resulting domination of soybean monoculture weakens diversification, which successful zero-tillage farming requires.

Table 3.1: Reduced Agricultural-production Emissions in the Low-carbon Scenario Using Zero-tillage Cultivation for the 2010-2030 period

Emission source	GHG emissions in the low-carbon scenario (Mt CO_2e)	Difference compared to the reference scenario	
		Mt CO_2e	% reduction
Change in soil carbon stock	348.4	236.8	40.5
Fertilizer and residue (including burning of sugar cane) and mineralization of nitrogen in the soil	631.0	54.6	8.0
Cultivation of wetland irrigated rice and burning of sugar cane	390.8	42.8	9.9
Use of fossil energy to power agricultural operations	322.4	21.1	6.1
Total	1,692.5	355.5	17.3

Figure 3.1: Avoided Emissions via Zero-tillage Cultivation in the Low-carbon Scenario, 2010–30
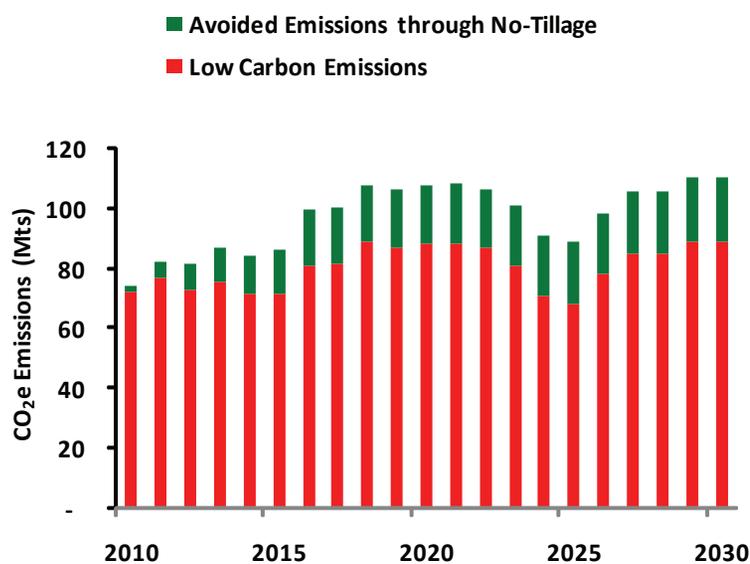
Various measures can be implemented to overcome these barriers, as follows:
- *Strengthen basic and technological research* and generate zero-tillage information that guarantees system sustainability throughout the country.
- *Restructure the rural extension system* and prepare technicians to serve as a link between research institutions, universities, and various segments of the productive sector. It is vital for technical universities and schools to incorporate the zero-tillage system into the professional training curricula.

- *Establish priority credit* for farmers who adopt the system (e.g., increase the budget for low-interest loans or lower insurance premiums over time).

- *Expand storage facilities and guarantee produce purchase* (e.g., corn); *develop financial "hedge" instruments* for prices of essential inputs, such as herbicides, for the zero-tillage system.

3.2 Mitigation Options for Livestock Activities

Given that methane (CH_4) emissions from beef-cattle farming account for the largest share of GHG emissions from livestock activities[54], the following mitigation options were explored:

- Genetic-improvement programs for forage to reduce methanogenesis (FAO 2007) and

- Incentive programs for using genetically superior bulls (improved animals have a shorter life cycle and emit a smaller quantity of CH_4 until slaughtered).

These two options directly affect emissions reductions per product unit, which are conventionally measured in tons of carcass equivalent. Beyond these two options, livestock emissions can be reduced via productivity gains. The transition from a lower to a higher productivity system alone has little effect on GHG emissions per animal (1.25 tCO_2e in the degraded-pastures scenario versus 1.15 tCO_2e in other scenarios). But higher productivity in more intensive systems generates a significant reduction in projected herd for 2030 (208 million head in the low-carbon scenario versus 234.4 million in the reference scenario), which, in turn, generates significant emissions reduction per unit of meat (figure 3.2) and in total value (figure 3.3).

Figure 3.2: Comparison of Methane Emissions per Unit of Meat (kg CO_2e per kg), 2008–30

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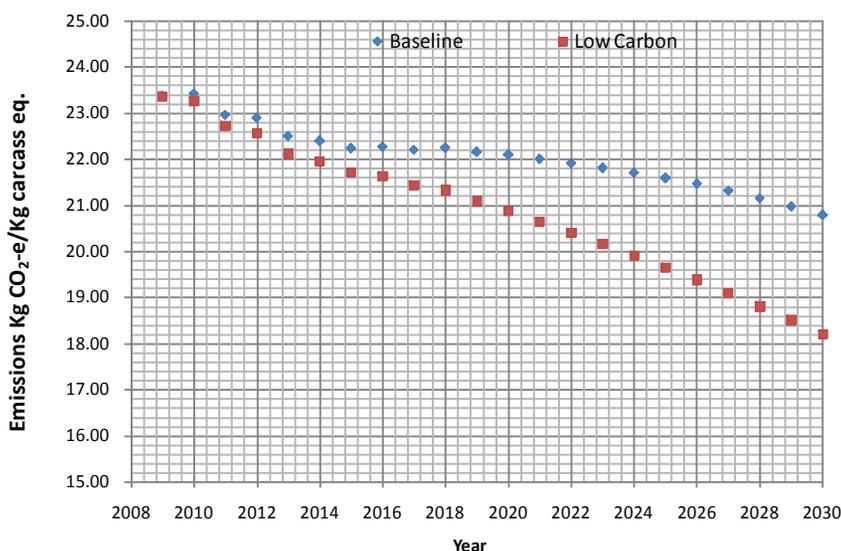
54   CO_2 equivalent of emissions from livestock activities are estimated base on a GWP of 21. However, if a different metric were applied, for instance the GTP, the corresponding estimates would vary significantly. In particular, using GTP would lead to smaller numbers. However, this issue being still debated, the study opted for maintaining the GWP metric, using the value of 21 for methane.

Figure 3.3: Comparison of Methane Emissions from Beef-cattle Raising (Mt CO$_2$e per year), 2008–30
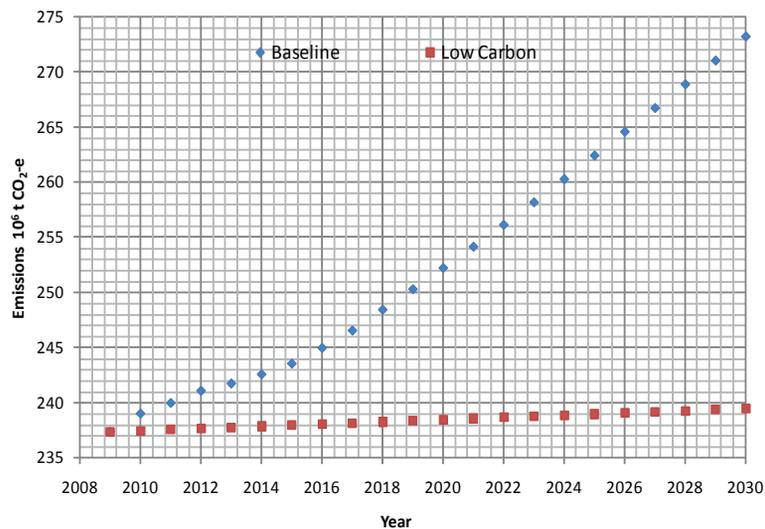
The combination of improved forage and genetically superior bulls, combined with the proposed increase in livestock productivity, would reduce direct livestock emissions from273 to 240Mt CO$_2$ per year in 2030; that is, maintain emissions at about the 2008 level.

But productivity gains may have a greater effect on the general balance of emissions associated with land use and land-use change. Indeed, higher meat-production rates per hectare means that less pasture land is needed. The release of pasture land for other uses helps reduce overall land demand and the need to remove native vegetation and therefore emissions from deforestation. This potential contribution from the livestock sector to help reduce emissions from deforestation is further explored in section 3.3.

The hurdles involved in these proposed mitigation options could be surmounted by building on current programs and policies. Currently, Brazil's forage improvement programs, which emphasize the use of genetic materials with favorable agronomic and pest- and disease-resistant characteristics, do not pursue the objective of reducing GHG emissions; however, ongoing research programs test evaluation techniques for in vitro CH$_4$ production in forage plants. Thus, public policies could be put in place to promote the funding of research programs that encourage universities and research institutions to select forage of higher nutritional value and implement better management strategies to produce cultivars with lower CH$_4$ emissions potential for ruminants. According to preliminary estimates by the EMBRAPA team, launching a 12-year research program on genetically improved cultivars would cost about R$4 million.

Use of genetically superior bulls has a longer period of return. Programs that provide incentives for evaluating bulls and subsidies for acquiring tested animals of good lineage may contribute to sector efficiency over the medium term, as well as reduce GHG emissions. Assuming that 2.3 million bulls are needed to maintain the national herd (a bull-to-cow ratio of 30:1), a 50-percent premium for improved animals above their slaughter value, and four years of useful life for the bull, the total value of subsidies for the national herd would amount to about R$350 million per year. Positive externalities for adopting such a measure include increased productivity, better-quality carcasses, and increased calving rates (assuming andrological testing of improved bulls).

Since the 1990s, the rise in per-animal productivity of beef-cattle farming has significantly reduced emissions per kilogram of carcass produced. Higher productivity has coincided with greater adoption of mixed crop and livestock systems and feedlot systems. But the carrying capacity of pastures has changed little over the period, suggesting that pasture degradation may offset the gains obtained by productivity gains observed in other places (IBGE 2008)—hence the importance of promoting degraded pastures renovation.

Although improved and more intensive systems are more attractive with regard to economic returns, the cost of restoring low-productivity pastures is relatively high (estimated at R$2,924.92 per ha in investment and R$21,300 per ha in expenditure). Even more costly are the investments required to implement such systems, particularly the acquisition of animals. Since the economic value of the activity is not high, credit at low-interest rates would be required to finance the purchase of animals to increase the rate of carrying capacity; otherwise, ranchers would likely underuse available forage resources. Favorable economic performance of past programs using crop-livestock systems (e.g., PROLAPEC and PRODUSA) suggests that such incentives could reduce business risk, increase income in the field, and renovate degraded pasture areas, facilitating agriculture-livestock expansion in already deforested areas. Incentive policies for the early slaughter of animals may also generate gains in productivity and reduce emissions (e.g., the Early Bullock Program in Mato Grosso do Sul). Finally, given that more intensive systems demand greater management, public policies that promote rural extension and training for cattle ranchers are important.

3.3 Increased Livestock Productivity to Reduce Deforestation Emissions

In the reference scenario, the main emissions source is deforestation. While significant, the mitigation and carbon uptake potential described above remains limited compared to the large volume of GHG emissions resulting from deforestation. As mentioned above, a main trigger of deforestation is the need to convert native vegetation into land to accommodate crops and pasture expansion. The land-use modeling developed by this study makes it possible to estimate the volume of additional land needed and associated deforestation in the reference scenario. To avoid emissions from deforestation, ways would need to be found to reduce global demand for land, while maintaining the same level of products supply as in the reference scenario. In systemic terms, the mitigation of emissions through land-use change could be achieved by absorbing the expansion of these activities via the increased productivity of other ones.

Brazil's major agricultural activities already show high levels of productivity and consequently do not offer opportunities to increase productivity on the scale required to absorb these additional levels of demand for land. For example, the productivity of a soybean plantation in Brazil was 2.86 tons per ha in 2008, compared with 2.81 tons per ha in the United States (table 3.2).

Table 3.2: Average Productivity of Selected Crops in Various Countries (tons per ha), 2008

Country	Crop (tons per ha)			
	Soybean	Corn	Cotton	Rice
Argentina	2.78			
Bangladesh				3.93
China, People's Republic of	1.61	5.17	1.30	6.43
EU-27		5.67		
India	1.06	2.3	0.57	3.31
Indonesia				4.66
Mexico		3.22		
Pakistan			0.65	
Paraguay	2.62			
Thailand				2.76
United States	2.81	9.46	0.99	
Uzbekistan, Republic of			0.83	
Brazil	**2.86**	**3.99**	**1.49**	**4.20**

Beef-cattle farming shows much greater potential for increasing productivity per hectare, which can be applied to a much larger pasture area, since pastures occupy 207 million ha compared to 70 million ha for agricultural activities in 2030 in the reference scenario. Consequently, increasing the technological level and the intensification of livestock-raising can play an essential role in reducing the need for land for this activity, while releasing the land required for expansion of other activities.

3.4 GHG Removal via Carbon Uptake Options

Brazil's major available options for carbon uptake, as discussed in chapter 2, are production forests and native forest recovery—particularly reforestation of riparian forests and legal reserves. This section identifies the carbon removal potential of these options and analyzes and explores ways to overcome barriers to their implementation.

3.4.1 Production Forests

Brazil is endowed with climatic conditions and soils characteristics that favor the growing of production forests. Furthermore, the country has some of the world's most advanced wood-production technologies based on fast-growing, high-productivity clones. Despite these assets and the coordinated efforts of sector enterprises, research centers, and universities, Brazil has a deficit of plantation forests.

The added uptake potential in the low-carbon scenario was estimated assuming the total substitution of non-renewable plant charcoal starting in 2017 and the increased use of plant charcoal for up to 46 percent of total production of iron and steel ballast by 2030 (the end of the period considered). This would result in a doubling of annual uptake by the end of 2030 compared to the reference scenario; the total uptake volume in the low-carbon scenario would equal 377 Mt CO_2, 62 Mt CO_2 more than in the reference scenario at that time.

However, achieving that potential presupposes overcoming certain barriers. The cycle of Eucalyptus, Brazil's principal plantation-forest species, is generally completed within 21 years
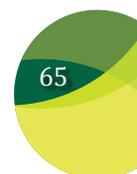
(i.e., three seven-year rotations), as discussed in chapter 2. Thus, the activity requires a long maturation period involving large volumes of land investments. Because the first returns on investment occur only after the seventh year, corresponding loans should ideally have a 7-year grace period and a minimum 10-year duration. Currently, this credit structure does not exist in Brazilian commercial banks and is rare in public banks. The funding of most federal funding programs (e.g., PROPFLORA or PRONAF) is limited to small-scale production, which, although necessary, is insufficient to counter the country's plantation-forest deficit. Although state-level experiences, such as the Proflorestas Program of the Minas Gerais Development Bank (BDMG) have proven relatively successful, they too suffer from a lack of financial resources.

Access to credit is another barrier, owing to collateral issues and environmental policy requirements. For example, various banks still use plantation forests as a guarantee source for loans, while for other agricultural crops, "crop in the ground" can be used as collateral. Oftentimes, only the land can be considered as the guarantee. Non-compliance with environmental-licensing requirements by enterprises requesting credit exacerbates the issue, demonstrating the need for better coordination between public funding policies and the capacity of economic agents.

Other hurdles are related to the regulatory framework for silviculture, transaction costs, and the conversion technologies used. Enterprises are required to obtain licenses to harvest and transport wood from plantation forests, which is not the case for the harvesting of agricultural crops. Furthermore, the transaction costs for planting and managing production forests for renewable plant charcoal (e.g., long maturation period and large quantities of required labor) are significantly higher than those for alternative products that result from deforestation (e.g., non-renewable plant charcoal). Finally, traditional carbonization technologies used to convert wood into plant charcoal are inefficient.

Overcoming these barriers suggests key measures to improve the funding and regulatory environment. First, current funding instruments could be adjusted to facilitate the increased availability of credit along the productive chain of the iron and steel industry using renewable plant charcoal. Support of the Clean Development Mechanism (CDM) of the Kyoto Protocol would allow Brazil to take advantage of already existing methods that cover a significant portion of the productive chain.[55] Moreover, revision of the sector's regulatory framework could aim to simplify the environmental licensing process without harming the socio-environmental integrity of activities. To guarantee control over the origin of wood, measures could be taken to strengthen the inspection structure for the illegal use of non-renewable plant charcoal resulting from deforestation.

3.4.2 Native Forest Recovery

As illustrated in chapter 2, there is some potential for CO_2 removal through natural regrowth of degraded forests, which has already been mentioned in the reference scenario. But because of the botanical obstacles mentioned earlier, the carbon-capture potential associated with natural regrowth remains limited. Despite these challenges, various studies and projects have demonstrated that forest plantings can foster the accelerated reestablishment of native plant cover; such plantings induce microclimatic changes favorable to germination and establishment of plantlets and generation of a layer of litter and humus, which increases soil fertility. In addition, shade from young trees helps to suppress invasive grasses. Because of the large areas of degraded

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55 Several methodologies were already approved by the CDM for reforestation for industrial and commercial use and for reforestation in protected areas.

ecosystems, such as abandoned pasture and croplands, where native forest recovery activities could be implemented, such activities can represent a significant carbon-removal potential in Brazil.

3.4.2.a Modeling the Potential for Carbon Uptake through Native Forest Recovery

To assess the potential for CO_2 removal through native forest restoration, the study developed a model of biomass potential in the most promising biomes, the Cerrado and Atlantic Forest. These biomes, home to large forested areas in former times, have suffered severely from deforestation over the past two centuries. Meteorological data (e.g., rainfall, dry season, and temperature) and edaphic variables (soil and topography) were used to generate potential biomass indices (figure 3.4). These were calibrated with values in the literature to simulate the carbon-uptake potential for non-riparian and riparian forests in the Cerrado and Atlantic Forest biomes,[56] for which maps were created (figure 3.5).

Figure 3.4: Flowchart of Model Used To Map Potential CO_2 Removal by Reforestation

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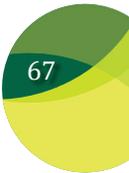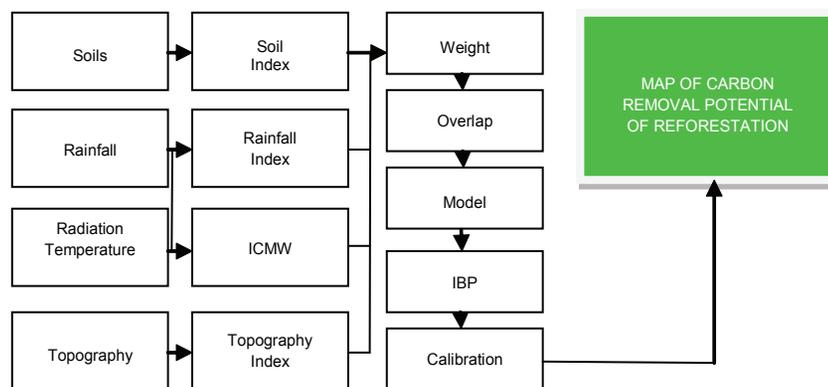
56   Riparian forests, which border rivers, are less subject to hydric deficit than other forest formations in these biomes.
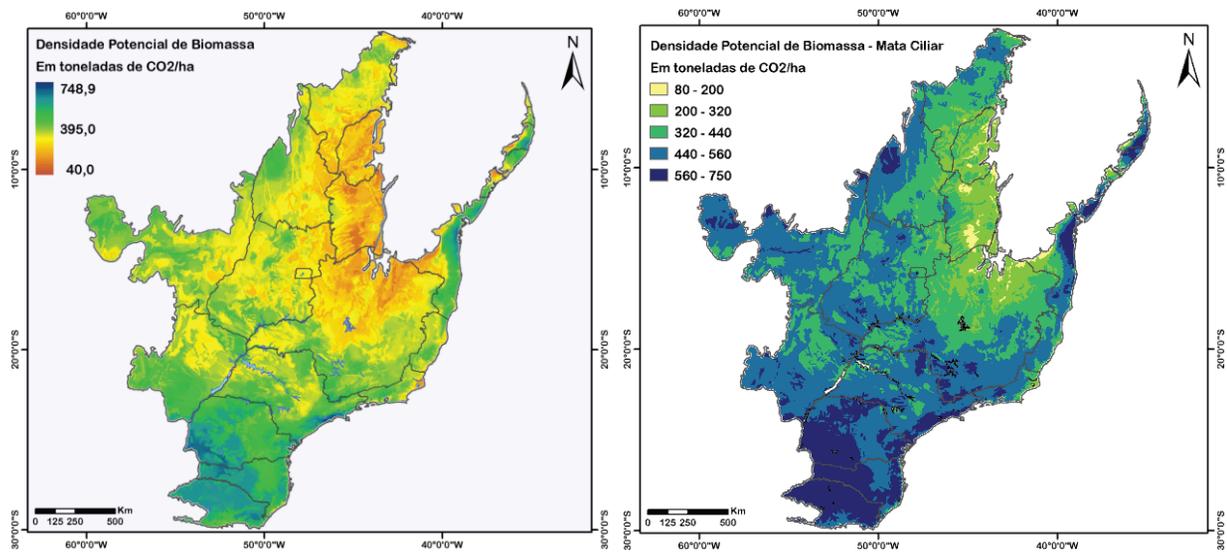
Non-riparian Forests   *Riparian forests*

Economic, as well as ecological, reasons limit native forest recovery. First, it is an expensive activity. Second, rural properties would lose productive areas during the period of plant-cover regeneration. For these reasons, forest recovery is rarely voluntary; rather, it occurs mainly as a legal obligation. But because of the costs incurred for landowners, enforcement of such legislation is not easy. For example, the state of São Paulo has a deficit of more than 1 million ha of riparian forests despite efforts of the state government to create reforestation programs (e.g., the GEF-funded Project to Restore Secondary Forests) and federal credit lines aimed at restoring plant cover on rural properties. Estimating the potential for carbon removal through forest recovery thus requires target-setting for such activities. As a result of consultations with government representatives, this study adopted as a target compliance with the forestry law regarding legal forest preservation areas and reserves. The cost of implementing such a target is analyzed in chapter 7.

3.4.2.b Compliance with Forestry Laws

The largest reforestation potential for carbon uptake in Brazil considered in this study centers on a "Legal Scenario" involving compliance with and enforcement of laws governing the management and use of riparian forests and legal reserves (box 3.1). Estimating that potential requires a two-step calculation: (i) determine the area required for compliance and (ii) estimate the potential for CO$_2$ removal resulting from restoring native forest in this area.

Permanent Preservation Areas

Permanent preservation areas (PPAs) are forested areas found along the edges of rivers, lakes, and other water bodies that preserve hydrological resources, prevent soil erosion, maintain landscape and geological stability, and ensure human well-being. In Brazil's riparian forests, the width of the PPA depends on that of the river (table A).

Table A: Width comparison of river and PPA

River width (m)	PPA width (m)
Up to 10	30
10–50	50
50–200	100
200–600	200
Over 600	500

Legal Reserves

Legal reserves are areas inside Brazil's rural properties or land plots (with the exception of PPAs) that are vital to the sustainable use of natural resources, conservation and rehabilitation of ecological processes, and biodiversity conservation. The percentage of land set aside as a legal reserve varies by biome :

- • 80% in rural property located in the Legal Amazon;

- • 35% in rural property located in cerrado biome and located in the Legal Amazon;

- • 20% in rural property located in forest areas or other forms of native vegetation in other regions of the country, especially the Atlantic Forest.

To estimate the amount of land needed for reforestation to comply with the Legal Reserve Law, this study used area of the municipality as the basis for calculating the percentage of legal reserve. The study excluded conservation units (Cus), indigenous lands, PPAs of major watercourses, areas with declivity above 15 percent, unfit soils, and urban areas. Legal reserve percentages defined by the Forest Code were used (box 3.1, table B). Also excluded were areas with native vegetation, including secondary vegetation, savanna, and forests. The area left equaled the intended area for forest recovery in compliance with the Legal Reserve Law.

To estimate the uptake potential, the study team assumed that legal-reserve areas to be restored would be reforested gradually until 2030, when full legality would be achieved. Starting in 2010, 1/21 of the total area for reforestation would be deducted every year from the area available for agricultural production. The environmental liability for the country was estimated at about 44 million ha, about one-third of which would be located in the Amazon region (table 3.3).

Table 3.3: Area Needed for Reforestation under Brazil's Legal Reserve Law, by State

State	Area for reforestation (ha)	State	Area for reforestation (ha)
Mato Grosso do Sul	3,398,792	Acre	721,161
Mato Grosso	9,465,888	Amazon	34,848
Goiás	2,611,730	Roraima	46,757
Distrito Federal	0	Pará	11,369,199
Maranhão	40,959	Amapá	0
Piaui	0	Tocantins	1,644,537
Rio Grande do Norte	3,062	Parana	1,711,257
Paraiba	27,167	Santa Catarina	398,679
Pernambuco	58,239	Rio Grande do Sul	1,184,241
Alagoas	91,861	Minas Gerais	2,682,095
Sergipe	118,800	Espirito Santo	205,436
Bahia	242,079	Rio de Janeiro	178,087
Rondônia	4,794,589	São Paulo	3,314,927
Total for Brazil: 44,344,390 ha			

Sources: ICONE, UFMG.

The study estimated the carbon-uptake potential for the Legal Scenario at about 2.9 Gt CO_2 over the study period; that is, about 140 Mt CO_2e per year (figure 3.6).[57]

Figure 3.6: Carbon Uptake Potential of Forest-recovery Activities and Production Forests
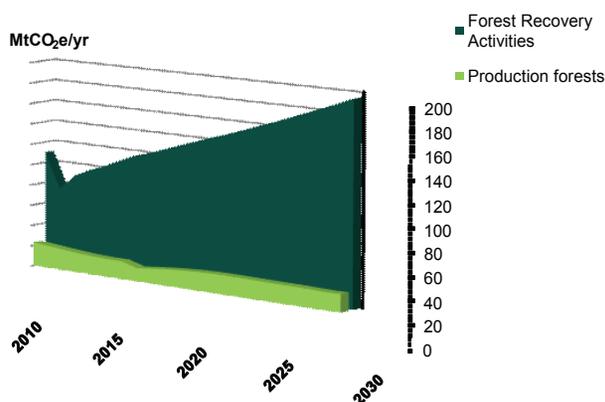
It is important to note that enforcing forest legal reserves implies releasing the corresponding land currently occupied by other activities (i.e., crops or pastures). This means that the land use and land-use change projected in the reference scenario (chapter 2) would need to be revised. Such a revision would be significant since the area released for legal enforcement of the forestry law would equal more than twice the estimated deforested area under the reference scenario. This runs the risk that the benefits gained from carbon uptake resulting from forestry activities could be partially lost via increased conversion of native vegetation to accommodate crops and pastures displaced by restored legal reserves.

57   If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 112MtCO2 per year on average.

3.5 Striking a Balance: A New Dynamic for Land Use and Land-use Change

This study proposes a low-carbon scenario for land use and land-use change in Brazil focused mainly on (i) containing national land demand for crop and pasture expansion to reduce emissions from deforestation, (ii) scaling up the identified mitigation options for agriculture and livestock, and (iii) maximizing the carbon uptake potential associated with legal forest reserves and production forests. This section presents suggested ways for implementing this scenario and the results expected from an improved carbon balance in the LULUCF sector.

3.5.1 A New Dynamic for a Low-carbon Scenario

A key conclusion from the study's investigations on emissions mitigation is that reducing the main source of emissions, deforestation, requires freeing up enough land from existing pastures to accommodate all new activities and thus avoid the conversion of native vegetation.

The previous sections presented opportunities for GHG emission avoidance and carbon uptake associated with land use and land-use change, particularly emissions from agricultural production and livestock activities and carbon uptake via production forests and native forest recovery. But putting together a low-carbon scenario for land use is not a simple exercise of adding (in the case of emission avoidance) or subtracting (in the case of uptake) the volumes of greenhouse gas associated with these opportunities. For example, while increasing the land area allocated to forest recovery and production forests leads to carbon uptake and reduction in ironworks emissions, it also decreases otherwise available land for the expansion of agriculture and livestock activities. The potential conversion of more native-vegetation areas for the expansion of these agriculture and livestock activities would generate a carbon leakage. To avoid this situation, ways must be found not only to reduce the additional amount of land needed under the reference scenario, but also to release land for the envisioned mitigation and removal activities while maintaining the same level of products.

3.5.1.a Additional Land Needs for Carbon Uptake Activities and Biofuel Export

In the low-carbon scenario, the amount of additional land required for emission reductions and carbon uptake totals more than 53 million ha. Of that amount, more than 44 million ha—twice the land expansion projected under the reference scenario—is for forest recovery under Brazil legal reserve law. The total volume of additional land required is more than 70 million ha, more than twice the total amount of land planted with soybean (21.3 million ha) and sugar cane (8.2 million ha) in 2008 or more than twice the area of soybean projected for 2030 in the reference scenario (30.6 million ha) (table 3.4).
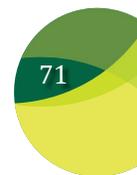
Table 3.4: Mitigation and Carbon uptake Options for a
Low-carbon Scenario and Associated Needs for Additional Land

Scenario	Additional land needed (2006–30)
Reference Scenario: additional volume of land required for the expansion of agriculture and livestock activities	*Expansion of agriculture and livestock production to meet the needs anticipated in 2030:* →*16.8 million ha*
Low-carbon scenario: additional volume of land required for mitigation measures	Elimination of non-renewable charcoal in 2017 and the participation of 46% of renewable planted charcoal for iron and steel production in 2030: → *2.7 million ha*
	Expansion of sugar cane to increase gasoline substitution with ethanol to 80% in the domestic market and supply 10% of estimated global demand to achieve an average worldwide gasoline mixture of 20% ethanol by 2030 → *6.4 million ha*
	Restoration of the environmental liability of "legal reserves" of forests, calculated at 36.2 million ha in 2030. → *44.3 million ha*
Total	***70.4 million additional hectares***

One possible consequence is that the expansion of land use for activities that promote lower levels of emission, fossil-fuel substitution (as detailed in chapter 4), or even carbon capture may provoke an excess in land-use demand, which, in turn, could generate deforestation, inducing a lower net balance of carbon uptake.

3.5.1.b Toward a New Pattern of Productivity for the Livestock Industry

The study simulated the new distribution of livestock productive systems that should be promoted to free up enough pasture land to accommodate all demand for additional land derived from crops expansion in the reference scenario and the implementation of new emission reduction and carbon uptake options proposed under the low-carbon scenario.

To increase livestock productivity per hectare—thereby absorbing the expansion of agriculture and other low-carbon activities without causing deforestation while reducing emissions per unit of meat—five options were considered: (i) promote the recovery of degraded pasture; (ii) stimulate the adoption of productive systems with feedlots for finishing; (iii) encourage the adoption of crop-livestock systems; (iv) develop genetic improvement programs for higher-quality, lower-emissions forage adapted to Brazil; and (v) develop incentive programs for the use of genetically superior bulls.

The projected effect of the productive systems considered for the reference and low-carbon scenarios are compared below (figure 3.7).

Figure 3.7: Variation in Number of Head of Cattle in Productive Systems, 2009–30
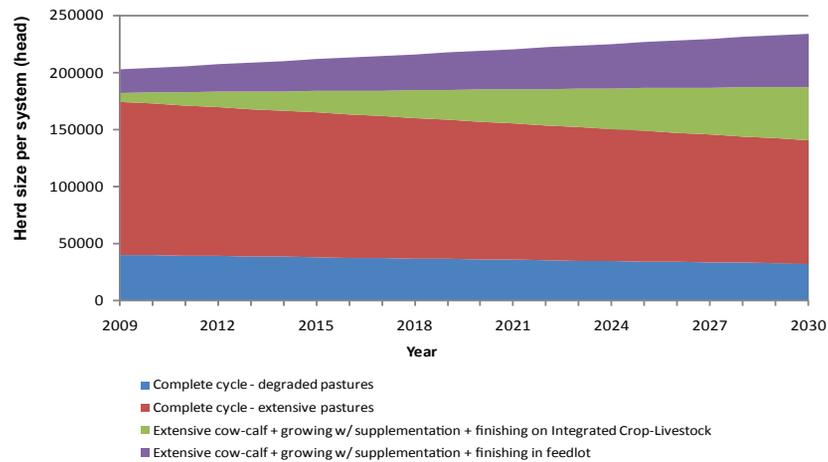
Reference Scenario
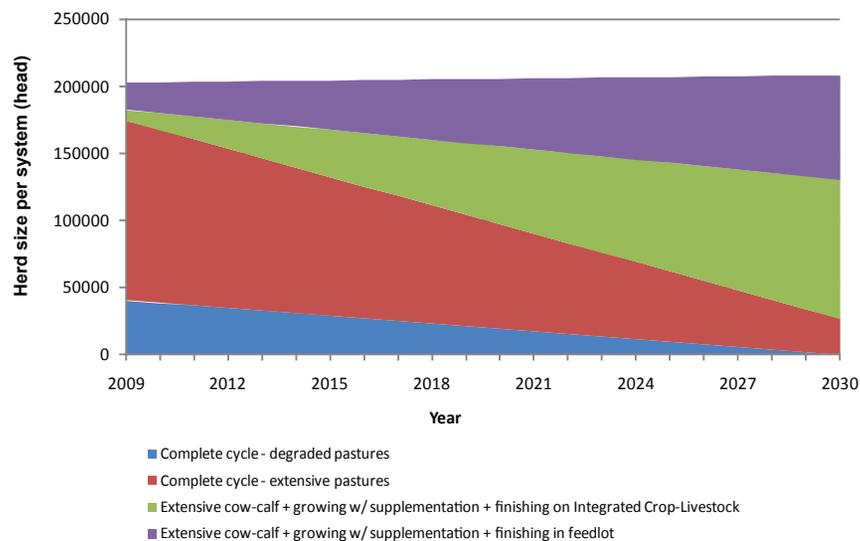
Low-carbon Scenario

Increased carrying-capacity rates associated with greater herd productivity as a combined effect of the recovery of degraded areas and the adoption of more intensive livestock stocking and finishing systems (integration of crop-livestock systems and feedlots) are reflected in an accentuated reduction in demand for land, projected at about 137.82 million ha in the low-carbon scenario, compared to 207.06 million ha in the reference scenario for the year 2030 (table 3.5). The difference would be sufficient to absorb the demand for additional land associated with both expansion of agriculture and livestock activities in the reference scenario, as well as the expansion of mitigation and carbon uptake activities in the low-carbon scenario (figures 3.8).

Table 3.5: Comparison of Land-use Results for the Reference and Low-carbon Scenarios (millions of ha)

Land use	2006	2008	Reference scenario		Low-carbon scenario		Difference (2030) between low-carbon and reference scenarios
			2030	Var. 2030–2006	2030	Var. 2030–2006	
Grains (harvest)	38.94	37.79	47.92	8.98	47.86	8.92	(57)
Sugar cane	6.18	8.24	12.70	6.52	19.19	13.01	6.49
Production forest	5.27	5.87	8.45	3.18	11.17	5.90	2.72
Pasture	208.89	205.38	207.06	(1.83)	137.82	(71.07)	(69.24)
Total area for agriculture and livestock[1]	259.27	257.28	276.13	16.85	216.04	(43.23)	(60.08)
Restoration	-	-	-	-	44.34	44.34	44.34
Balance						1.11[2]	(15.74)
Herd (per 1,000 head)	205.890	201.410	234.460	28.570	208.000	2.120	(26.46)

[1] Total area allocated to cotton, bean (1st harvest), corn (1st harvest), soybean, sugar cane, production forest, and pasture.
[2] Represents expansion of agricultural area between 2006 and 2008 in the Northern and Northeastern regions.
Source: ICONE.

Figure 3.8: Evolution of Brazil's Demand for Land by Crop, 2006-30 (Millions of Ha)
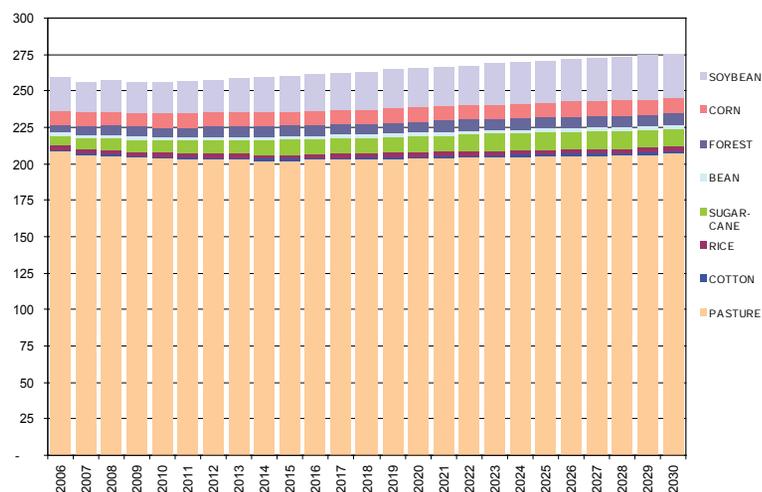
Reference Scenario
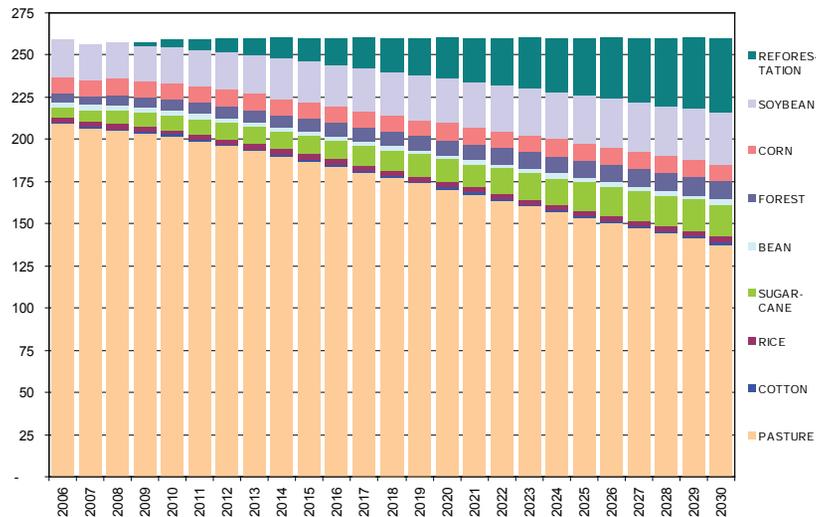
Low-carbon Scenario

Source: Adapted from ICONE (2009).

3.5.1.c A New Land-use Scenario for Main Crops and Pastures

With new data provided by the economic modeling team for land demand in a low-carbon scenario—the development of which is based on a wide array of improvements in zootechnical livestock indices and the consequent reduction in the need for pasture areas, increased area allocated to sugar-cane production, restoration of environmental liability with regard to legal reserves and PPAs, and greater share of plant charcoal for ironworks—the simulation model for land-use change used in the reference scenario was run again.

Based on the simulation results, maps showing the dynamic of land-use change in the low-carbon scenario were created for major agricultural products, pasture lands, and forest plantations. Of all the products simulated, sugar cane exhibits the territory's most altered dynamic compared to the reference scenario due to the greater cultivation area required to increase ethanol production. Geographical distribution patterns remain the same, accompanied by an intensification of the areas of expansion mentioned in the reference scenario (figure 3.9).

With regard to the dynamic of forest plantation cover, simulation results revealed major differences between projections for the reference- and low-carbon scenarios. In the reference scenario, areas of expansion were few; but in the low-carbon scenario, they occurred frequently in areas close to earlier plantations.

For soybean cultivation, simulation results showed few changes between the reference- and low-carbon scenarios. The geographic distribution pattern remained the same (i.e., states in the South, Center-West, Minas Triangle and Western Minas, Western Bahia, Piaui, and Maranhão regions).

The dynamic of pasture areas in the low-carbon scenario, owing to its new assumptions, revealed major changes compared to the reference scenario. Since a considerable decrease in demand for pasture land is anticipated for the low-carbon scenario, lands already allocated to this use in 2007 intensified their role as a "land donor" for other crops, especially

in the Central-South and Northeastern regions. With the exception of a few scattered areas of expansion in northeastern Minas Gerais, Rio Grande do Sul, Paraná, and Santa Catarina, the contraction of pasture areas predominates in this vast part of the country. Moreover, in micro-regions where there is both demand for land and environmental liability (i.e., deforestation above the lawful limit), the low-carbon scenario indicates a turn-around in the rate of deforestation due to implementation of the environmental recovery process. However, areas of expanded pasture land can still be observed as a result of deforestation in the Amazon, given the coincidence between demand for more land for this use and the absence of environmental liabilities on developed lands (figure 3.10).

Figure 3.9: Comparison of Land-use Dynamic for Sugar-cane Cultivation, 2007–30

Low-carbon Scenario

Source: UFMG (2009).

Reference Scenario
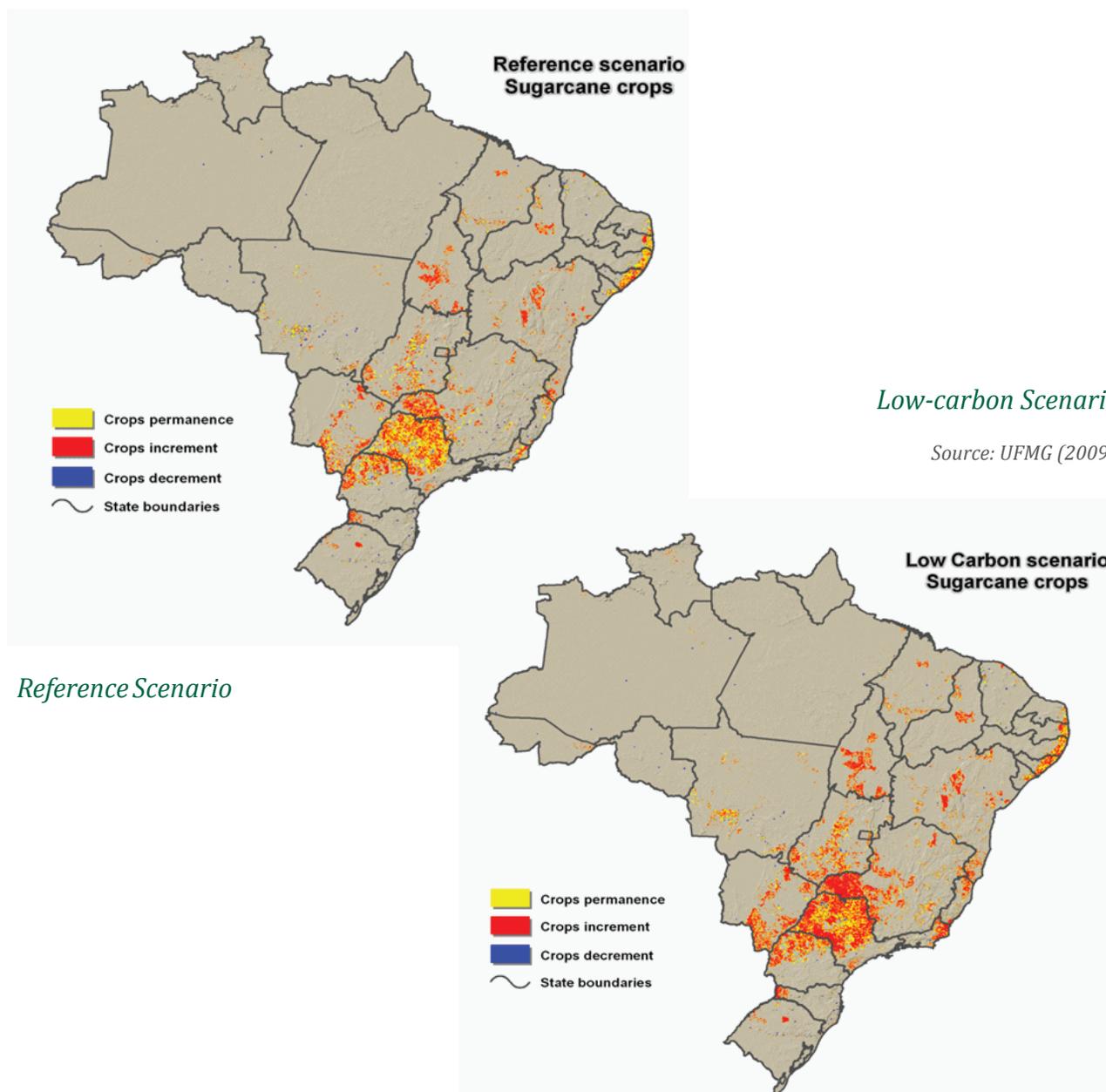
Figure 3.10: Comparison of Land-use Dynamic for Pasture Areas, 2007–30

Reference scenario
Pasture

Pasture permanence
Pasture increment
Pasture decrement
State boundaries

Reference Scenario

Low Carbon scenario
Pasture

Pasture permanence
Pasture increment
Pasture decrement
State boundaries

Low-carbon Scenario
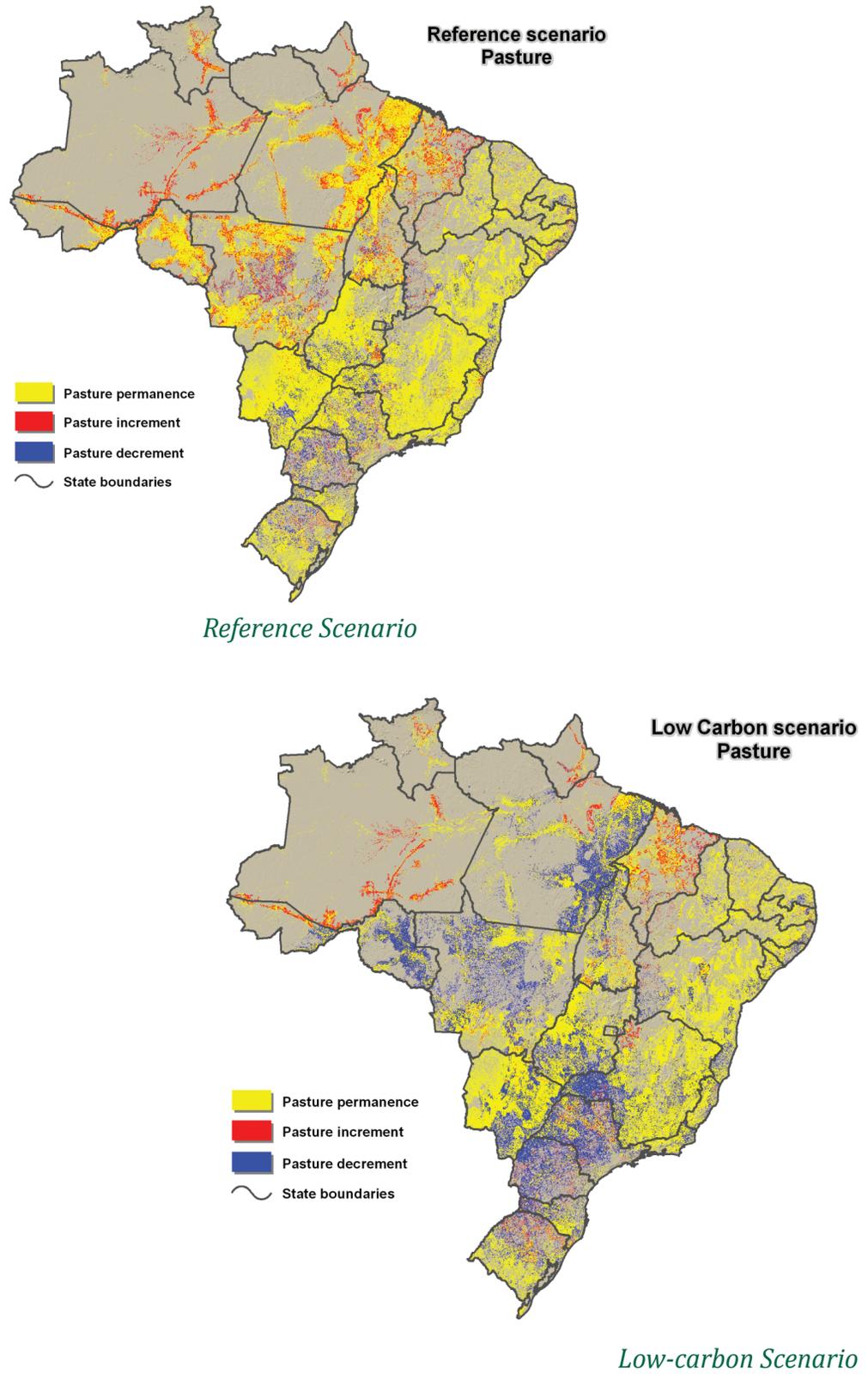
Source: UFMG (2009).

Decreased demand for land, which was calculated based on assumptions made for the low-carbon scenario, will lead to a reduction in deforestation rates compared to the reference scenario. New soils-use and deforestation maps were produced with the same spatial emissions model for land use developed with the EGO Dynamic platform (figure 3.11). The model for the low-carbon scenario works like a legal scenario; that is, when there is environmental liability, deforestation rates are set to zero and a simulation of a regeneration process for the micro-region in question is started.

Figure 3.11: Comparison of Cumulative Deforestation, 2007–30
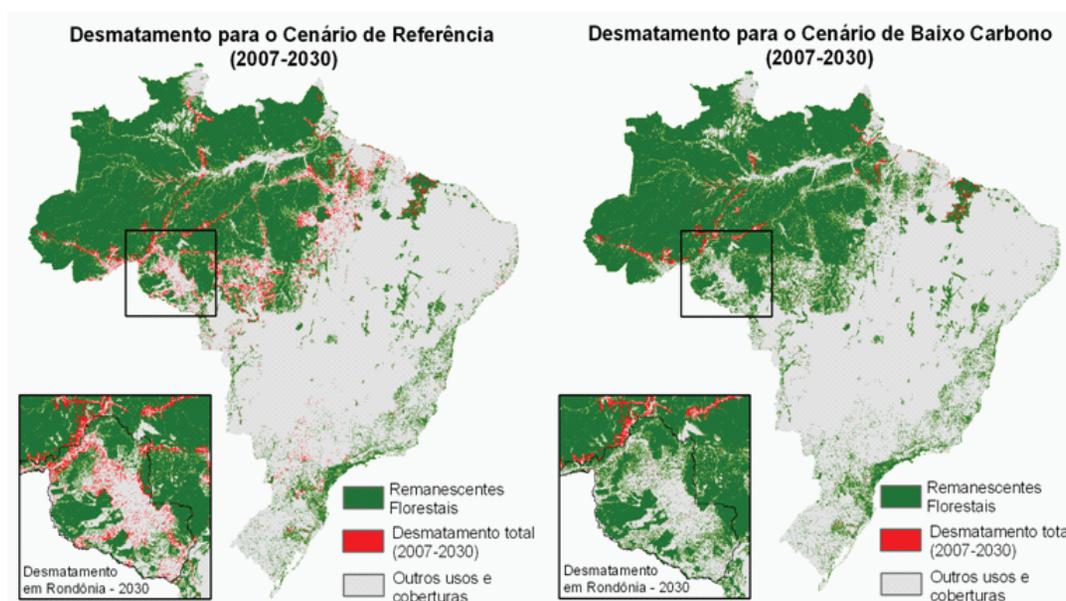
Reference Scenario   Low-carbon Scenario

Model-based projections indicate that, under the new land-use dynamic, deforestation would be reduced by more than two-thirds (68 percent) compared to the reference scenario; in the Atlantic Forest, deforestation would be reduced about 90 percent, while the Amazon region and Cerrado would see reductions of 70 percent and 65 percent, respectively. In the Amazon region, the level of deforestation would fall quickly to about 17 percent of the historic annual average of 19,500 km^2.[58]

It was expected that, with demand for pasture land reduced to zero as projected by the ICONE module, deforestation rates would also be reduced to zero; however, that was not the case. Deforestation still continues in certain parts of the Amazon states of Acre and Pará due to the model's incorporation of indirect causes, through spatial lag regression (as in the reference scenario). Thus, in micro-regions where the legal limit for deforestation was not reached in 2009—where there is still room for legal deforestation and where the indirect dynamics modeled are the determining factors—deforestation will continue to occur.

Moreover, although the residual deforestation is not quite zero, its remaining amount is compatible with the 70-percent Amazon deforestation-reduction target the PNMC set for 2017, having as its baseline the historic average of 19,500 km^2 per year. Therefore, average annual amounts of 4,000 km^2 produced by the model are below the 5,000 km^2 per-year threshold established as a final target for Brazil (figure 3.12).

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58   Over the 1996–2005 period, the historical rate of deforestation in the Amazon region was 1.95 million ha per year, according to the PNMC.

Figure 3.12: Evolution of Deforestation in the Low-carbon Scenario (curve) (km² per year)
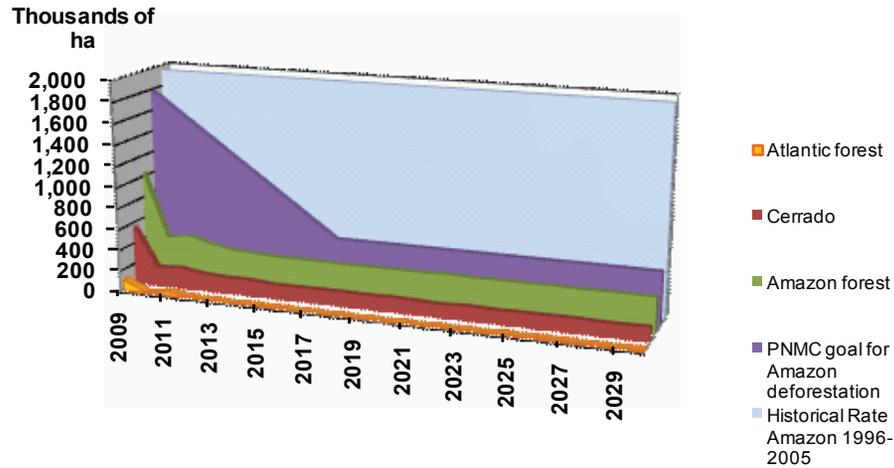
Source: UFMG (2009).

3.5.2 A New Carbon Balance Close to Equilibrium

The interaction between these new inputs in the model register the annual emissions for 2007–30 resulting from uptake, land use, and land-use change for each micro-region. Compared to projections in the reference scenario (figure 3.13), emissions from deforestation are considerably lower under the new land-use dynamic considered in the low-carbon scenario (figure 3.14), at about 170-190 Mt CO_2e per year over much of the period. This decrease is due to less demand for pasture area and the subsequent drop in the need to convert land via deforestation, as explained earlier. Annual land-use emissions (i.e., agriculture and livestock) rise 310–340 Mt CO_2e over the period, with agricultural emissions accounting for most of this increase. Still there is a 6-percent overall reduction in emissions compared to the reference scenario. CH_4 emissions from beef cattle remain relatively stable, at 236–249 Mt CO_2e per year, since the gains from reduced CH_4 production per unit of meat are offset by increased production.

*Figure 3.13: Emissions from Land use and Land-use Change
under the New Land-use Dynamic in the Low-carbon Scenario*

Brazil Low-carbon Country Case Study
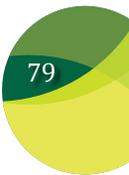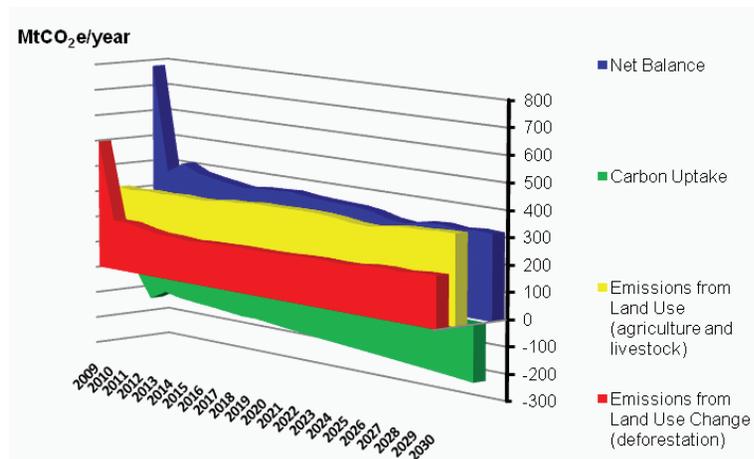
Finally, carbon uptake shows a growing trajectory, presenting an initial rate of approximately 133 Mt CO_2 per year for 2010 and a final rate of 213 Mt CO_2 per year for 2030, as a function of the growth in forest plantation cover and recovery of environmental liabilities of legal reserves and PPAs. The resulting balance between use, change, and uptake shows a decrease in the amount of net emissions between 2007 and 2030, reaching a rate of approximately 321 Mt CO_2e per year in 2030, a reduction of nearly 65 percent compared to the reference scenario[59].

3.6 Additional Forest Protection Measures

According to the assumptions adopted in the model, the reduction in demand for pasture land is not enough to reduce deforestation rates to zero in the low-carbon scenario since indirect factors also cause deforestation. The model includes indirect causes that also contribute to deforestation and have not been captured by land-availability variables. These results reflect the need for additional measures to contain the process, although many of them have already been put into practice through the implementation of the Plan of Action for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM), which increases the capacity for enforcement and consolidation of conservation policies for the Amazon rainforest.

Among the measures in force and further proposals, key programs in five major areas are highlighted below.

Protected Areas Expansion and Consolidation. Under the Amazon Region Protected Areas Program (ARPA), initiated by the Brazilian government in 2003, more than 30 million ha of conservation units (CUs) have been created as Integral Protected Areas and Sustainable Use Protected Areas via an initiative supported by national (MMA and ICMBio) and international (World Wildlife Fund, World Bank, and KfW) partners, who have committed to investing R$400,000 in the Protected Areas Fund. The ARPA is being implemented in three stages and will create about 50,000 ha of protected areas (table 3.6).[60]

Table 3.6: Snapshot of Protected Areas in the Amazon Biome and ARPA Participation

Protected or military area		No.	Area (km²)	Portion of biome (%)	Protected area supported by ARPA (%)
Military area		6	26,235	0.6	-
Indigenous land		282	987,219	23.4	-
Total protection	State	44	137,385	3.3	22.5
	Federal	37	231,072	5.5	80.6
Sustainable use	State	72	201,918	4.8	13.2
	Federal	80	233,523	5.5	26.2
Total		**521**	**1,817,355**	**43.0**	**16.8**

Source: Soares-Filho et al. (2008).

Various studies have confirmed the importance of protected areas and of ARPA, in particular, in helping to avoid deforestation. A decrease in the historic rates of deforestation per region as of 2004–05 can be attributed, in part, to a series of measures that are part of the PPCDAM, including the creation and consolidation of CUs. According to Soares-Filho et al. (2009), the probability that

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59   If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 112MtCO2 per year on average, thus reducing net emissions.
60   Details are available at www.mma.gov.br/sitio/index.php?ido=conteudo.monta&idEstrutura=154.

deforestation will occur around protected areas is 10 times greater than in the interior. Based on the analysis of historic rates of deforestation around protected areas, this study demonstrated that there is no significant redistribution of deforestation in other areas due to the creation of protected areas. Nevertheless, the consolidation of protected areas is a strong mitigation measure against the deforestation process observed in the Amazon at a relatively low cost. These authors estimate that 10.5 billion dollars (NPV) will be required to consolidate and manage the network of protected areas in the Amazon over a 30-year period. Amend et al. (2008) estimate the cost of maintaining these areas at US$3.72 per ha.[61]

Deforestation and Forest-degradation Monitoring. The National Institute for Space Research (INPE) has developed several major forest monitoring programs. PRODES, financed by the MCT, in collaboration with IBAMA and MMA, has been implemented by the INPE since 1988. PRODES carries out analyses based mainly on the use of images from the TM sensor onboard the North American satellite Landsat and provides annual rates of gross deforestation in the Legal Amazonia, increments of deforested areas, and specialized data in vector and raster formats. The Detection System for Deforestation in Real Time (DETER), another program developed by INPE, is based on data from the MODIS sensor from the Land/Water satellite and WFI sensor from the CBERS satellite (the data is less refined than PRODES data). The DETER system provides close to real time information on changes in forest cover to support enforcement activities by IBAMA. A third program, Mapping of Forest Degradation in the Brazilian Amazon (DEGRAD), maps degraded (i.e., partially deforested) forest areas in the Amazon using CBERS and Landsat satellites imaging.

According to a recent management report of the INPE, available resources for satellite monitoring of the Amazon (including the aforementioned programs), totaled more than R$7 million over a three-year period (table 3.7).[62]

Table 3.7: INPE Resources for Amazon Monitoring via Satellite, 2006–08

Year	Estimate (R$ million)	Total liquidated (R$ million)
2006	1.42	0.46
2007	2.75	2.07
2008	2.85	2.08

Source: INPE (2009).

Integrated Projects Development. The PPCDAM, coordinated by the President's Office, is implemented through the coordinated action of 13 ministries. The general aim of PPCDAM is to reduce deforestation rates in the Brazilian Amazon through a set of integrated actions involving territorial and land ordinances and monitoring and evaluation to foster sustainable production activities involving partnerships between federal agencies, state governments, mayoral offices, civil society, and the private sector. PPCDAM has three main axes around which activities are conducted: (i) land and territorial ordinances, (ii) environmental monitoring and evaluation, and (iii) productive and sustainable activities. During 2008–10, the government plans to invest approximately US$500 million in PPCDAM-related initiatives.

The Sustainable Amazon Program (PAS) strives for a new development landscape by

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61   The authors arrived at this estimate based on the annual costs presented for the maintenance of 10 protected areas in the Amazon, with a total cost of US$1.76 million per year; details are available at http://conservation-strategy.org/en/reports/reports.

62   Details are available at www.inpe.br/dspace/bitstream/123456789/896/11/RG2008.pdf.

focusing on environmentally sustainable, economic solutions. Its targets and directives are based on a current diagnosis of the Amazon. The program is implemented according to an agreement between federal and state governments. It promotes the integration of protection and production. It calls for greater participation of local-level governments in developing actions and strategies, improving and regulating the dynamic of space allocation, providing conditions for implementing such projects through the guarantee of social rights for populations and communities, and inclusion of private-sector capital.

Sustainable Use of Forest Resources and Payment for Environmental Services and Products. To promote forest conservation, the concession for the sustainable use of public forests aims to increase forest appreciation. In support of this goal, Law 11.284 was created in 2006 to regulate forest management in public areas; the law also established the Brazilian Forest Service and National Fund for Forest Development. To maximize socioeconomic benefits, the concessions granted cannot are restricted to national companies, and follow such criteria as better price, less environmental impact, improved efficiency, and enhanced accumulation of local value. In addition, the Forest Grant Plan annually identifies public forests in the national registry eligible for conversion, as well as needed monitoring and other management resources (table 3.8).[63]

Table 3.8: Projected Costs for Public Forest Management, 2009

Anticipated activity (summary)	Resource (R$ million)
National register of public forests	8.0
Support activities for forest management	7.8
Forest concessions	10.0
Monitoring of public forests	15.0
Creation of national forest information system	5.4
National Forest Development Fund	2.5
Implementation of the SFB administrative structure	8.0
Total	**56.7**

Source: National Forest Grant Plan (2009).

The Bolsa Floresta (Forest Allowance) program, one of Brazil's first applications of the concept of paying for environmental services, is being implemented by the Amazonas state government. Already in the implementation phase, Bolsa Floresta plans monthly payments of R$50 to families registered with the project and residents of state CUs. The families' permanence in the program is linked to the development of sustainable activities in these areas, which principally revolve around the production of products and services that contribute to environmental protection, including the reduction of deforestation practices. The state target covers about 60,000 families and extends access to indigenous communities. Program resources come from the State Fund for Climate Change, Environmental Conservation, and Sustainable Development, which was created by the State Law for Climate Change.[64]

Socio-environmental Register. The Socio-environmental Commitment Register (CCS) is a voluntary register of properties whose owners are committed to improving the socio-environmental performance of their properties. The CCS already has more than 1.5 million

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63   Details are available at www.mma.gov.br/estruturas/sfb/_arquivos/paof_2009_vf_95.pdf.
64   Details are available at www.florestavivaamazonas.org.br/download/Lei_est_n_3135_de_050607.pdf.

ha of property, a large part of which is located at the headwaters of the Xingu River. Registered properties receive preferential treatment by meat-processing plants in the region (e.g., the Independência and Bertim meat-processing plants already pay a better price for cattle from properties listed in the CCS).

3.7 Integrated Strategy for a Low-carbon Scenario

In summary, the study proposes a comprehensive strategy to avoid future emissions from deforestation, complemented by measures to mitigate emissions from agriculture and livestock and increase forestry-related carbon uptake. The strategy to avoid emissions from deforestation works on two complementary fronts: (i) eliminating the structural causes of deforestation and (ii) protecting the forest from remaining attempts to cut. The first part would work with stakeholders on already deforested land, while the second presupposes working with those with vested interest in cutting the forest.

Eliminating the structural causes of deforestation would mean reducing virtually to zero the need for additional land for expanded agriculture and livestock activities. This would be achieved by improving livestock productivity to release pasture, particularly degraded pasture, to accommodate crop expansion on already deforested land. However, the model results show that the drying up of additional demand for crops and livestock may not be enough to eliminate the complex dynamics that currently lead to forest clearing, either in protected forested areas or in areas where deforestation is still legally possible. Thus, complementary forest protection measures are required, at least in areas where deforestation is illegal, to thus achieve the goal set by the PNMC to reach zero illegal deforestation.

To protect the forest from further attempts to cut, the study proposes that protection measures be taken in forested areas where deforestation is illegal; this could be done in various ways, ranging from repressive police action to projects that promote sustainable use of forest resources.

Reducing pasture area and protecting forests can together lead to a sharp decline in deforestation emissions. This was demonstrated in 2004–07, when new forest-protection efforts, combined with a slight contraction in the livestock sector and resultant pasture area,[65] led to a 60-percent reduction in deforestation (from 27,000 km^2 to 11,200 km^2). Such a rapid decline resulted from deforestation and its associated emissions being related to the *marginal expansion* of agriculture and livestock activities. Unlike other sectors, whose energy-based emissions are usually proportional to the *full size* of the sector activity, emissions from deforestation are related only to the *marginal expansion* of agriculture and livestock activities. Without marginal expansion of the land required for these activities, there is little or no need to convert more native vegetation into crop land or pasture. This means that emissions from deforestation can fall rapidly, as explained above. If enough pasture is released to accommodate crop-land expansion, the need to deforest can fall rapidly to very low levels.

However, to surpass the two-thirds deforestation reduction resulting from the strategy proposed in this study, additional measures that offer viable alternatives to deforestation in regions where the legal limit to deforest has not yet been reached, particularly in the Amazon region, would need to be considered. Various experiences and studies have proposed innovative ways to combine regional development and reduction of deforestation in areas where it is still

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65   The 2005–07 period witnessed the first decline in herd size (207 million to 201 million head), following a decade-long increase, together with a slight contraction in pasture area (from 210 million to 207 million ha).
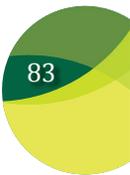
legal to deforest. These have included instruments that offer landowners incentives to forfeit their right to deforest up to the legal limit; such incentives would be calibrated so that the opportunity cost would be sufficiently compensated. Such alternatives, on which this study could not elaborate further, should be consistent with a region's socioeconomic development and thus be integrated into a broader development perspective that not only considers compensation for eliminating economic opportunities but also proposes new opportunities consistent with maintenance of the forest.

Beyond proposing ways to avoid deforestation, the study proposes activities to remove atmospheric CO_2 via carbon uptake activities (i.e., forest plantations and native forest recovery). The target considered here is compliance with the Forest Reserve Law. It also proposes mitigation options, including scaled-up zero-tillage cultivation and development of new low-emissions forage and genetically improved bulls to reduce direct emissions from agriculture and livestock.

In these ways, the result would be a net emission of GHGs of 331 Mt CO_2 per year from LULUCF in 2030, instead of the net of 816 Mt CO_2e per year, which was observed in 2008 and is expected to continue under the reference scenario.
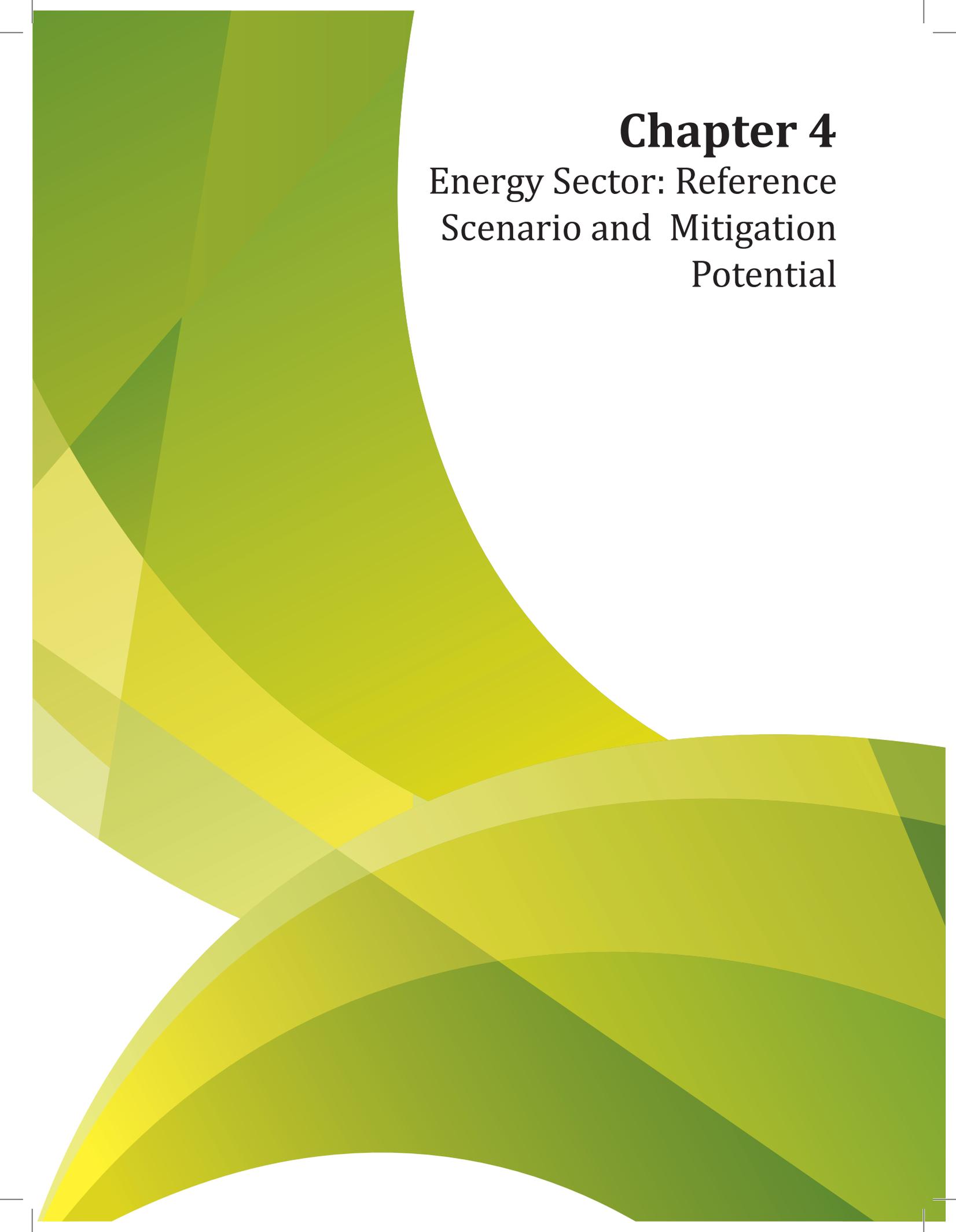
Chapter 4
Energy Sector: Reference Scenario and Mitigation Potential

In Brazil's energy sector, the intensity of greenhouse gas (GHG) emissions is comparatively low by international standards, owing to the significant role of renewable energy—particularly hydroelectricity and biomass (alcohol, sugar-cane bagasse, and plant charcoal)—in the national energy matrix.[66] In 2006, renewable energy accounted for 45.1 percent of Brazil's domestic energy supply, compared to 2004 global and OECD-country averages of 13.2 and 6.1 percent, respectively (MME 2007) (figure 4.1).

Figure 4.1: Internal Supply Structure for Primary Energy, by Source (2006)

Biomass
30.23%

Petroleum and Derivatives
37.72%

Hydraulics and
Electricity 14.83%

Derivatives
1.62%

Mineral Charcoal
and Derivatives
5.99%

Natural Gas
9.61%
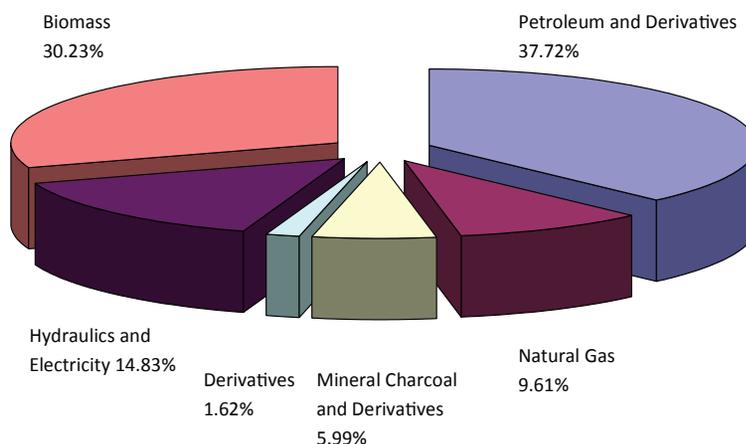
In 2005, Brazil's energy sector accounted for 329 Mt CO_2, compared to 27 Gt worldwide, corresponding to an annual average of 1.77 tCO_2 per capita, significantly less than the global (4.22 tCO_2) and OECD-country (11.02 tCO_2) annual per-capita averages (IEA 2007). Even so, increased electricity supply from renewable-energy sources, particularly from large hydroelectric plants, faces various problems, and, as a result, it is expected that more carbon-emitting sources (e.g., thermoelectric charcoal, fuel oil, and natural gas) will account for major supply increases. In addition, growth in the agro-industrial and cargo transport sectors suggests greater use of petroleum derivatives, particularly diesel fuel; moreover, growth in the iron and steel industry may signal increased consumption of mining coal.

Given these unique features, any reasonable attempt to identify the potential for emissions reduction and the associated abatement costs must rely on serious sectoral production and consumption planning exercises that factor in such announced shifts from past tendencies. To this end, section 4.1 describes the methodology used, while section 4.2 presents the energy-sector reference scenario for projected emissions over the 2010–30 period. Demand- and supply-side mitigation options considered to reduce Brazil's energy-sector emissions are presented in section 4.3, while section 4.4 presents additional opportunities to reduce emissions in other countries through ethanol exports and hydro-complementarity with Venezuela. Finally, section 4.5 aggregates the total GHG emissions reduction that could be achieved under a low-carbon scenario for Brazil's energy sector.

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66   Hydroelectricity accounts for 75.9 percent of domestic electricity supply.

4.1 Methodology Overview

This study aimed to estimate the GHG emissions derived from energy generation and use that could be avoided via a low-carbon scenario over the next two decades. This first required estimating the emissions that the energy sector would otherwise generate over the same period, thus establishing a reference scenario. Such a reference scenario was based on the National Energy Plan (PNE 2030), the Brazilian government's most recent major effort to monitor the evolution of the country's overall energy system, taking into account long term policies already defined by the government by the date of the publication of the PNE 2030.[67] Second, the low-carbon emissions scenario was developed; this was based on an analysis of mitigation options along the energy chain for both the power and oil-and-gas subsectors.

This study also considered mitigation options that, despite the cost incurred in Brazil, seek to prevent or reduce GHG emissions in other countries, particularly ethanol exports to substitute for gasoline and the interconnection with Venezuela to optimize the use of hydroelectricity (section 4.4).

The PNE 2030 is an optimized reference scenario established using state-of-the-art modeling planning tools (section 4.2). Since the PNE2030 already takes into account some new policies, such as the development of nuclear energy, more energy conservation and the exploration of new renewable energy potential like large hydroelectriciy generation opportunities in the northern part of the country and the development of biodiesel, it already projects lower emissions than those projected in the baseline scenario established by the government for the energy sector. The study's low-carbon scenario is a variation on the reference scenario, whereby certain technologies are substituted by less carbon-intensive ones that meet the same demand. Although the low-carbon scenario may not be the most cost-effective, the study is technically consistent between all subsectors and mitigation options, thereby avoiding double counting and inconsistencies. Emissions associated with the use of fuels for vehicles were counted as transport sector–related emissions (chapter 5), whereas emissions associated with the corresponding refining activity were counted as energy-sector emissions.

4.2 Reference Scenario

The reference scenario for developing Brazil's energy sector reflects recent sector policies and basic market tendencies and features, including the dynamic of incorporating technology and the evolution of energy supply and demand. As mentioned above, the PNE 2030, developed by the EPE and published by the MME, was used as this study's reference scenario. By documenting analyses and research, the PNE 2030 provides information with which to formulate a strategy for increasing energy supply and manage development of demand, with a long-range policy view toward integrated and sustainable use of available resources[68]. The study team frequently consulted the EPE with regard to the PNE 2030 principles and hypotheses, thereby ensuring

[67]   Developed by the Energy Planning Company (EPE) in 2007, the PNE 2030 did not anticipate the macroeconomic planning effects of the recent global economic crisis. Also, it expected increased use of the country's remaining hydraulic potential, which is has been delayed due to legal constraints (the last energy auctions indicated conjunctural increased use of thermoelectric power). Despite these limitations, the PNE 2030's view toward long-term technical and economic consistency renders it an important tool for creating a reference scenario for the country's energy sector.

[68]   As a result, this reference scenario differs from the projections of national and sectoral emissions officially announced by the Brazilian Government in 2009 along with the voluntary commitment to reduce emissions, which are reflected in law Law 12.187. The difference between the reference scenario defined in this study and the one established by the Brazilian government on the basis of past trends reflects the positive impact on emission reductions of the policies already adopted in the PNE2030.

coherence between that work and the current study, particularly with related to interfaces with other sectors (e.g., transport and agriculture) included in the study.

The PNE 2030's main simulation tool for final energy consumption was a parametric technical-economic model, called the Integrated Energy Planning Model (MIPE), developed by the Office of Post-Graduate Engineering Programs Coordination (COPPE) at the Federal University of Rio de Janeiro (UFRJ). The Residential Energy Demand Projection Model (MSR), developed by the EPE, was applied specifically to electricity consumption in the residential sector. In this bottom-up model,[69] residential consumer demand is obtained from data on household ownership and use of appliances. Calibration of the model was thus based on research conducted in this area, made available by the National Electrical Energy Conservation Program (PROCEL) coordinated by Eletrobrás. Application of the model enabled the incorporation of energy-efficiency principles into this segment of consumption.

On the supply side, two models were applied to evaluate the processing of primary energy. The Refining Study Model (M-Ref), developed by COPPE's Energy Planning Program, was used to measure expansion of the oil refinery complex in order to adequately meet projected demand for derivatives. The Long-Term Expansion Model (MELP), an optimization model developed by the Research Center for Electrical Energy (CEPEL),[70] enabled finding solutions to increase electrical energy supply while minimizing the cost of expansion and operation, taking into account the investment costs for expanding interlinkages between subsystems.

All of the results obtained from the PNE 2030's supply and demand studies were integrated via application of the so-called MESSAGE model developed by the International Atomic Energy Agency (IAEA). This model was used to select the means of energy production to meet useful energy demand in a way that minimized operation and maintenance costs for the entire energy system during the period observed; at the same time, a linear programming model was used to cover the overall energy system. The MESSAGE model analyzed possible substitutions between energy sources in the various processing centers through final consumption level and restrictions on available potential (e.g., reserves and capacity for electricity generation and transmission) and environmental impact levels (e.g., maximum patterns of atmospheric emissions). In short, by making it possible to visualize Brazil's evolving composition of domestic energy, the PNE 2030 allowed for formulating formal hypotheses and energy matrixes based on 25-year projections (figure 4.2).

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69 Design of this more disaggregated model is based on the relation of demand to supply.
70 Two versions of the MELP optimization model were developed: one that uses linear programming and another that uses mixed programming.

Figure 4.2: PNE 2030 Calculation Models
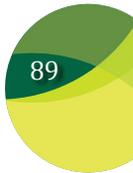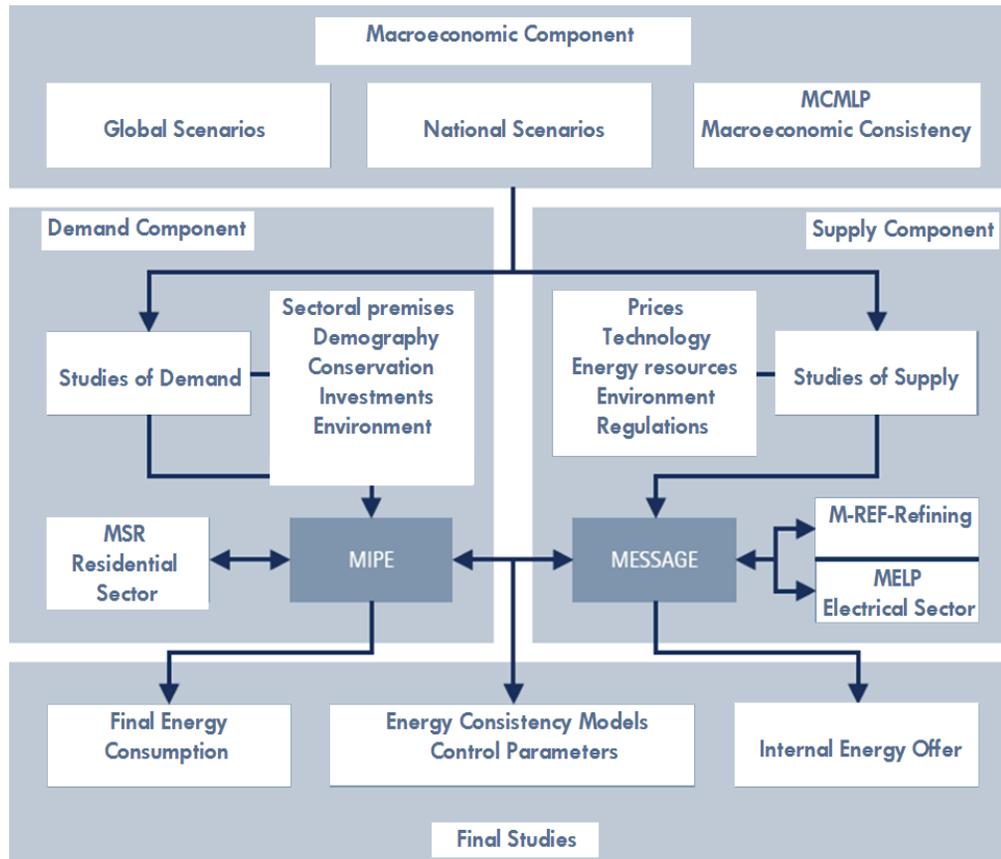
Although the Brazilian government has published other official studies since the PNE 2030, none have matched its scope in terms of consistent simulation of the country's energy chains.[71] This study's analysis used a PNE 2030 projection (scenario B1) as an intermediate scenario showing the country's average economic growth (table 4.1).

Table 4.1: Macroeconomic Growth Parameters of the PNE 2030

Parameter	2010	2020	2030
Population (millions of people)	198.04	220.09	238.56
Gross national product (trillions of US$)	0.96	1.38	2.13

Expected growth in gross national product (GNP) is an average of 4.1 percent annually, with service and agriculture sectors growing 4.2 percent and the industrial sector 3.7 percent per year.

In accordance with the EPE (2007), over the next 20 years, the average emissions factor for the Brazilian grid should move from 0.094 tCO_2e per megawatt hour (MWh) in 2010 to 0.069 in 2020 to 0.079 in 2030 (table 4.2). This study interpolated the average grid emissions factor for periods between 2010, 2020, and 2030.

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71   The PNE 2030 analysis incorporates a range of sectoral studies, including electricity, oil and gas, and ethanol.

Table 4.2: Energy Parameters of the PNE 2030

Parameter	2010	2020	2030
Petroleum (WTI) (US$/bbl)	40	45	45
Electricity emissions factor (tCO$_2$e/MWh)	0.094	0.069	0.079
Average expansion cost (US$/MWh)	56.9	56.4	55.9

While renewable energy is expected to continue to account for a large share of Brazil's future energy matrix, the PNE 2030 anticipates a higher emissions level over time; the projected figure for 2030 is just over 970 million tCO$_2$ (figure 4.3).

Figure 4.3: Evolution of Brazil's Energy Emissions (Mt CO$_2$) by Sector, 2005–30
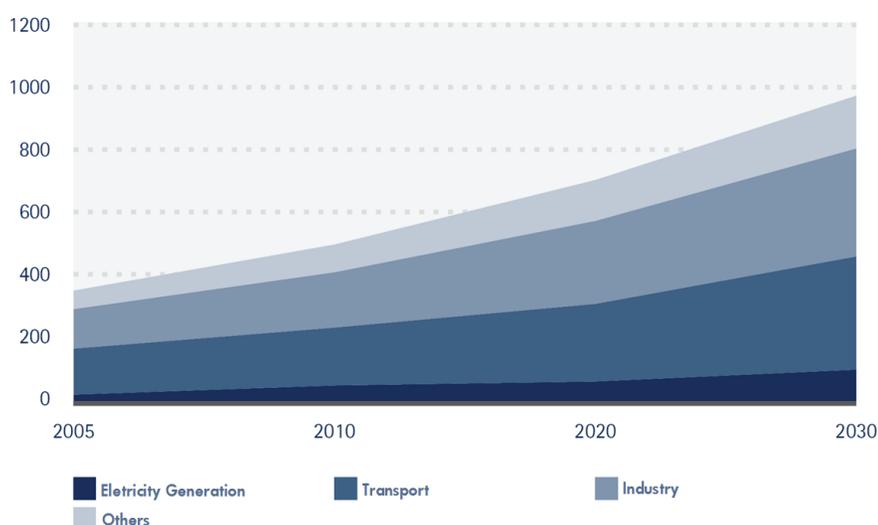
Source: PNE 2030

As figure 4.3 shows, the transport and industry sectors are expected to contribute the most to long-term emissions growth. But, for the 25-year period in question (2005–30), electricity generation presents the greatest rate of emissions growth—nearly 7 percent per year—meaning that this segment's emissions contribution will increase by about two-thirds (from 6 to more than 10 percent) over the 25-year period. However, for circumstantial reasons, (i.e. adverse hydrological conditions), Brazil's higher use of more thermoelectric power in recent years was anticipated by the PNE 2030.

Based on the most recent developments regarding power generation, this emissions estimate can be considered conservative for the first years of the period. Indeed, as a result of circumstantial reasons (i.e. adverse hydrological conditions), more thermal energy had to be used. Additionally, some delays in inventory and feasibility studies and some difficulties observed in the environmental licensing processes restrained the participation of hydropowerplants in recent auctions. As a result of this situation, the new generation capacity being built in the beginning of the period is more heavily thermoelectric power than anticipated in the PNE 2030. If this tendency were to continue over a longer term, the Brazilian grid's average emissions factor would be greater than that projected by the MME in 2007, incurring higher emissions over the period considered.

4.3 Mitigation Options

The study investigated a series of emission mitigation options on both the demand and supply sides for electricity and oil and gas. The categories of mitigation measures for which emission reductions were estimated are: (i) demand side: energy efficiency, fuel switch to low-carbon content and/or renewable-energy consumption and recycling and (ii) supply side: renewable energy for power generation (wind farm and biomass cogeneration) and optimized refinery schemes and gas-to-liquid (GTL).

Not all forms of energy were analyzed because certain mitigation options promoted by government policies already play a large role in the reference scenario, making it difficult for this study to identify more opportunities to achieve additional emissions reductions through these options. This is especially so for large hydroelectricity and nuclear energy. Indeed, the level of use projected for hydroelectricity in the PNE 2030 would correspond to virtually full exploration of Brazil's remaining large hydro potential; thus, the study considered that there would not be any other major opportunity to further reduce emissions through expansion of hydroelectricity under a low-carbon scenario. Regarding nuclear energy, the PNE 2030-based reference scenario considers the construction of 4–6 nuclear plants by 2030. The low-carbon scenario does not consider the construction of additional nuclear plants other than what is envisioned in the reference scenario. This seems reasonable since it isunlikely that more than 6 nuclear plants would be built in Brazil over the next 20 years, given the extensive prior planning that would be required, including choice of ideal sites for new plants, planning for their related nuclear-waste disposal, lengthy licensing process, acquisition of specific equipment with limited foreign only manufacturing with backlogs of possibly several years, as well as a long construction period (5–8 years).

For each category of the mitigation measures examined, the study evaluated technical options for avoiding GHG emissions during energy consumption and production within the framework of the reference scenario. Subsections 4.3.1 and 4.3.2 below highlight the mitigation options considered on the demand and supply sides, respectively.

4.3.1 Demand-side Mitigation Options

4.3.1.a Energy Consumption: More Efficient Electricity Use

Because of the grid's low emissions factor, which results from the high share of renewable energy already considered in the reference scenario, the emissions reduction potential that can be achieved through the adoption of more efficient electrical devices is not expected to be large, and certainly not the largest in the energy sector. However, Brazil is experienced in demand-side management, as demonstrated by the successful implementation of energy conservation during the energy crisis of 2001, which prevented energy shortages. Therefore, as further examined in the economic analysis presented in chapter 7, Brazil has "low-hanging fruits" in this area.

With regard to efficiency in electricity consumption, three subsectors were examined: (i) residential, (ii) industrial, and (iii) commercial. In the residential subsector, the five mitigation options evaluated fell under four key uses:

- **Lighting**: Switch from incandescent light bulbs to energy-saving, compact fluorescent lamps (CFLs) beginning in 2010.

- **Food refrigerators**: Adopt stricter mandatory efficiency standards starting in
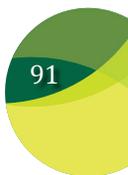
2015. Initiate a substitution program for obsolete refrigerators in low-income communities.

- ***Air conditioning units***: Adopt stricter mandatory standards (U.S. standards) for units starting in 2015.

- ***Water heaters for bathrooms***: Substitute 75 percent of electric water heating with solar energy, adding 1 percent of all homes in South, Southeast, and Center-West Brazil each year, with a goal of 22-percent coverage by 2030.

In the industrial subsector, two mitigation options were considered, each of which related to a key use:

- ***Electric motors***: Increase market participation of high-performance electric motors as of 2015.

- ***Lighting***: Increase installation of more efficient lighting systems in industrial parks starting in 2015.

- Regarding the commercial subsector, one mitigation option related to final energy use was evaluated:

- ***Lighting****:* Increase market participation in installing more efficient lighting systems as of 2015.

As expected, the volume of GHG emissions that could be avoided by efficient electrical devices is limited: only 22 Mt CO_2e over the 2010–30 period, representing only 0.3 percent of energy-sector emissions.[72] However, as shown in chapter 7, most of these emissions reductions are economically attractive. On top of that, Brazil has already established a legal framework appropriate for harvesting these low-hanging fruits, particularly an energy efficiency law and several mechanisms promoting energy efficiency (e.g., PROCEL, CTEnerg, and PROESCO). Problems that persist include an overemphasis on procedures, discontinuity in program funding, and lack of criteria to monitor and maximize results. Other barriers to be addressed are: (i) price distortions that introduce disincentives for energy conservation and (ii) separation of the energy-efficiency efforts of power and oil-and-gas institutions.

4.3.1.b Energy Consumption: Reduced Fossil-fuel Emissions by Industry

With regard to the industrial subsector's potential to reduce CO_2 emissions resulting from the consumption of fossil fuels, the most promising areas are: (i) energy efficiency, (ii) recycling and materials use reduction, (iii) fuel switching, (iv) renewable energy substitution, and (v) reduction or elimination of solid fuels derived from non-renewable biomass.

Energy Efficiency*.* Options for mitigating emissions through greater energy efficiency focused on (i) combustion optimization, (ii) processes heat-recovery systems, (iii) furnace waste heat recovery, (iv) steam systems optimization (v) switching to more modern and efficient processes, and (vi) operations maintenance and control. Options for optimized combustion included more expensive, higher-efficiency burners, improved furnaces and boilers operation, and enrichment of combustion air with oxygen. Options for process heat (180–450°C) recovery included process integration ("pinch technology"), which can be applied mainly in the chemical, petrochemical,

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72   Not including emissions from fuels for vehicles, which this study counted as transport sector–related emissions.

and refining industries. Furnace heat can be recovered in cement, glass, steel, and petrochemical industries for pre-heating combustion air or other process fluids. Steam systems optimization covered a series of measures, including recovery of condensate, recovery of waste gases from boilers, flash vapor recovery, pressure control, and steam traps operation improvement. New and more efficient processes considered technologies already commercially available, including Basic Oxygen Furnace and Electric Arc Furnace in the steel industry, dry processing in the cement industry, and a series of technologies likely to penetrate the market over the next two decades, particularly those in the cement, steel, paper and cellulose, chemical, textile, ceramics, and glass industries.[73] Finally, the options considered for improved operations maintenance and control centered on eliminating heat leaks, temperature control, thermal insulation of equipment and heated tubing, and valve and steam-trap maintenance.

Recycling and Materials Use Reduction. Mitigation options were also considered for materials recycling, which reduces the energy consumed in the manufacture of new products, particularly use of additives in cement production; scrap in the steel and aluminum industry; glass shards in the glass industry; waste paper in the paper industry; and reduction of losses of materials in the ceramic industry.

Fuel Switching. Regarding fuel switching, which substitutes a fossil fuel with a high-emissions factor with a fuel whose carbon-emissions factor is lower, the study considered substitution of fuel oil, petcoke, or coal by natural gas.

Renewable Energy Substitution. With regard to substituting fossil fuels with renewable energy, the study considered greater use of biomass (e.g., wood, sugar-cane bagasse, and agricultural residues for traditional burning processes in ovens and cauldrons or via gasification) and solar energy for complementary water-heating systems for use in low-temperature processes, particularly in sectors that require the cooking, washing, or drying of products.

Reduction or Elimination of Solid Fuels Derived from Non-renewable Biomass. Using biomass fuels, such as trees or plants, is carbon neutral because they emit only CO_2 that has been previously removed from the atmosphere during the growth cycle. Therefore, reforestation options were considered to reduce or eliminate the use of solid fuels derived from non-renewable biomass energy, whose CO_2 emissions are equally or even more harmful than those of fossil fuels. It was thought that increased plantings of energy forests using fast-growing trees and high biomass production per area could substitute for non-renewable energy sources in iron metallurgy and ceramics.

By implementing all of the mitigation options proposed, reductions in industrial fossil fuel–based emissions could amount to more than 1.3 Gt CO_2e over the 2010–30 period (62 Mt CO_2e per year on average), representing about 70 percent—by far the largest share—of the GHG emissions-avoidance potential in the energy sector.

The technical potential for implementing energy-efficient options generally has a short-term return period and an attractive IRR for companies. But energy-conservation options have not been prioritized, as companies prefer to invest their resources in other parts of the productive process or projects. The failure to prioritize energy-conservation investments stems mainly from the low impact on final production costs (this is not the case for energy-intensive segments). Added to this factor are a lack of information, non-existent or negligible incentives, minimal communication between agents, insufficient technical capacity, and cultural issues.

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73   More than 25 technologies were considered; a list can be found in the companion report on the energy sector, and more details are in the special report on industry prepared for this study by INT.

Simpler energy-efficiency options can be implemented at lower or no cost to the extent that they can be made viable through appropriate technical information and assistance. Other available options involve substitution of complete processes or installation of high-cost systems.

Given the nature of the barriers to implementing the options considered, a list of proposals of accompanying measures was established in the following areas:

- Energy Efficiency:

  Improve the information database on the profile of energy use in industry and the potential for energy efficiency.

  Provide incentives through exemptions (or reductions) of the industrial products tax (IPI) for high-efficiency equipment (burners, boilers, furnaces, and heat exchangers).

  Establish specific maximum energy-consumption targets by sectors or groups of similar industrial sectors, with the creation of bonuses or rewards for the best performers.

  Promote the market for ESCOs (credit lines with this objective have already been set up in BNDES [BNDES PROESCO]).

  Review ongoing governmental programs that support the promotion of energy efficiency, particularly CONPET, in order to incorporate more specific actions that target the industrial sector.

- Recycling and Materials Use Reduction:

  Support and finance used-materials recycling associations and cooperatives.

  Create or promote selective materials-collection programs (paper, glass, metals, and plastics) in medium- and large-sized towns.

  Stimulate companies that operate as bridges between the collection of scrap materials and the supply of these materials to various other companies, performing the stages of separation, classification, and cleaning.

  Create or stimulate recycling programs with greater visibility in the media, such as green certificates for recycled products.

- Natural Gas Replacement for Other Fossil Fuels:

  Speed up the construction of natural gas pipelines and distribution networks in states with high concentration of industrial clusters.

  Increase lines of finance for industry as a whole, so as to facilitate the introduction of natural gas.

  Continue and promote investments in R&D to stimulate the market for natural gas, developing new products and more efficient equipment.

  Support and finance projects on compressed natural gas (CNG) and liquefied natural gas (LNG).

- Greater Use of Renewable Energy Sources and Reduction in the Use of Non-renewable Biomass

  Finance energy forest projects for the production of firewood and charcoal for energy purposes.

  Finance, under more attractive conditions, the acquisition of industrial equipment for the use of these renewable energy sources (e.g., boilers and furnaces).

Reduce substantially the IPI for solar energy products (hot-water/hot-air solar collectors and photovoltaic solar panels).

Target specific R&D resources for the development of solar-energy fed industrial equipment (driers).

4.3.2 Supply-side Mitigation Options

4.3.2.a Energy Generation: Biomass Cogeneration

Biomass cogeneration from sugarcane bagasse can be considered carbon neutral since the CO_2 released by bagasse combustion has been previously removed from the atmosphere and captured by the sugar cane; thus, no GHG emissions should be associated with the electricity generated. Today, cogeneration from biomass totals 5 GW, of which 3.7 GW are based on sugar-cane bagasse. Other biomass (paper and cellulose and wood industries) represent less than one-third of the total (ANEEL 2008). Therefore, this study focused only on cogeneration from sugar-cane bagasse.

Estimates of cogeneration-based electricity depend on two main parameters: (i) the volume of available sugar cane, which is tied to the production of ethanol and sugar and (ii) the technology used. According to the PNE 2030, on which the reference scenario is based, sugar-cane production over the 2008–30 period is expected to grow from 560 Mt to 1,273 Mt, while ethanol production is projected to increase from 28.5 billion liters to 75.6 billion liters over the same period.[74] In 2030, 7.13 billion liters would be produced from a hydrolysis process (9.4 percent of total production). Sugar production would vary from 34.3 Mt in 2008 to 55.9 Mt in 2030.

The estimated potential for additional cogeneration was based on the additional ethanol production proposed to substitute for gasoline abroad (section 4.4) and for the domestic market under a low-carbon scenario for the transport sector (chapter 5). Under such a scenario, ethanol production would reach 147 billion liters per year in 2030 and annual sugar-cane production would climb to more than 1.7 billion tons, or 36 percent more than in the reference scenario (figure 4.4). In 2030, 12.2 percent of sugar cane would be processed through hydrolysis. Sugar production projections would remain unchanged.

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74 In 2008, 20.6 billion liters would go to the domestic market, 5.2 billion liters for exports, and 2.7 billion liters for stocks; in 2030, 59.2 billion liters would go to the domestic market, 13.1 billion liters for exports, and 3.2 billion liters for stocks.
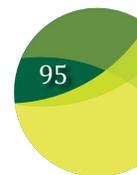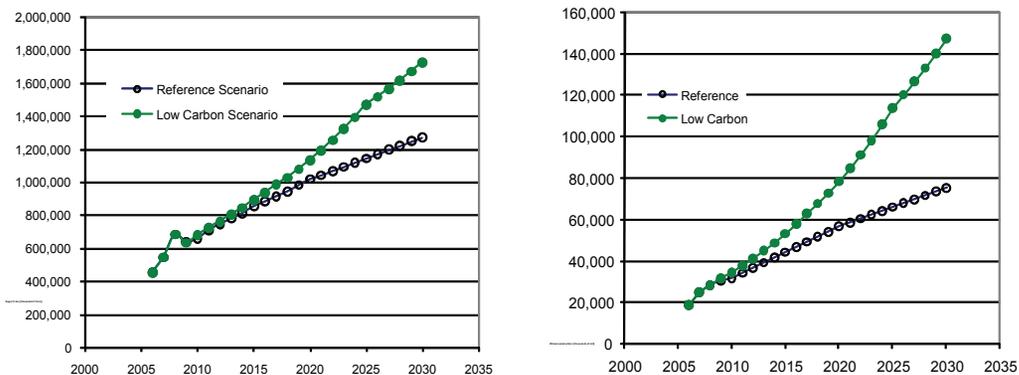
Two main technology configurations dominate: (i) modernization of existing plants, including installation of an extractor-condensing turbine, producing steam at 90 bars and 520°C, operating year-round and using up to 50 percent of available straw; (ii) new plants using mainly extractor-condensing turbines, back-pressure steam turbines for the few new plants using additional hydrolysis processes (also 90 bar, 520°C) and, for a limited number of new plants not using hydrolysis processes, Biomass Integrated Gasifier to Gas Turbines (BIG-CC systems).

Under a low-carbon scenario, installed capacity in excess of 39.5 GW, compared to 6.8 GW in the reference scenario, would be available in 2030 to export electricity to the grid;[75] 40 percent of that amount would be derived from already existing plants that would be modernized before 2015. The corresponding amount of electricity generated in 2030 would be about 200 TWh per year, compared to 44.1 TWh per year in the reference scenario. As a result, avoided GHG emissions would amount to 158 Mt CO_2 over the 2010–30 period (7.5 Mt CO_2 per year on average).

For cogeneration, the main barrier is the cost of interconnection with the sometimes distant or insufficient transmission grid, which reduces the feasibility of biomass cogeneration vis-à-vis other thermal generation alternatives for which the connection can be optimized. Owners of sugar-cane mills—the potential investors in electricity produced from sugar-cane residual biomass—have other investing priorities and opportunities, and are not always familiar with the electricity sector.

The investment environment for biomass cogeneration should be adequate over the long run, as a window of opportunity for such investments presents itself each time a new sugar mill is built or an existing one is refurbished.

Proposals to overcome barriers to biomass cogeneration include:

A strategy to expand electricity production based on biomass cogeneration with a minimum capacity that would be regularly installed (e.g., each year or every two years). Such a strategy should be based on an evaluation of the benefits of biomass cogeneration to the electricity sector (e.g., electricity generation only during the harvest period or year-round) and the location of sugar-cane mills (the grid interconnection issue should

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75   In addition to the electricity needs of the sugar and ethanol industry itself.

be properly addressed).

R&D efforts to expand biomass availability (i.e., sugar-cane residues that should be recovered in the fields and transported to the mills) and residue burned for steam generation at high pressure and temperature.

Continued financial support for such investments through programs that foster use of the most efficient technologies.

4.3.2.b Energy Generation: Wind Power

According to the Atlas of Wind Energy in Brazil (CEPEL 2001), the potential of power generation from wind is considerable (about 140 GW), which is more than the current total generation capacity installed in the country. But to date, only 33 wind farms have been built, representing a maximum capacity of 415 MW–only 0.4 percent of the national power-generation capacity.

The PNE 2030, taken as the reference scenario, plans strong growth for the wind-power sector—a tenfold increase in capacity (up to 4,682 MW) to serve 1 percent of national electricity demand by 2030. Such prospects are based on the worldwide maturation of wind energy and the relative success of pioneer programs to develop renewable energy in Brazil, namely through auctions (PROINFA program and auctions for reserve energy).

The main barriers that limit the penetration of wind energy, and which would have to be tackled to reach the target proposed by the PNE 2030 and any other ambitious low-carbon scenario are related to high generation and equipment costs, in particular investment cost, as well as regulatory and financing constraints.

The competitive frontier of wind-power production as a primary source of energy is jeopardized by the elevated cost of electricity generation compared to other conventional energy sources, even in critical hydrological conditions. The high cost of wind power generation is due to the low economy of scale and use of imported equipment.

Additional barriers include difficulty in accessing equipment. In principle, the nationalization index of 70 percent, initially imposed in the PROINFA program, was aimed at creating an incentive to develop the national industry for equipment. But the wind-power sector considered this measure a bottleneck factor because Brazil has only three turbine and components manufacturers, and most of this production is designated for export. This reality has delayed the scheduling of wind power plant projects for some time.

The 2003 electricity-sector reform created public auctions for renewable energy in order to insert small hydro, wind, and biomass energy production into the public grid. The auctions were structured so that three sources of renewable energy would compete among themselves. However, this current format of the public auctions tends to penalize the investment cost-intensive energy generation and decentralized energy sources, such as wind power, which require costly interconnection. In response, the government published a proposal in 2009 to promote auctions for wind energy only.

Proposals to overcome these barriers include the implementation of specific public auctions for wind power energy purchase (this measure has recently been adopted and the first wind
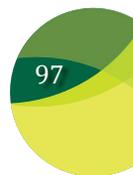
power-specifc auction was held on December 14, 2009[76]); reduction or elimination of the nationalization index from 70 percent to 50 percent (this index was simply eliminated in the December 2009 auction); reduction of customs duties to favor the import of turbine components over the import of entire turbines in order to create incentives for local manufacturing; provision of subsidies to interconnect the wind power produced with the public-power system; and provision of carbon-credit market incentives. Based on these proposals and projections made by the Brazilian Wind Energy Association, which considers it feasible to expand to 10 GW by 2020, this study considered an expansion of installed capacity to 15 GW by 2030 (figure 4.5).

Figure 4.5: Projected Installed Capacity for Wind Energy in the Reference and Low-carbon Scenarios, 2010–30

MW of installed capacity
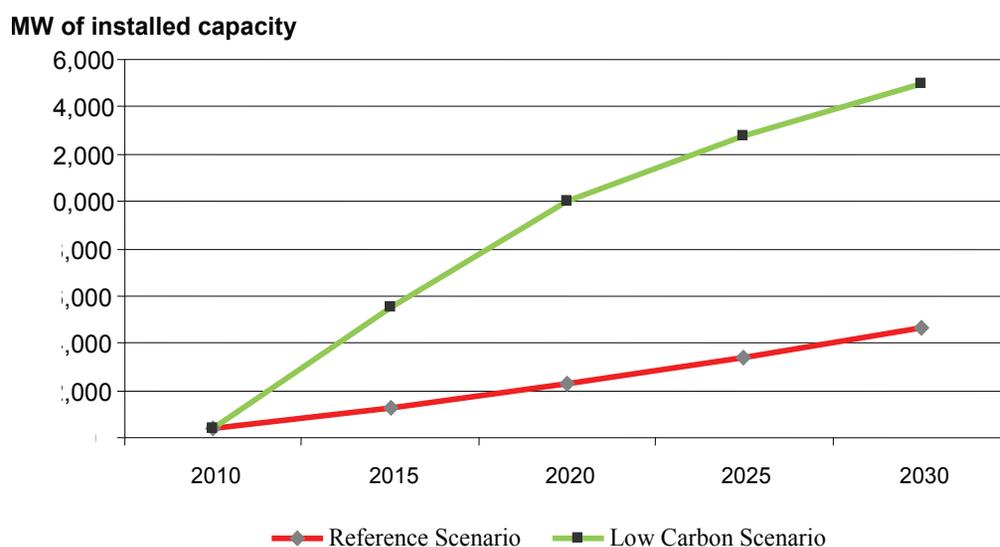
As a result, GHG emissions reductions would amount to 19.3 Mt CO_2e over the 2010–30 period, a relatively small amount that is explained by (i) the still small but quickly growing share of installed capacity that wind energy would ensure by 2030; (ii) the relatively low load factor of this type of intermittent energy source; and, above all, (iii) the low emissions factor for the grid energy in the reference scenario that it would displace.

4.3.2.c Energy Generation: Optimized Refinery Schemes and GTL

Regarding the production sector for oil, gas, and refinery products, the study examined several emissions mitigation alternatives for existing refineries, developed simulation models for new ones, and compared gas-to-liquid (GTL) costs with those used in conventional refinery processes.

The alternatives considered for existing refineries were (i) heat integration, (ii) fouling mitigation, and (iii) advanced processes control. Heat integration is the main option for reducing short-term fuel consumption in refineries. Major temperature differences between hot and cold current indicate the potential for energy integration, thus reducing the need for external hot or cold inputs. In the design of thermal transfer networks, fouling mitigation, which reduces

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76   This first wind power-specific auction was very successful, with a total installed capacity of 1,805 megawatts contracted in 753 lots) at an average price of R$ 148,39 MWh, that is 21.49% below the ceiling price stated in the tender document.
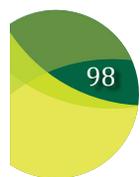
thermal efficiency and heat transfer capacity, affects the definition of approach and pinch point temperature. Advanced process control systems are based on computer models and the extensive use of sensors, which increase the reliability of production. These systems enable control of production quality, which reduces stoppage for maintenance and its cost.

With regard to the design of a new refinery focused on diesel-fuel production and integration with petrochemicals, two alternatives based on an optimization model were submitted. The simulation resulted in choosing the refinement scheme (or production routes of derivatives), whose goal was to restrict GHG emissions.

In the case of GTL—an alternative to flaring associated gas on offshore oil production sites—the added costs were calculated and compared with those of conventional processes used to make high-quality diesel marginally in Brazil; in addition, avoided emissions were calculated.

The combination of these four sets of mitigation measures would allow for avoiding about 245 Mt CO_2e compared to the reference scenario, as defined in the PNE 2030. This would represent 13 percent of the GHG emissions reduction potential proposed by this study for the energy sector.

The maturity levels of some of the technologies examined in this study may negatively affect the risk perception of private agents (Petrobras in this case), which can result in higher transaction costs. Even for the several commercial technologies analyzed (heat integration, fouling mitigation, and advanced processes control), the difference between the infrastructure-investment discount rates used by private initiatives in the oil industry and the state is considerable, underscoring the high opportunity cost for oil companies.[77]

For GTL plants, the main barriers to investing in flared-gas reduction are the technology's high cost and low maturation level. For the latter reason, private-sector agents (oil platform operators) draw high discount rates (about 25 percent per year). Offshore GTL, which is not yet a commercial technology, carries higher transaction costs and is a riskier mitigation option. While training of planners, designers, and equipment operators, mandatory standards and tax exemption can help offset the capital cost of the new technology, it is expensive; thus, R&D investment is vital (Castelo Branco et al. 2008).

Another group of mitigation alternatives analyzed for oil refining has been associated with a change in the optimum scheme for refining, subject to different carbon costs. In this situation, changes in optimal refining schemes were only observed at carbon prices of about US\$100 per tCO_2. However, there was a variation in this result when the alternative for carbon capture and storage (CCS), at a cost of US\$50 per tCO_2, was considered. This indicates that CCS could become an alternative to reduce CO_2 emissions in refineries in the future, most probably beyond the time horizon considered by this study, affecting not only specific operation units inside refineries, but also their layout. Thus, the economic viability of this alternative would depend greatly on both technological advances and cost reductions. In such cases, the CT-Petro fund could be a vital tool to help develop these alternatives.

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77   Oil companies usually inventory their carbon emissions figures and have both the technical and financial capacity to act; however, they generally prefer to invest in their main business, which centers on exploration and discovery of new reserves and oil production.

4.4 Additional Options: Ethanol Exports and Hydro-complementarity with Venezuela

In addition to the emissions mitigation options discussed above, two additional opportunities for which Brazil has accumulated considerable experience and could assist other countries to reduce their GHG emissions were considered: one involving hydro-complementarity, which aims to reduce CO_2 emissions in the energy sectors of Brazil and neighboring Venezuela,[78] and another focused on the large-scale export of ethanol, which seeks to reduce the fossil-fuel emissions of transport sectors worldwide. The total potential emissions reduction represented by these two additional options is estimated at nearly 695 Mt CO_2 (table 4.3).

Table 4.3: Potential of Additional Mitigation Options, 2010–30

Low-carbon mitigation option	Emissions reduction (Mt CO_2)
Hydro-complementarity (Brazil-Venezuela interlinkage)	28
Large-scale ethanol exports	667
Total potential	**695**

The hydro-complementarity option proposes a significant increase in hydropower production by connecting existing and planned hydropower plants located in complementary regions (in terms of seasonality of their hydrological regimes). Exchanging power between north and south would make it possible to get firm hydro energy and thus displace thermal plants used for "valley filling" and water (currently wasted), which could then generate additional power. Brazil's Tucurui hydropower plant, located in the Amazon Basin (right bank of the Amazon River), would be linked via a transmission line to Venezuela's Simon Bolivar hydropower plant, situated in the Caroni Basin (left bank of the Amazon River). Brazil's Belo Monte hydroelectric power plant, to be constructed in the Amazon Basin, would also be linked to the Simon Bolivar plant. In the future, 21,720 GWh might be available for exchange between Venezuela and Brazil. The energy gain facilitated by this hydro-complementarity option could be considered a zero GHG expansion of the system, thus avoiding about 28 Mt CO_2e over the study period. While the volume of emissions avoided may be considered limited, though achieved by a single project, it is noteworthy that this reflects the low carbon content of the reference scenario considered and the conservative calculation method, using the grid emissions factor.

Based on a detailed analysis of the worldwide growth in ethanol use, particularly mandatory standards for blending gasoline with bio-ethanol, this study considered increasing Brazil's ethanol exports to 70 billion liters (57 billion liters more than in the reference scenario) by 2030. This would represent slightly more than 10 percent of bio-ethanol demand, reaching an average target of 20 percent ethanol blend in gasoline worldwide and displacing slightly more than 2 percent of global gasoline demand.

Simulation studies conducted by the Interdisciplinary Center for Strategic Planning (NIPE) at the State University of Campinas (UNICAMP) for the Center for Strategic Management and

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78   The level of use of hydroelectricity projected in the PNE 2030 would correspond to virtually full exploration of the remaining large hydropower potential in Brazil. For this reason, the study considered that there would not be any large opportunity to reduce emissions through an expansion of hydroelectricity in Brazil beyond what was already considered in the PNE 2030, adopted as the reference scenario

Studies (CGEE) show that Brazil is indeed capable of achieving this physical goal based on available land and other resources.[79] The proposed low-carbon scenario would include a major share of ethanol production via hydrolysis, particularly from currently wasted sugar-cane straw, assuming advances in new conversion processes, as discussed below.

With regard to the additional land needed specifically for sugar-cane plantations, the modeling of projected land use demand for agriculture, livestock, and forestry, detailed in chapters 2 and 3, showed that, as long as the proposed goals for increasing productivity in livestock raising are met, Brazil will have enough land to accommodate expansion of these activities, including the growing of sufficient sugar cane to meet both increased domestic consumption (chapter 5) and the large-scale export goal. Therefore, this scenario assumes that the expansion of sugar cane would not displace forested or conservation lands, either directly or indirectly, such as through the displacement of cattle production on forested lands. The area planted in sugar cane would be about 19.1 million ha in 2030, which is 51 percent more than in the reference scenario (+ 100 percent compared to 2010) (table 4.4). By that date, the sugar-cane area would still be less than half the area planted in grains, and less than one-seventh of pasture area.

Using a conservative substitution ratio of 1 liter of ethanol for 0.66 liter of gasoline and an emissions factor of 2.634 gCO_2e per liter of gasoline (BEN 2006), the potential for liquid GHG emissions reductions through gasoline substitution by ethanol would total 667 Mt CO_2e over the 2010–30 period, with the annual reduction increasing progressively from 1.0 Mt CO_2e to 72 Mt CO_2e per year (table 4.5).

Table 4.4: Sugar Cane and Ethanol Production: Reference and Low-carbon Scenarios

Production	Reference scenario 2030	Low-carbon scenario 2030	Difference (%)
Sugar cane for sugar (million tons/year)	362	362	–35
Sugar cane for ethanol (million tons/year)	720	1,369	90
Total sugar cane (million tons/year)	1082	1,739	60
Ethanol (conventional) (million liters/year)	68,870	130,009	89
Ethanol (hydrolysis) (million liters/year)	7,130	17,337	143
Total ethanol (million liters/year)	76,000	147,346	94
Ethanol for domestic market	62,900	77,678	23
Ethanol exports (million liters/year)	13,100	69,668	432
Sugar (million tons/year)	55.88	55,885	0
Sugar-cane productivity (tons/ha)	100.30	100.3	0
Total area planted to sugar cane (million ha)	12.69	19.1	51

Table 4.5: Ethanol Exports and Emissions Reductions in the Low-carbon Scenario

Ethanol exports (billion liters)	Total	2010–14	2015–19	2020–24	2025–30
Reference scenario	297.5	49.7	75.6	85.9	86.3
Low-carbon scenario	826.6	69.6	143.6	229.4	384.0
Additional	529.1	19.9	68.0	143.5	297.7
Emissions reduction (Mt CO_2e)	666.8	24.0	83.8	179.7	379.3

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[79] The NIPE study explored a range of scenarios for scaled-up ethanol export of up to 205 billion liters per year in 2025, corresponding to 10 percent of worldwide gasoline demand for that year, equal to about 5 times the target considered in this study.

For ethanol exports, the main barriers to implementation are those related to the protection of local production in many countries through high import duties, certification requirement, or product specifications. In terms of emissions, social costs, and economic production costs, ethanol from sugar in Brazil is superior to alternatives in others countries, reflecting a significant comparative advantage to serve the growing international demand for low-carbon vehicle fuels. Reducing or eliminating the high trade barriers and enormous subsidies currently in place in many countries would produce economic benefits for both Brazil and its trade partners, and reduce GHG emissions.

From a technological perspective, conventional ethanol from sugar cane is a mature technology, being close to the limits except in the energy economy, water use, and effluent treatment; it is important to highlight that adequate technical options already exist for these areas, but they have not yet been implemented due to high investment costs and cultural reasons. At the same time, ethanol from the lignocellulosic residues of sugar cane (bagasse and straw) has not yet reached the commercial stage, despite large R&D investments and efforts in many developed countries over the past three decades; this is a technological barrier to this alternative fulfilling its role in the low-carbon scenario.

A reasonable size security stock, or strategic reserve, is important as a guaranty to reassure potential importers that the country has the capability of supplying large quantities of ethanol in a sustainable way.

Proposals to overcome these barriers are:

- Elaboration of certification procedures, including reliable data on land use and land-use change; logistics; labor issues; and socioeconomic, environmental, and life-cycle analyses.

- Assistance in developing the hydrolysis technology associated with conventional ethanol-production processes. Large investments in R&D are needed, especially in the technology deployment stage, when large demonstration plants must be built and operated, producing ethanol at a higher cost compared to conventional production.

- New legislation for the security stock for ethanol, to help stabilize the price of the product throughout the year (to cope with seasonality of production) and assure importers that ethanol will be available in quantity and quality.

4.5 Results: Summary of the Energy Sector Low-carbon Scenario

Final study results reveal that, according to the PNE 2030 reference scenario, Brazil's energy-sector emissions will nearly double over the next 20 years, rising from about 232 Mt CO_2 in 2010 to more than 450 Mt CO_2 by 2030 (excluding fuel for transport) (figure 4.6).

If the 27 low-carbon mitigation options proposed by this study were implemented, energy-sector emissions would be reduced from 450 to 297 Mt CO_2 per year in 2030 (excluding fuel for transport) (table 4.6).

Figure 4.6: Energy-sector Reference Scenario[80] and CO_2 Emissions Mitigation Potential (PNE 2030), 2005–30
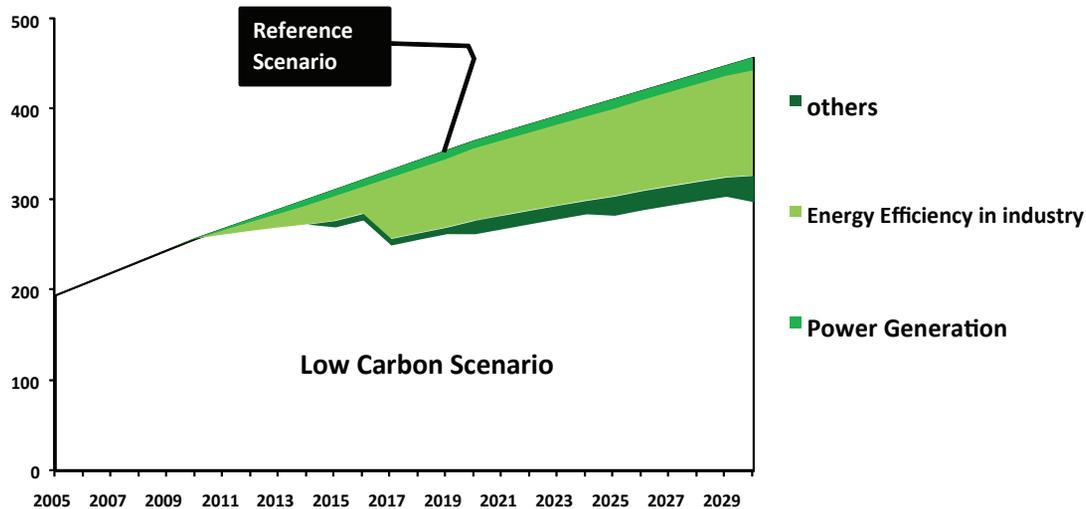
Brazil's transition from the reference scenario to a low-carbon emissions scenario would result in a significant reduction of CO_2 emissions in the energy sector—1.8 billion tons—over the next 20 years (2010–30). This transition should emphasize the elimination of non-renewable biomass as solid fuels for industrial use. Indeed, substituting plant charcoal from forests with plant charcoal from tree plantations represents 31 percent of the sector's total emissions-reduction potential.

From the energy point of view, the mitigating options considered in the low carbon scenario influence the national system in three main ways: change in the energy mix for the power supply, reduction in energy demand (both electricity and fossil fuels) and energy sources replacement by renewable fuels.

In order to better visualize the energy impacts, the mitigating options are shown divided into 5 groups: increase in electricity supply form renewable, increase in fossil fuels supply, reduction in electricity consumption, reduction in fossil fuels consumption and energy sources replacement by renewable sources[81].

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80   The reference scenario adopted in this study, the PNE2030, differs from the emissions projections for the energy sector officially announced by the Brazilian Government in 2009 along with the voluntary commitment to reduce emissions, which are reflected in law Law 12.187. The difference between the reference scenario defined in this study and the one established by the Brazilian government on the basis of past trends reflects the positive impact on emission reductions of the policies already adopted in the PNE2030.

81   The impact on energy as a consequence of the replacement of more carbon intensive fossil fuels (e.g., fuel oil) by natural gas are not reflected here. However, this fuel switch, which corresponds to substituting 4.6% of the more carbon intensive fossil energy by natural gas in 2030, was considered in the calculation of the GHG emissions reductions

Table 4.6: Potential Energy-sector Emissions Reduction for Brazil, 2010–30

Low-carbon	Emission reductions 2010–30	
mitigation options	(MtCO$_2$)	%
Demand Side	**1,407**	**77**
Electricity	**28**	**2**
Solar heating	3	0
Air conditioning (MPES)	3	0
Air conditioning ("Procel Seal")	0	0
Refrigerators (MPES)	10	1
Refrigerators (low-income populations)	6	0
Motor	2	0
Residential Lighting	3	0
Industrial lighting	1	0
Commercial lighting	2	0
Fossil Fuels	**1,378**	**75**
Fuel combustion optimization	105	6
Heat recovery systems	19	1
Steam recovery	37	2
Oven heat recovery	283	15
New processes	135	7
Other efficient energy use (UEE) measures	18	1
Thermal solar energy	26	1
Recycling	75	4
Natural gas substitution (including ducts)	44	2
Biomass substitution	69	4
Substitution of non-renewable biomass with charcoal from tree plantings*	567	31
Supply Side	**423**	**23**
Power Generation	**177**	**10**
Wind generation	19	1
Biomass cogeneration	158	9
Oil and Gas	**246**	**13**
GTL	128	7
Refining		
Improved energy use in existing refinery units (heat integration)	52	3
Improved energy use in existing refinery units (fouling mitigation)	7	0
Improved energy use in existing refinery units (advanced control)	7	0
Optimized design of new refineries	52	3
Total	**1,830**	**100**

If the analyzed mitigating options are implemented, in the following years, fossil fuel energy conservation would be responsible for the greatest impact (see 4.7). The share of renewable sources, in turn, may increase by more than 410 Mtoe from 2010 to 2030. During the 2010 - 2030 period, the total energy impact would be greater than 0.8 Gtoe for all mitigation options together.

Table 4.7 – Energy Differences between the Low Carbon and the Reference Scenarios (Mtoe)

	2010-2015	2016-2020	2021-2025	2026-2030	Total	% diference in 2030
Additional Electricity generation from renewable	26,5	48,9	61,4	71,5	208,3	+ 14.6% [1]
Additional electricity conservation	1,3	4,3	8,1	11,6	25,2	- 3.0% [2]
Zero carbon additional fossil fuels production (GTL)	0,4	2,7	5,1	8,7	16,9	+ 0.4% [3]
Additional fossil fuel energy conservation	30,7	80,0	119,3	157,9	387,9	- 11.4% [4]
Additional energy substitution from fossil fuel to renewable	1.4	47.8	69.4	83.6	202.1	+ 5.9% [5]
Total	60.3	183.7	263.3	333.2	840.5	

Source: calculations based on the individual reports

(1)   *increase of generation from renewable in Low Carb. Scenario as a % of total generation in Ref. Scenario in 2030*
(2)   *reduction of electricity consumption in Low Carb. Scenario compared to Ref. Scenario in 2030*
(3)   *increase of fossil fuel with no increase of GHG emissions in Low Carb. Scenario compared to Ref. Scenario in 2030*
(4)   *reduction of fossil fuel consumption in Low Carb. Scenario compared to Ref. Scenario in 2030*
(5)   *share of fossil fuel used in Ref. Scenario in 2030 substituted by renewable in Low Carb. Scenario in 2030*

Chapter 5

Transport Sector: Reference and Low-carbon Scenarios

Brazil's transport sector has a lower carbon intensity compared to that of most other countries because of its widespread use of ethanol as a fuel for vehicles. Still, the transport sector accounts for more than half of Brazil's total fossil-fuel consumption (figure 5.1).[82] Transport-sector emissions are rapidly growing, especially in urban areas, due to increased motorization and congestion. In 2008, the transport sector accounted for about half of the country's energy-related carbon dioxide (CO_2) emissions.

Figure 5.1: Fossil-fuel Consumption, by Sector
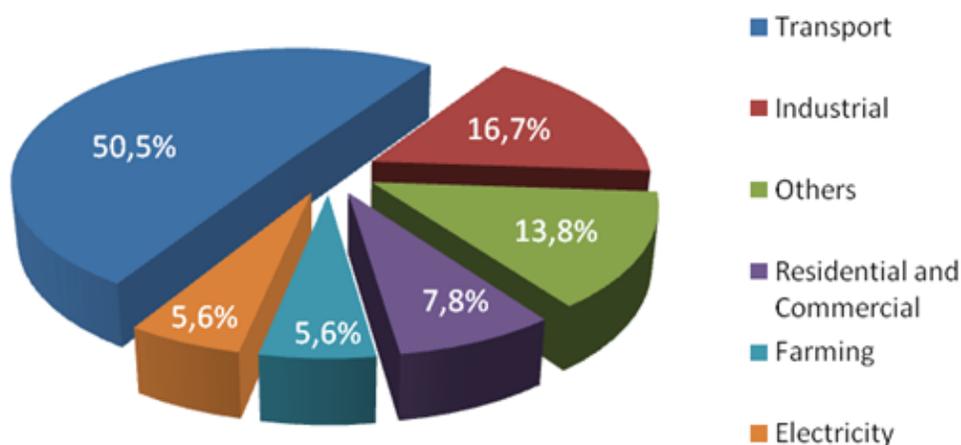
Source: National Energy Balance (BEN) (2008).

Road transport is responsible for more than 90 percent of transport-sector emissions. Urban transport, which accounts for 58 percent, is almost exclusively road-based (car or bus).[83] The accelerated rate of motorization in already congested cities is further deteriorating existing systems and infrastructure. In São Paulo, for example, the fleet is growing at an annual rate of 7.5 percent, with nearly 1,000 new cars bought each day. In 2008, that city's average rush-hour congestion exceeded 190 km.[84] Such intense congestion results in higher inefficiencies, greater fuel consumption, and increased local pollution and GHG emissions. Therefore, continued significant growth in transport-sector emissions is expected in the coming decades.

In this chapter, section 5.1 presents the method adopted to build emissions projections consistent with projections of transport demand and supply growth. Section 5.2 describes the method used to build scenarios for Brazil's transport sector, and section 5.3 presents the reference scenario. Sections 5.4 and 5.5 then present the mitigation options the study considered for regional and urban transport, respectively, while section 5.6 focuses specifically on the increased use of bio-ethanol. Finally, section 5.7 presents the proposed the low-carbon scenario for Brazil's transport sector.

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82   Owing to the large use of hydropower in the electricity sector.
83   Trucks, which account for three-fifths of regional freight transport, substantially increase GHG emissions (PNLT 2007).
84   On May 9, 2008, São Paulo set an all-time congestion record of 266 km (30 percent of monitored roads).

5.1 Bottom-up Load and Emissions Model

This study used a bottom-up approach to estimate fuel consumption and GHG emissions in the transport sector. CO_2 emissions were calculated by mode of transport, based on the projected demand of passengers or freight, number and length of trips, and types and energy content of the fuels consumed. Trips were categorized as urban/metropolitan or inter-urban/regional. The study first estimated the load (i.e., volume of passengers x km or tons x km [for freight]) for each mode of transport (road, rail, air, and waterway) and subsector (urban transport [passenger and freight]) and inter-urban/regional transport [passenger and freight]). The study then estimated the resulting emissions.

5.1.1 Modeling Supply and Demand of Transport Modes To Model Emissions

Predicting the evolution of demand and load for each mode of transport is a complex task. Each mode has its unique operational characteristics, many types of freight are moved, and user behavior and reasons for travel vary widely. To facilitate analyses of future demand and scenarios, the study team divided the transport sector into four separate groups: (i) regional freight transport, (ii) regional passenger transport, (iii) urban freight transport, and (iv) urban passenger transport. All trips taken outside the urban limits of Brazil's 5,564 municipalities were categorized as "regional." Regional trips using vehicles on stretches of main road that pass through large urban centers were counted as "regional trips."

The study used a traditional four-stage transport model, which enables the application of physical, economic, and social changes in both inter-urban/regional and urban-metropolitan contexts (figure 5.2):

- *Trip generation*: This stage defines the total demand for transport, which is attributed to each traffic zone as a function of its potential as a producer or an attractor for trips.

- *Trip distribution*: At this stage, flows are distributed based on estimated movements between origins and destinations considering such constraints as distance.

- *Mode choice*: Movements between origins and destination are disaggregated by transport mode. This function depends on the availability of each mode, respective costs, and user preferences. The resulting information is represented in a series of demand or trip matrices for each transport mode, flow type, and period considered.

- *Route assignment*: All estimated trips by origin, destination, and transport mode are loaded on the transport network (with the general qualification that users want to minimize their travel time). If the traffic exceeds the capacity of specific transport segments (which is often the case), congestion occurs and affects travel time. This factor, in turn (via a feedback process), may influence trip generation and distribution.

Figure 5.2: Sequencing of Four-stage Transport Model
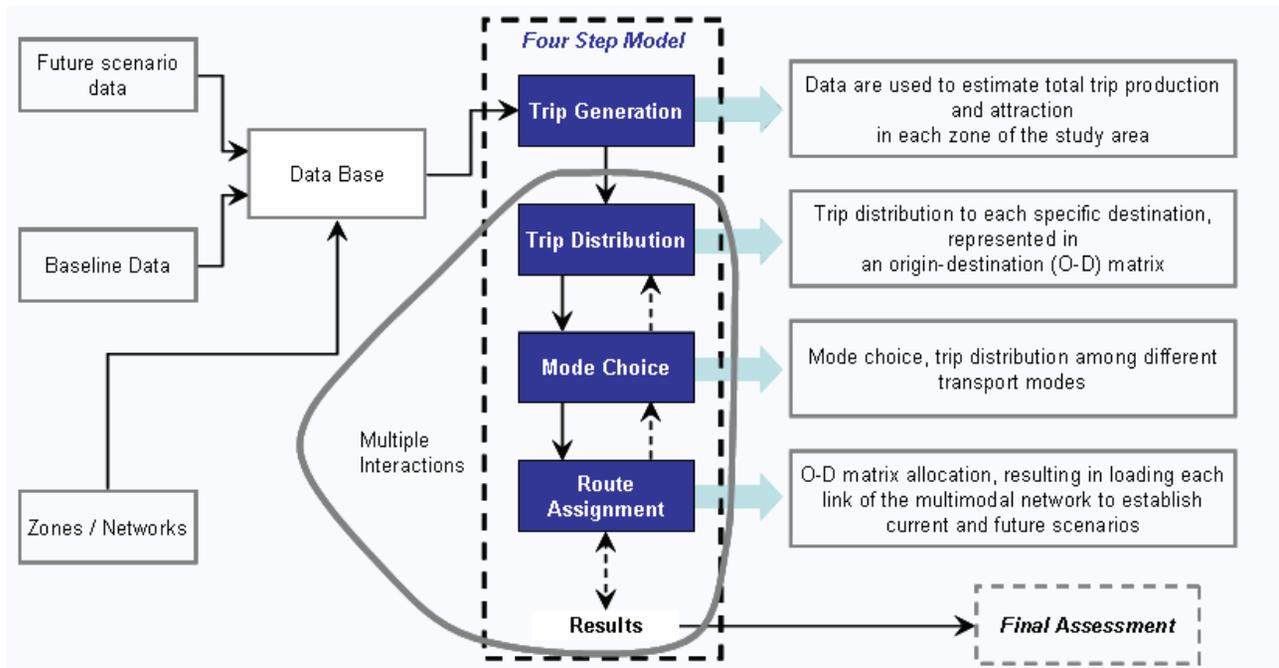
Transport planning models developed for regional and urban contexts (TransCAD, EMME, and MANTRA) were used to evaluate various alternatives and scenarios via multiple interactions and calibrations.

Brazil's regional transport network has five transport modes (road, rail, air, waterway, and pipeline), which are georeferenced in the TransCAD software. Major transport routes usually have a radial format leading to capital cities and large metropolitan areas (figure 5.3).

Figure 5.3: Multimodal Georeferenced Network

5.1.2 Emissions Model for the Transport Sector

All transport-related emissions are ultimately derived from the fuels burned by the types of vehicles used. To calculate emissions, it is first necessary to link the supply of transport with fuel type (figure 5.4).

Figure 5.4: Linking Regional and Urban Transport to Fuel Consumption
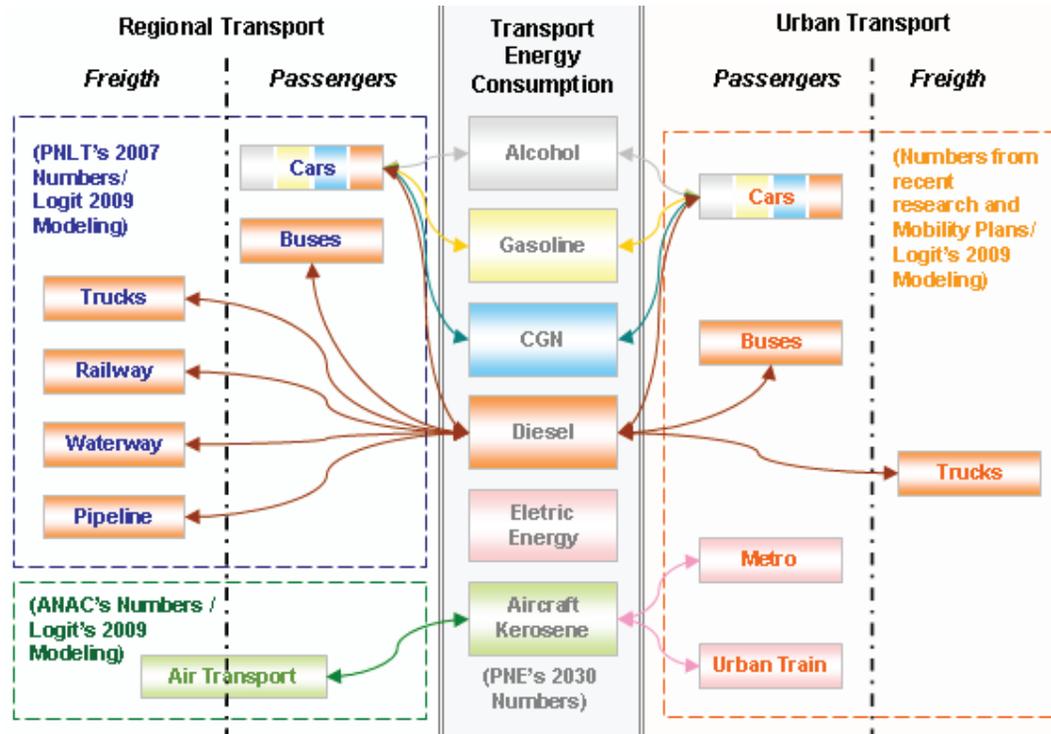
Based on the four-stage transport model's trip allocations, the COPERT 4 model was used to calculate GHG emissions. Used in the European Union, COPERT 4 software was adjusted to the Brazilian context to accommodate available data, fleet characteristics, operational conditions, and fleet-maintenance conditions (box 5.1). In addition, the Environmental Sanitation Technology Company (CETESB), which is responsible for Brazil's vehicle emissions certification program, provided emissions data and helped to develop emission curves as a function of vehicle type and speed.

Box 5.1: COPERT Model: A Bottom-up Approach to Estimating Emissions

COPERT 4 is a computer software program designed to calculate transport-sector emissions. Used by European Union (EU) countries, COPERT 4 can be adapted to other regions and countries. The tool can be applied at regional and national aggregate levels, and can be used at the micro-region level over a 1-k^2 area without loss of reliability.

The model differentiates between "cold" emissions (estimated at the outset of a trip before a vehicle reaches its correct working-efficiency level and engine temperature) and "hot" emissions (calculated when the engine reaches its stability level). It also accounts for vehicle deterioration resulting from age or high mileage. The emissions calculated include main sector GHGs, local pollutants, particulate matter, hydrocarbons, persistent organic pollutants, and heavy metals.

Entry data are:

- fleet categorized by class of vehicle-engine technology for each year of study (urban, regional, and road);
- total mileage by class of vehicle-engine technology for each year of study;
- average trip mileage, by year and class of vehicle-engine technology;
- average speeds by class of vehicle-engine technology (urban, regional, and road);
- size of fuel tank and canister by class of vehicle-engine technology;
- percentage of fuel injection;
- percentage control of fuel evaporation by type of engine and category (urban, regional, and road);
- maximum and minimum ambient temperature, by month and year;
- atmospheric pressures recorded by month and year and the beta distribution parameter;
- chemical composition of each fuel type;
- record of improvements in the emissions of each type of pollutant, by year; and
- fuels used by class of vehicle-engine technology and annual fuel consumption.

5.2 Government Plans for Designing Scenarios

To the extent possible, the study adhered to official plans to develop reference and low-carbon scenarios for the transport sector. The key emissions-reduction challenge for the transport sector, unlike other sectors, is not shifting to a less carbon-intensive technology to achieve the same supply level; rather, it is financing and developing new and faster capital-intensive infrastructure, most of it already identified, to develop the transport offer and avoid or reduce congestion. Thus, existing government plans are important for building not only the reference scenario but also the low-carbon scenario. The main difference between these two scenarios is the pace of implementation. Because the reference and low-carbon scenarios use the same methodology, they are defined together in the subsections that follow on options for (i) regional and (ii) urban transport.

5.2.1 PAC and PNLT: Basis for Regional-transport Scenarios

To build the reference and low-carbon scenarios for regional transport, the study considered two main government plans: the Government Accelerated Growth Plan (PAC) and the National Logistics and Transport Plan (PNLT). Based on discussions with transport-sector specialists and Brazil's Ministry of Transport (MT), it was agreed that such PAC investments as infrastructure rehabilitation and construction would be included in the reference scenario.[85] The PNLT, prepared by the MT in 2007, resulted from a participatory planning process involving various national- and state-level stakeholders. The plan's overall goal includes long-term environmental and sustainability objectives, which are reflected in support of a gradual reduction in highway investments and a gradual increase in rail and waterway investments. The initial time horizon for implementing the proposed projects is 2023. But given the current economic context and related uncertainties regarding the viability of this time frame, it was agreed that some projects contained in the PNLT would be considered as part of the low-carbon scenario. Based on the PAC and PNLT, the total investments required for the reference and low-carbon scenarios are US$19.6 billion and US$29.3 billion, respectively (table 5.1).

Table 5.1: PAC and PNLT Investments Considered for the Reference and Low-carbon Scenarios

Transport mode	Reference scenario			Low-carbon scenario		
	US$ (billions)	% of total	% of PAC	US$ (billions)	% of total	% of PNLT
Road	15.1	77	126	13.3	45	52
Rail + waterway + pipeline	4.5	23	100	16.0	55	63
Total	**19.6**	**100**	**119**	**29.3**	**100**	**57**

In addition to the PAC and the PNLT, the study adopted the macroeconomic scenario of the National Energy Plan (PNE 2030) developed by the Energy Planning Company (EPE) to ensure that the assumptions used for projecting the movement of freight and passengers would be compatible with those adopted in the models of the other three sectors. Demand scenarios created for freight transport integrated the possibilities of expanding agricultural frontiers, increasing productivity, and projecting the balance between product supply and demand.

5.2.2 Urban Mobility Plans: Basis for Urban-transport Scenarios

The urban transport sector is more complex. Freight and passenger transport is regulated by multiple state and municipal authorities that pursue divergent, often contradictory agendas. In metropolitan and other densely populated areas, transport users are at the mercy of political and institutional interests. Given that commuter trips often cross municipal boundaries, users would greatly benefit from a more integrated transport management system with a common institutional framework, policies, budget, and fare system.

Because official mobility plans were not available for every urban center—the 36 largest ones have 516 municipalities (IBGE 2008)—the study grouped the figures needed to evaluate urban transport emissions into eight urban-center categories. For the five categories corresponding to larger municipalities and urban centers, investment estimates were based on origin/destination

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85   The PAC allocates more than US$16.5 billion for transport-related projects, of which approximately US$3 billion is absorbed by concessions and other public-private partnerships (PPPs).
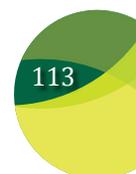
surveys and recent transport master plans (table 5.2).[86]

Since major opportunities to reduce emissions in urban transport derive from investment in mass transport systems, the study assumed no significant infrastructure difference between the reference and low-carbon scenarios for categories corresponding to smaller municipalities.

Table 5.2: Available Urban-transport Master Plans

Category no.	Metropolitan Region or Municipality
1	São Paulo and Rio de Janeiro
2	Belo Horizonte, Curitiba, Recife, and Porto Alegre
3	Baixada Santista and Greater Vitória
4	Cuiabá-Várzea Grande, Florianópolis, Londrina, Maringá, Maceió, Campo Grande, Vitória da Conquista, Ribeirão Preto, and Juiz de Fora
5	Petrópolis, Piracicaba, Campina Grande, Rio Branco, and Santa Maria

Of the many ambitious urban-transport investment plans reviewed, the most feasible solution for cities is Bus Rapid Transit (BRT), which requires smaller infrastructure investments and takes less time to execute. The BRT system can provide an upgraded alternative to deteriorating and inefficient bus systems and attract private motorized-vehicle users. All of the investment types and values were modeled and respective investment probabilities were given for the reference and low-carbon scenarios (table 5.3).

Table 5.3: Investments in Public and Mass Transport Systems

Category (no.)*	Densely populated urban municipalities and metropolitan regions	System type	No. km to be constructed	
			Reference scenario	Low- carbon scenario
MR with investments (1)	São Paulo and Rio de Janeiro	BRT	180	1.263
		Metro	30	405
RM with investments (2)	Belo Horizonte, Federal District and Environs (RIDE), Fortaleza, Curitiba, Recife, Porto Alegre, and Salvador	BRT	289	670
		Metro	25	280
MR with probable investments (3)	Belém, Baixada Santista, Goiânia, Campinas, Manaus, and Greater Vitória	BRT	60	300
		Metro	0	100

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86   It should be noted that the reference scenario considered the selection of Brazil as the host of the 2014 FIFA World Cup, a major event that will require investment in public-transport infrastructure. Since most host cities are located in large metropolitan areas, it is expected that considerable investments will be made in bus and metro systems to ensure compliance with the conditions established for hosting this event.

MR/ municipalities with probable investments (4)	Cuiabá-Várzea Grande, Aracaju, Grande Teresina (RIDE), Grande São Luís, Florianópolis, Londrina, João Pessoa, Maringá, Maceió, Natal, São José dos Campos, Ribeirão Preto, and Juiz de Fora	BRT	80	240
		Metro	0	0
Municipalities with probable investments (5)	São José do Rio Preto, Campina Grande, Piracicaba, Bauru, Montes Claros, Jundiaí, Anápolis, Foz do Iguaçu, Franca, Rio Branco, Uberaba, Cascavel, and Volta Redonda	BRT	40	120
		Metro	0	0

* MR = metropolitan region.

5.3 Emissions Projections in the Reference Scenario

Based on the proposed investments discussed above, projected year-to-year transport loads and emissions of urban and regional transport modes were modeled for the reference scenario. From 2007 to 2030, sector emissions are projected to increase by more than half (from 144 to 248 Mt CO_2) (table 5.4), with urban transport accounting for about half of overall sector emissions. Substantial growth in private-vehicle use of ethanol is expected over the period. According to Brazil's National Association of Motor Vehicle Manufacturers (ANFAVEA), by 2030, virtually the entire passenger fleet will consist of "flex-fuel" vehicles. While gasoline-powered vehicle loads will increase 25% from 355 billion to 444 billion passengers x kilometer, passenger loads of ethanol-fueled cars will increase 4.5 times from 118 to 541 billion passengers x kilometer (table 5.4).

115

Table 5.4: Load and GHG Emissions for the Reference Scenario, 2007–30

Load type	Transport mode	Vehicle type	Fuel type	Load (Mt * km or pax * km/ year)		Global direct CO$_2$ emissions* (Mt CO$_2$)		
				2007	2030	2007	2030	2010 - 2030
Urban Freight	Road	Truck	Diesel	32,436	49,151	7.6	7.6	-
	Total urban freight			**32,436**	**49,151**	**7.58**	**7.58**	**-**
Urban passenger	Road	Bus	Diesel		730,799	33.8	51.3	887.7
		BRT		0	102,332	0.0	3.36	32.4
		Car	Ethanol	96,399	364,894	0.0	0.0	0.0
		Car and motorbike	Gasoline	272,570	347,346	36.6	66.2	1,087.0
	Rail	Metro	Electricity	28,412	55,385	0.021	0.039	0.63
		Train		35,370	50,699	0.022	0.029	0.55
	Total urban passenger			**864,078**	**1,651,46**	**70.4**	**120.8**	**2,007**
	GHG emissions from urban transport			**-**	**-**	**75.2**	**128.3**	**2,137.5**
Regional freight	Rail	Train	Diesel	321,240	552,364	4.4	6.4	112.5
	Waterway	Boat		26,984	81,349	0.2	0.5	8.1
	Pipeline	Pipeline		15,732	24,727	0.1	0.1	1.5
	Road	Truck		689,057	1,274,440	48.0	77.3	1,323.5
	Total regional freight			**1,053,013**	**1,932,880**	**51.9**	**82.6**	**1,418.8**
Regional passenger	Road	Car	Ethanol	21,905	176,485	0.0	0.0	0.0
		Car and motorbike	Gasoline	83,166	97,031	4.2	5.2	94.8
		Bus	Diesel	154,845	276,915	4.4	7.5	125.6
	Air	Plane	Aviation kerosene	45,259	127,569	8.4	23.7	324.0
	Rail	High-speed train	Electricity	-	-	0.0	0.0	0.0
	Total regional passenger			**305,175**	**678,001**	**17.0**	**36.5**	**544.5**
	GHG emissions from regional transport			**-**	**-**	**68.9**	**119.1**	**1,963.2**
	TOTAL TRANSPORT-SECTOR EMISSIONS					**144.0**	**247.5**	**4,100.7**

(*) in order to avoid double counting with emissions already accounted for in the agriculture and energy sectors, only direct emissions are accounted here.[87].

The evolution of emissions for the reference scenario shows that cars, trucks, and buses together account for 87 percent of emissions over the 2010–30 period. Since most power is generated from hydroelectricity, metro mass transport systems are expected to generate virtually no direct emissions. Brazil's significant role for ethanol in the PNE 2030 explains the relatively stable contribution of private vehicles over the period (figure 5.5a). The widespread use of ethanol to fuel light-duty vehicles suggests that the reference scenario is one of low emissions compared to those of other countries with similar growth in private-vehicle use. In

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87   While not accounted here to avoid double counting, "upstream" or "indirect" emissions associated to the production of the fuels and electricity used in the transport sector are calculated and presented in the special companion report on transport.

this study, since emissions from agriculture and from land-use changes are already accounted in chapter 2 as emissions from land use and land use changes, Ethanol is considered to have net-zero emissions since tailpipe CO_2 emissions from ethanol-fueled vehicles is based on carbon captured from the atmosphere by sugar-cane plants. Indeed, the study found that, without biofuels, sector emissions would be 50 percent higher in 2030 (371 versus 247 Mt CO_2e per year) and cumulative emissions would also grow by 45 percent (figure 5.5b).

Figure 5.5a: Evolution of Emissions by Vehicle
Type for the Reference Scenario, 2008–30
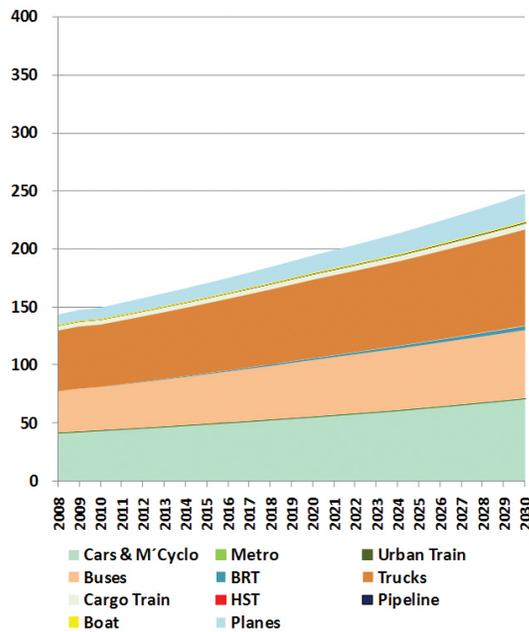
Figure 5.5b: Projected Transport-sector
Emissions without Biofuels, 2008–30
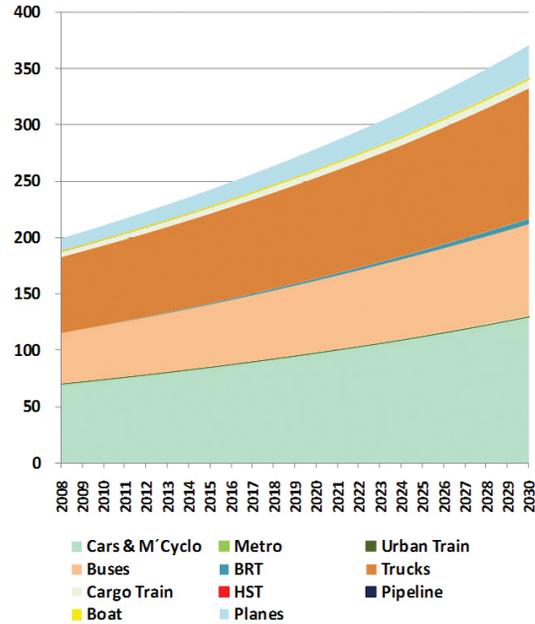
The following sections describe options to mitigate regional and urban-transport emissions, respectively. Further expansion of ethanol consumption as a substitution for gasoline is also considered.

5.4 Emissions Mitigation Options for Regional Transport

Based on consultations with specialists, bibliographic research, and analyses of master plans for metropolitan regions and government programs and plans, a set of feasible emissions mitigation options, to be implemented by 2030, was selected for the low-carbon scenario. Some of these options, already considered in the PNLT, were retained because of their potential to avoid emissions; another portion, consisting of new options, was proposed by the study team.

Corresponding policies and investments center on creating incentives and enabling a gradual change in the country's mix of transport modes, whereas, in the regional framework, road transport is the main means considered in the reference scenario for transport of goods (approximately 60 percent of total volume) and passengers. Regarding the transport of large volumes of freight, whether solid grain (e.g., soybean) or liquid (e.g., petroleum and ethanol and other derivatives), rail and waterways are more energy efficient and are therefore the preferred modes for the low-carbon scenario whenever possible.

5.4.1 Freight Transport: Modal Shift from Road to Rail and Waterways

Improving the efficiency of Brazil's freight transport and reducing related emissions require a significant shift in the freight transport matrix. Both the PNLT and the National Plan on Climate Change (PNMC) emphasize the need to reduce the volume of freight transported on roads, and replace it with more energy-efficient transport modes. A gradual shift from road to rail, inland and coastal waterways, and pipelines is being planned (see figure 5.6).

Figure 5.6: Example of modal shift for Regional Transport – Bahia

In the Reference Scenario all the load istranported by trucks

In the Low Carbon Scenario most of the load is shifted to new cargo trains

New East Bahia Railway

Reference Scenario 2030   Low Carbon Scenario 2030
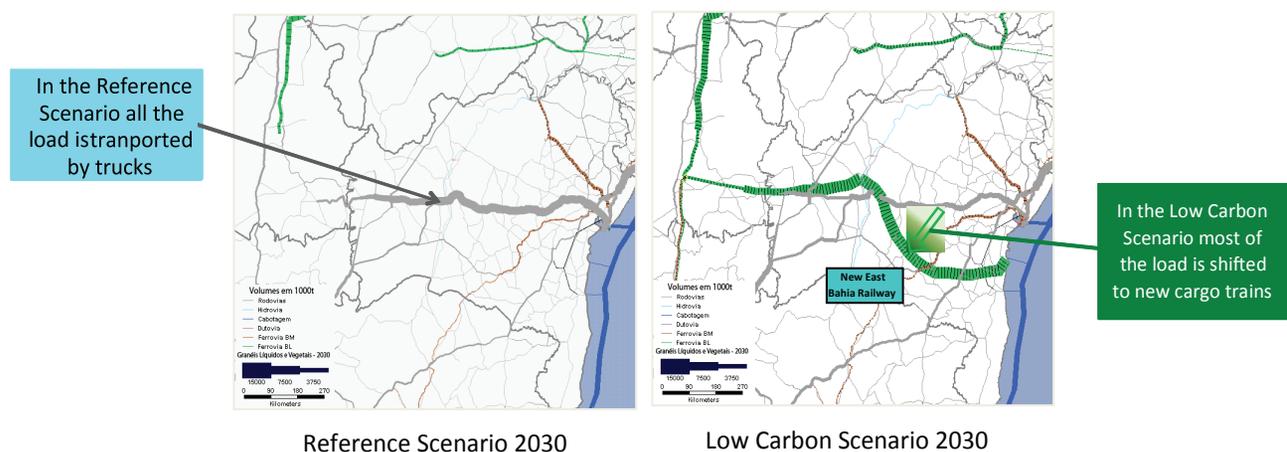
Interventions aimed at modifying the transport matrix should be guided by national, regional, and international market needs and demands. In Brazil's North, Northeast, and Center-West regions, transport demand currently focuses almost entirely on agricultural and mining commodities, which already have their own logistical solutions and face severe competition from other modes. Therefore, the potential in these regions for establishing new waterways and railways appears more limited than generally considered. Such new high-cost investments, which are technically possible, could indeed become underused.

By adopting the proposed modal shift, 13 percent of the load transported by truck over the study period is transferred to cargo train, boat, and pipeline, whose respective loads increase by 27, 64, and 8 percent. As a result, the low-carbon scenario shows an 8-percent potential reduction in total CO_2 emissions in 2030 compared to the reference scenario (from 82.6Mt CO_2 per year to 76 Mt CO_2 per year),[88] resulting mainly from a reduction in the share of road-based freight transport (from 66 to 56 percent).

For water transport, investments in the low-carbon scenario include dredging and construction of terminals, depending on the types of goods transported. To harmonize freight-transport targets in the low-carbon scenario, rail-transport investments require better integration of rail operators and the regulatory authorities responsible for services operation and improved operational partnerships among the concessionaires. Conservation of the existing rail network, as well as its expansion and development of interfaces with road, is fundamental to facilitating the freight-transport shift from road to rail. Finally, shifting from road-based to coastal transport requires better facilities for quick and efficient inter-modal transfer.

These various modes of transport, which are usually operated privately, should be integrated.

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88   Total emission reductions over the 2010–30 period would amount to 51 Mt CO_2.

Such integration would require new infrastructure and terminals to allow for inter-modal transfer (e.g., boat to road), which could efficiently process the volume of freight transported. Given the diverse actors involved, the Ministry of Transport (MT) should be responsible for coordinating policy implementation and the investments required to shift to a new modal division by 2030 (table 5.5).

Additional resources required for adopting the proposed modal shift in a low-carbon scenario (based on the PNLT) compared to the reference scenario (based on the PAC) total about US$17 billion, of which approximately US$1.8 billion could be absorbed by the private sector via public-private partnerships (PPPs). This could result in reducing 126 Mt CO_2 of emissions over the 2010 2030 period. Fuel savings could provide a considerable benefit on the order of US$2.8 billion.

Table 5.5: Regional Freight Transport: Comparison of Investments
in the Reference and Low-carbon Scenarios, 2010–30

Year	Reference scenario (million US$)			Low-carbon scenario (million US$)		
	Rail and waterway	*Road*	*Total*	*Rail and waterway*	*Road*	*Total*
2010	0.396	-	0.396	0.396	-	0.396
2011	0.793	-	0.793	0.793	-	0.793
2012	1.189	-	1.189	1.189	-	1.189
2013		-	-	-	-	-
2014	0.356	2.788	3.144	0.356	2.548	2.905
2015	0.712	5.575	6.288	0.712	5.097	5.809
2016	1.069	8.363	9.432	1.069	7.645	8.714
2017	-	-	-	-	-	-
2018	-	0.554	0.554	1.331	0.554	1.885
2019	-	1.108	1.108	2.661	1.108	3.769
2020	-	1.662	1.662	3.992	1.662	5.654
2021	-	-	-	-	-	-
2022	-	-	-	0.581	-	0.581
2023	-	-	-	1.162	-	1.162
2024	-	-	-	1.742	-	1.742
2025	-	-	-	-	-	-
2026	-	1.251	1.251	-	1.185	1.185
2027	-	2.503	2.503	-	2.369	2.369
2028	-	3.754	3.754	-	3.554	3.554
2029	-	-	-	-	-	-
2030	-	-	-	-	-	-
Total	**4.516**	**27.559**	**32.074**	**15.984**	**25.722**	**41.707**

In order for this group of policies to be implemented successfully, it is important to design an adequate and realistic program for allocating resources, as well as measures to facilitate the financing of the considerable investments required to adapt and build the infrastructure necessary for efficient intermodal transfers.

5.4.2 Passenger Transport: Modal Shift from Road and Air to Intercity Rail

The modal shift for passenger transport aims to reduce the number of road passengers and encourage regional rail transport. Earlier transfer of the railway network to private-sector operators, along with growth in regional air travel among higher-income populations, has contributed to a shift in the past from intercity rail to road transport. The proposed mitigation option to shift from road and air to intercity rail by 2030 would start with the largest metropolitan regions, based on results of recent studies to connect Rio de Janeiro and São Paulo via high-speed train (table 5.6).

The total emissions reduction of 0.5 Mt CO_2e associated with the proposed modal shift might not appear significant—it represents a 1.3-percent reduction compared to the reference scenario—but a reduction of nearly 3.4 gCO_2 per passenger x km when shifting from car to train shows that further expansion of the system could provide considerable emissions-reduction benefits.

An overall reduction of 10 Mt CO_2 in net emissions over the 2014–30 period may not justify the US$16 billion projected for the Rio de Janeiro-São Paulo high-speed rail link. But apart from the possible opportunity for further expansion and related emissions reduction, the Brazilian government expects considerable counterpart funding. Moreover, significant economic and social benefits could result from the high-speed rail.

Table 5.6: Comparison of Projected Emissions Reduction
for Regional Transport in 2030: Modal Shift Scenario

Segment	Transport mode	Vehicle type	Fuel type	Load (Mt * km or pax * km/ year)		GHG direct emissions* (Mt CO₂e/year)		Avoided emissions 2010 – 2030
				Reference scenario	Low-carbon scenario	Reference scenario	Low-carbon scenario	MtCO₂e
Freight	Rail	Train	Diesel	552,364	703,854	6.42	8.46	-28.24
	Water	Ship		81,349	133,503	0.52	0.88	-4.77
	Pipeline	Pipe		24,727	26,621	0.08	0.09	-0.15
	Road	Truck		1,274,440	1,113,926	75.63	66.57	84.14
Total freight (regional)				**1,932.880**	**1,977.904**	**82.65**	**76.0**	**51.0**
Passenger	Road	Car	Ethanol	176,490	165,460	0.00	0.00	0.00
		Car and motorbike	Gasoline	97,030	90,970	5.23	2.44	19.89
		Bus	Diesel	276,915	276,915	7.5	6.4	10.8
	Air	Plane	Aviation kerosene	127,569	127,569	23.74	23.13	6.75
Total passengers (regional)				**678,010**	**660,920**	**36.5**	**32.0**	**37.5**
TOTAL EMISSIONS: load and passenger (regional)						**119.1**	**108**	**88.5**

(*) in order to avoid double counting with emissions already accounted for in the agriculture and energy sectors, only direct emissions are accounted here.[89].

5.5 Emissions Mitigation Options for Urban Transport

Urban transport is more complex than regional transport due to the greater concentration of vehicles operating in densely populated areas. The close interaction between various modes of

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89 While not accounted here to avoid double counting, "upstream" or "indirect" emissions associated to the production of the fuels and electricity used in the transport sector are calculated and presented in the special companion report on transport.

transport and the links between transport, land use, local economic development, and spatial-growth policies all add to the complexity of modeling the effects of transport in urban areas.

Three groups of emissions mitigation options were considered in the urban transport subsector. The first one targeted a modal shift from private to low-carbon, public transport systems in larger cities and metropolitan regions. The second focused on interventions in travel demand management, where the priority is to reduce demand for and length of trips and promote a shift to high-occupancy transport. The third focused on developing zero-carbon, non-motorized transport.

5.5.1 Use of High-capacity, Public Transport Systems

The private vehicles in circulation are concentrated in metropolitan regions. Expanding and improving the quality of public transport systems can help reduce the use of private vehicles and thereby reduce emissions.

The Bus Rapid Transit (BRT) system has a great potential to reduce emissions in urban areas, given that bus travel accounts for about 85 percent of public trips in Brazilian cities. Compared to conventional bus systems, BRT can transport many more passengers, thereby reducing fuel consumption per passenger kilometer. Because BRT vehicles operate in reserved lanes, they have a higher average speed, resulting in better service and fewer emissions.

The investment required to build the nearly 650 km of BRT already considered in the reference scenario would total about US$6.5 billion. The modeling indicates that it would be possible to expand the BRT system to about 2,600 km, requiring an additional US$26 billion. This amount would require public-sector financing since investments in mass and public transport are unattractive to the private sector, given the level of effort required to obtain only limited operational efficiencies and low profit margins.

By comparing the loads and emissions of the reference and low-carbon scenarios and those resulting from the proposed expanded, high-capacity public-transport system based on diesel-fueled BRT, one observes a 7.5-percent emissions reduction in 2030 (from 128 Mt CO_2 per year to 119 Mt CO_2 per year),[90] even without any major technological changes.

This emissions reduction would result from an increased share in BRT ridership, which would grow from 6 percent at the start of the period to 30 percent in 2030. Sixty-nine percent of new BRT passengers would have shifted from use of conventional buses, whose ridership would have declined 17 percent (from 44 to 27 percent), while 17 percent would be potential users of individual motor vehicles, whose use would have declined 4 percent (from 43 to 39 percent).

The Metro system also has significant potential to reduce fuel consumption and emissions, particularly in large cities since it also displaces diesel buses and individual vehicles, frequently trapped in congestion, with an electricity-run system generated mainly by hydropower plants. In Rio de Janeiro, plans are under way to expand Line 1 to Ipanema. Within the next few years, connection of the downtown area with the Barra da Tijuca neighborhood via a private concession is likely to become operational. Plans for further expansion include new routes within the 2030 time frame of the low-carbon scenario. The master plans of Brasilia and Belo Horizonte similarly indicate the likelihood of extending their Metro systems until 2030.

The modeling indicates that it would be possible to build an additional 785 km of metro lines compared to the reference scenario; this would require an expenditure of approximately US$80

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90   Over the 2010–30 period, the proposed additional BRT would avoid 73 Mt CO_2.

billion, which could be partially co-financed by the private sector, following a similar Private Public Partnership (PPP) model adopted for the yellow line in São Paulo.

By combining the proposed metro lines with the proposed additional BRT lines, urban transport emissions would be reduced 8 percent more in 2030 than with the proposed BRT alone (figure 5.7). As a result, joint introduction of BRT and Metro would result in a total annual CO_2 emissions reduction of about 7.5 percent in 2030 (from 128 Mt CO_2 to 119 Mt CO_2 per year). With the addition of Metro in the low-carbon scenario, the modal share of conventional buses would decline further (from 44 to 21 percent), while the share of private motor vehicles would also be reduced (from 43 to 37 percent) (table 5.7).

Figure 5.7: Example of modal shift for urban transport – Belo Horizonte

Reference Scenario 2030   Low Carbon Scenario 2030
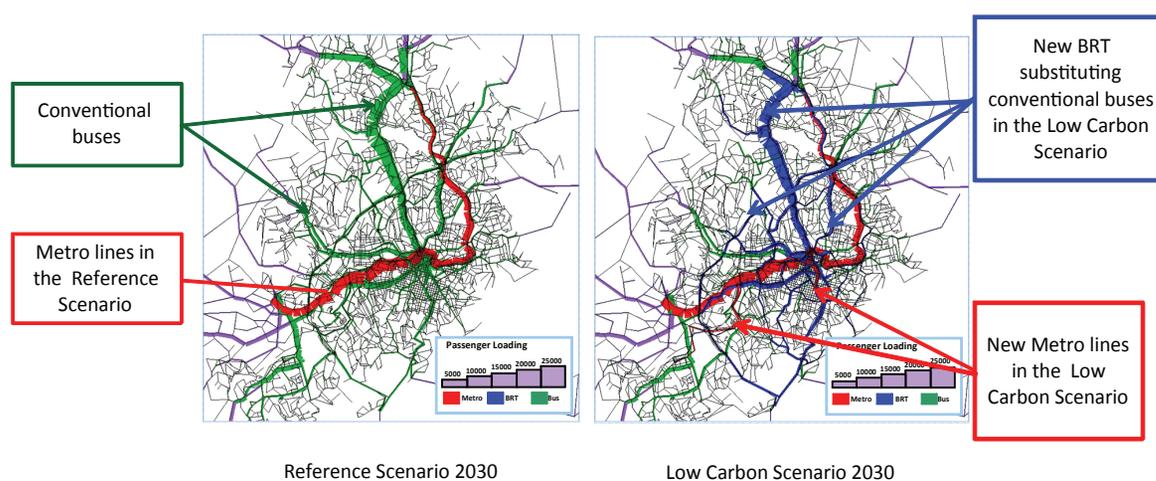
Table 5.7: Emissions Reduction in 2030 with Expanded Diesel BRT and Metro Systems

Segment	Transport mode	Fuel type	Load (millions of pass * km/year)		Global CO_2 direct emissions * (Mt/year)	
			Reference scenario	Scenario with BRT + Metro	Reference scenario	Scenario with BRT + Metro
Road	Truck	Diesel	49.15	49.15	7.49	7.49
Total urban freight			**49.15**	**49.15**	**7.49**	**7.49**
Road	Bus	Diesel	730,799	346,281	51.31	39.398
	BRT		102,332	470,621	**3.36**	**13.349**
	Car	Ethanol	364,890,	320,240	0	0
	Car and motorbike	Gasoline	347,350,	304,840	66.6	59.227
	Metro		55,385	212,844	0	0
Rail	Train	Electricity	50,699	26,577	0	0
Total passengers (urban)			**1,651,460**	**1,675,400**	**120.85**	**111.974**
GHG emissions from urban transport					**128.328**	**119.472**

(*) in order to avoid double counting with emissions already accounted for in the agriculture and energy sectors, only direct emissions are accounted here.[91].

91   While not accounted here to avoid double counting, "upstream" or "indirect" emissions associated to the

5.5.2 Travel Demand Management

In addition to BRT and Metro, travel demand management can reduce urban emissions significantly through public interventions; it combines a series of measures aimed at discouraging the use of private cars, while, at the same time, encouraging the use of public and mass transport systems. Traffic management measures can increase the average speed and thus reduce associated GHG emissions. For example, increasing the average hourly speed from 20 km to 25 km in large metropolitan areas can reduce emissions by 5 percent. Travel demand–management measures must be fully integrated with those that promote and enhance the quality of public and mass transport systems and the rational use of motor cars. The main measures are:

- Develop high-capacity bus and rail transport systems in high-demand corridors to improve speeds and overall traffic operations,

- Manage traffic mobility on road systems to minimize congestion,

- Design strategies that restrict use of private cars (e.g., via parking policies in downtown areas that restrict access),

- Integrate various modes of transport, and

- Integrate land-use and transport policies (reduce number and distance of trips taken).

According to the modeling, the proposed traffic management measures would further reduce urban transport emissions by 4.2 percent.[92]

Mitigation strategies based on travel demand management must consider questions of land use and occupation. Curitiba, Bogotá, and other Latin American cities illustrate the significant reductions in CO_2 emissions that can result from such integrated planning. Mixed-use development, for example, makes shops and services more accessible and thus reduces the need for short private-car trips. It also encourages more intensive use of public transport, which reduces traffic congestion and increases the viability of non-motorized transport. But for such strategies to succeed over the longer term, appropriate institutional, financial, and regulatory structures, as well as marketing and public outreach policies, must be in place.

While travel demand management reduces fuel consumption and emissions, a better flow of vehicles also runs the risk of creating more traffic resulting from previous suppressed demand, leading to a rebound in fuel consumption and emissions. Thus, demand management strategies must ensure a balance between the development of transport-services supply and trip demand management to prevent such a rebound effect.

5.5.3 Incentive Policies for Use of Non-motorized Transport

Finally, non-motorized transport—the only zero-emissions mode of transport—continues to represent many of the trips made in Brazilian cities. In São Paulo, for example, walking accounts for about one-third of all trips. Integrating safe and attractive walking infrastructure and expanded bikeway networks into public-transport policies and systems can enhance the overall urban landscape and avoid significant amounts of CO_2 emissions, estimated at about 1.6 percent of the urban-transport emissions in the reference scenario (table 5.8).

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production of the fuels and electricity used in the transport sector are calculated and presented in the special companion report on transport.

92   Over the 2010–30 period, the proposed traffic management measures would avoid about 45 Mt CO_2.
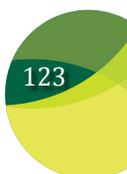
Table 5.8: Bikeway Loads and Gains in Avoided Emissions, 2010–30

Year	Load transfer to bicycle (millions of pass x km)	Avoided emissions (thousand tons CO_2/ year)	Cumulative value (thousands of US$)	
			Investment	Fuel savings
2010	88	7	14.000	136
2011	273	21	28.000	555
2012	563	42	42.000	1.418
2013	968	72	56.000	2.899
2014	1.497	110	70.000	5.187
2015	2.162	158	84.000	8.486
2016	2.973	215	98.000	13.014
2017	3.942	282	112.000	19.006
2018	5.083	360	126.000	26.714
2019	6.408	450	140.000	36.408
2020	7.932	551	154.000	48.375
2021	9.670	662	168.000	62.924
2022	11.501	777	182.000	80.188
2023	13.431	895	196.000	100.304
2024	15.464	1,015	210.000	123.402
2025	17.605	1,138	224.000	149.625
2026	19.857	1,264	238.000	179.119
2027	22.225	1,393	252.000	212.033
2028	24.715	1,525	266.000	248.513
2029	27.332	1,660	280.000	288.710
2030	30.080	1,798	294.000	332.784

Note: This potential scenario includes the construction of 8,400 km of bikeways and related facilities.

5.6 Increased Use of Bio-ethanol as a Fuel for Vehicles

All emissions from the transport sector ultimately result from the combustion of the fuel used to generate the energy for vehicle engines. Therefore, while emissions can be reduced by shifting transport modes, as described above, they can also be reduced by switching fuels used by certain modes. In the former sections, the study considered partial modal shifts from individual cars and trucks to less carbon-intensive modes. In this section, the study considers a fuel switch for remaining cars from gasoline to bio-ethanol produced from sugar cane. To the extent that the proposed measures to avoid further conversion of native forest are adopted (presented in chapters 2 and 3) and that emissions from fossil fuels, fertilizers, and sugar-cane burning are already accounted for as GHG emissions of the agricultural sector, GHG emissions associated with the use of ethanol from sugar-cane can be considered as nil since all CO_2 emitted by the engine was previously withdrawn from the atmosphere by the sugar-cane plant. Therefore, the substitution of gasoline by ethanol avoids the GHG emissions associated with the use of the gasoline substituted. This study considers an increased substitution of gasoline by bio-ethanol,

beyond the level projected in the reference scenario, as a GHG emissions mitigation option for the transport sector.[93]

Brazil already has a long tradition of substituting gasoline with ethanol. In 1975, Brazil initiated a major bio-ethanol substitution program; it culminated in the 1980s, with more than 85 percent of all new cars produced each year running exclusively on ethanol. By the early 1990s, higher sugar prices and lower oil prices meant that ethanol production was no longer cost-effective. The country faced a supply shortage, forcing customers to revert to gasoline-run cars. However, in 2003, the Brazilian car industry launched the first flex-fuel vehicle, equipped with an engine that can use any mixture of gasoline and ethanol. This innovation represented the flexibility the market needed for mitigating supply and price risks for customers. Since then, the number of flex-fuel vehicles has grown rapidly and now totals more than 8 million; in June 2009, 89 percent of all new vehicles produced in Brazil were flex-fuel (figure 5.6).

Two main parameters determine the substitution of gasoline by ethanol as a fuel for individual cars: (i) the share of flex-fuel vehicles in the national fleet and (ii) the relative price of ethanol compared to gasoline for the final customer. Regarding the share of flex-fuel vehicles, projections of the size and distribution of the fleet per type of engine were made using ANFAVEA data, macroeconomic PNE 2030 assumptions, and the "Winfrey-3 curve" to phase out old vehicles. Since the share of flex-fuel vehicles already grows rapidly in the reference scenario—from 29 percent in 2010 to 92 percent in 2030—the same projection also applies for any low-carbon scenario (table 5.9).

Figure 5.8: Evolution of Individual Vehicle Sales by Engine Type, 1979–2007 (showing number of cars sold per year)
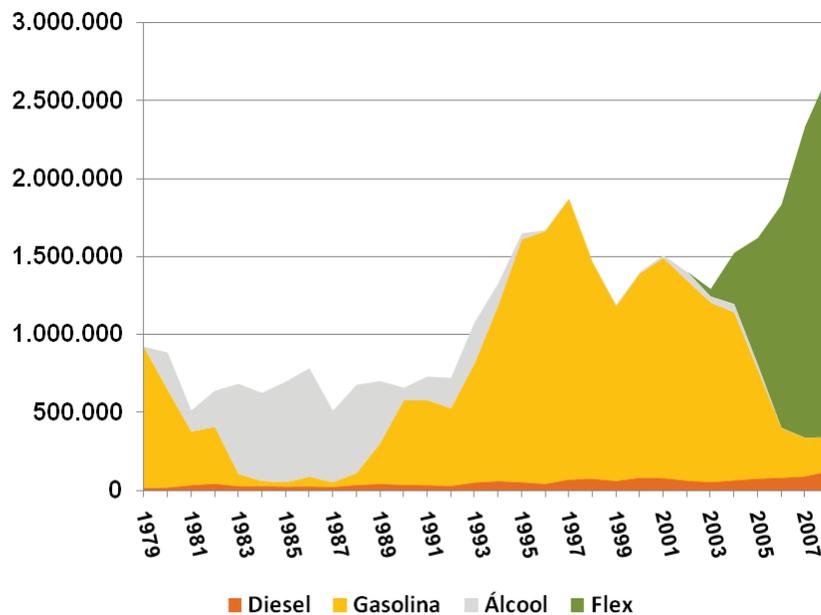
Source: ANFAVEA.

93 Although emission reductions can also be achieved by substituting petro-diesel by bio-diesel, this study did not consider any further substitution other than the one already projected under the PNE 2030 used for both the reference and low-carbon scenarios.

Table 5.9: Composition of Fleet of Individual Cars for Passengers by Engine Type, 2010–30

Year	Share of national fleet (%)		
	Flex-fuel	Pure ethanol	Gasoline
2010	29	6	65
2015	43	5	53
2020	57	3	39
2025	74	2	25
2030	92	1	8

Source: ANFAVEA, PNE 2030, and Processing LOGIT (2009).

At the customer level, the relative prices of ethanol and gasoline are highly sensitive to the fuel transport cost and therefore to the location of customers. Because it has a lower per-liter energy content than gasoline, ethanol is considered more attractive if its price is less than 70 percent that of gasoline. According to Brazil's National Agency of Petroleum, Natural Gas, and Biofuels (ANP), in 2009, ethanol was more attractive than gasoline for customers in 17 states, less attractive in 5 states, and equivalent in another 5. Relative price was the lowest in the state of São Paulo (53.4 percent) and highest in the state of Roraima (80.25 percent).

In the reference scenario, the rate of substitution of gasoline by ethanol is expected to grow from 40 percent in 2010 to 60 percent in 2030. Thus, it should be stressed that the reference scenario already has a low-carbon content when compared to international standards. If a zero-substitution rate were adopted, the study team calculated that the GHG emissions from the transport sector would increase 28 percent compared to the reference scenario over the 2010–30 period.

However, the substitution rate can be further increased compared to the reference scenario by adopting a policy that ensures the price of ethanol remains attractive for more customers over the period considered. Based on Brazil's long experience and other international experience, four main instruments can be used to sustain the attractiveness of ethanol for the car end-user:[94]

- *Financial incentive*: tax abatement and special loan conditions for vehicle purchase;

- *Regulatory standards*: mandatory minimum level of renewable fuels, emission standards, and energy-efficiency standards;

- *Taxation*: higher tax rate on fossil fuels; and

- *R&D*: incentive for developing more efficient use of alternative fuels.

Assuming that an appropriate pricing policy can be sustained to ensure the attractiveness of ethanol versus gasoline, the rate of gasoline substitution by ethanol could then increase from 40 percent in 2010 to 79 percent in 2030. As a result, emissions would be lowered an additional 12% percent in 2030 or 28.7 Mt CO_2e in absolute terms. Cumulative emission reductions achieved through gasoline substitution by bio-ethanol would total 176 Mt CO_2e over the 2010–30 period.

5.7 Aggregate Results: Low-carbon Scenario for the Transport Sector

The low-carbon scenario for the transport sector is built by combining the mitigation options proposed for regional and urban transport. Emission reductions are achieved by shifting part

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94   These instruments are consistent with the Petroleum Law (*Lei do Petroleo*, no. 9.478/97).

of the freight load and passenger trips from carbon-intensive to low- or zero-carbon transport modes (figure 5.7, 5.8; respectively). The most significant modal shifts are from truck to rail (freight transport) and from use of private vehicles to BRT and Metro, along with measures for travel demand management (passenger transport).

Figure 5.9: Comparison of Modal Distribution of Freight Load, 2008–30

Reference Scenario   **Low-carbon Scenario**
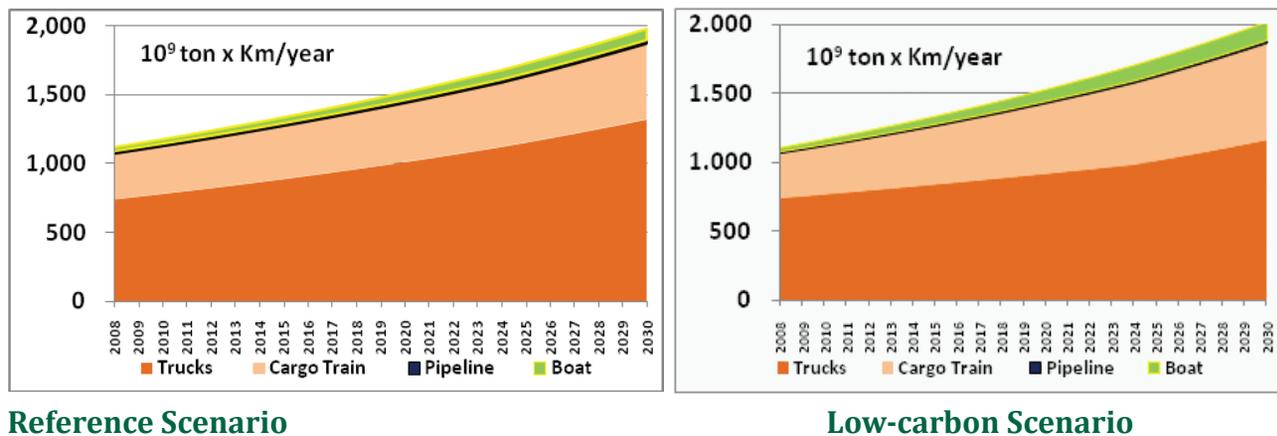
Figure 5.10: Comparison of Modal Distribution of Passenger Load, 2008–30

Reference Scenario   *Low-carbon Scenario*
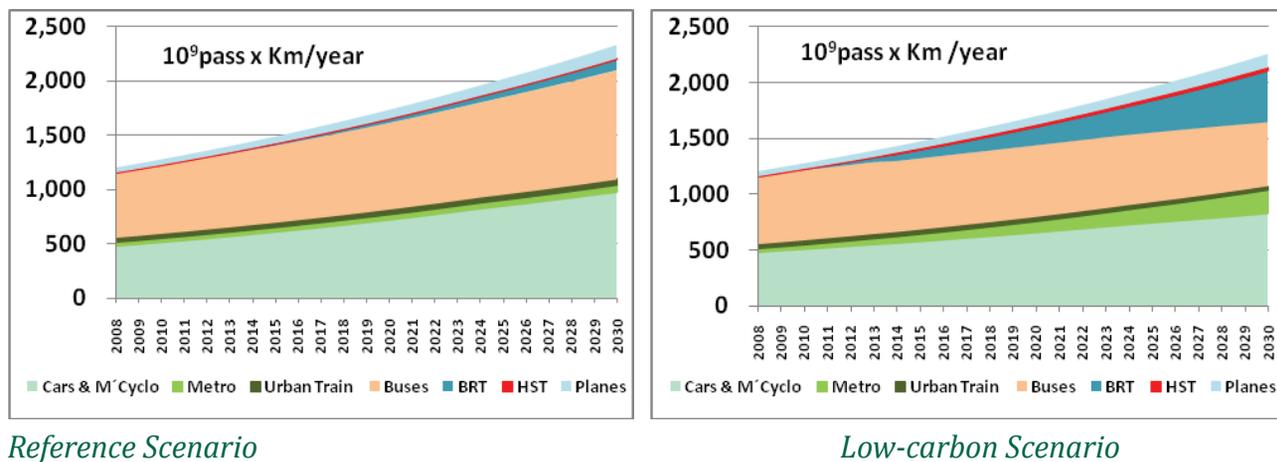
These modal shifts reflect an important emissions reduction, totaling about 7.3 percent over the study period or 302 Mt CO_2e. However, an other significant mitigation potential of around 4.3 percent could be harvested over the same period by increasing the use of ethanol, and another 1.5 percent by managing the demand for trips (figure 5.9). In this way, emissions would be reduced more than 13 percent.

Brazil Low-carbon Country Case Study
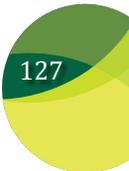
Figure 5.11 Emissions-reduction Potential in the Transport Sector, 2008–30
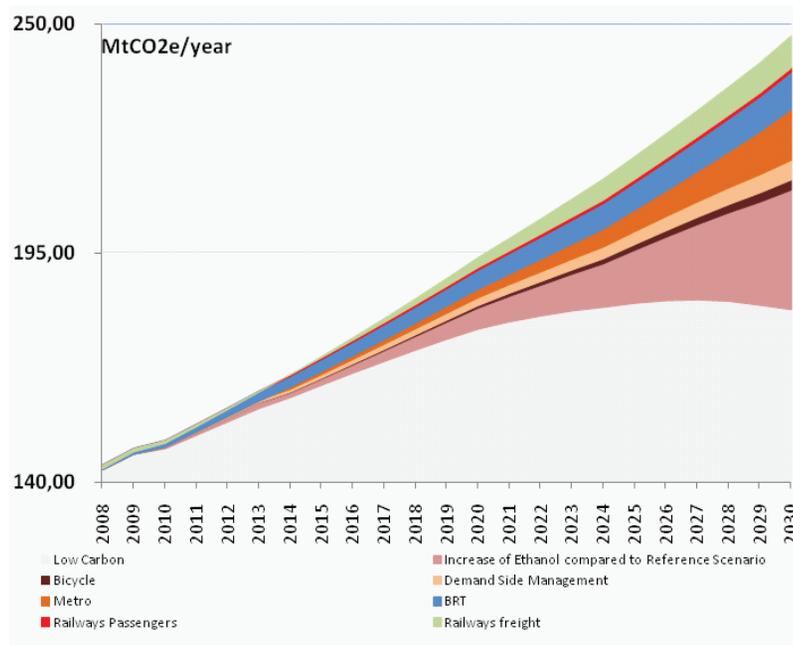
*Figure 5.12 Comparison of Emissions in Reference,
Low-carbon, and "Fossil-fuel" Scenarios, 2008–30*
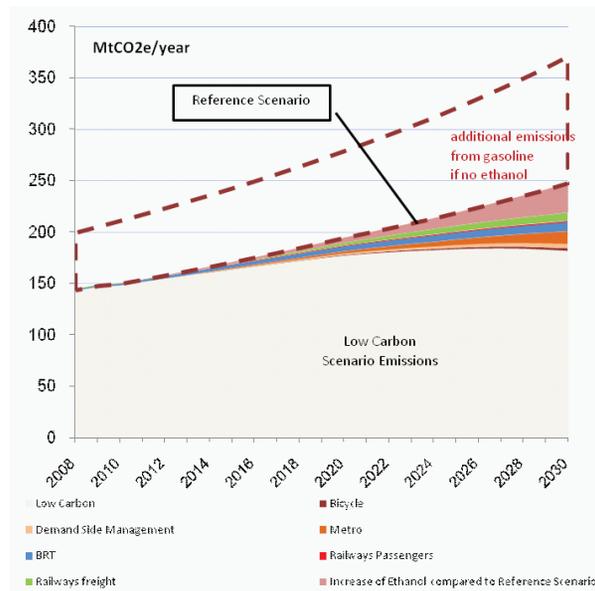
As result, the increase in sector emissions would be reduced from 60 percent in the reference scenario to only 18% in the low-carbon scenario. That is, from 247 in the reference scenario to 182 Mt CO_2 per year in the low-carbon scenario in 2030, compared to 154 Mt CO_2 in 2010, thereby avoiding a total of 487 Mt CO_2e, or 23 Mt CO_2e per year on average (table 5.10).

The potential for emissions reduction appears limited, given that biofuels, which are low carbon, play a large role in the reference scenario. For this reason, the study simulated the sector emissions that would result if biofuels were substituted by fossil fuels (mainly gasoline). In that case, reference-scenario emissions would be inflated by 50 percent in 2030 (45 percent in cumulative terms over the 2010–30 period), growing from 143 Mt CO_2 in 2008 to 371 Mt CO_2 per year in 2030. By comparison, emissions in the low-carbon scenario would be 51 percent lower in 2030 than in the "fossil-fuel" scenario (26% lower versus the reference scenario) (figure 5.10) and 39 percent in cumulative terms over the 2010-30 period, that is 1.65 Gt CO_2e less over the study period.

Table 5.10: Transport-sector Load and GHG Emissions in the Reference and Low-carbon Scenarios

Load type	Transport mode	Vehicle type	Fuel type	Load (Mt * km or pass * km/year)		Global CO$_2$ emissions (Mt CO$_2$e)		
				Reference scenario 2030	Low-carbon scenario 2030	Reference scenario 2030	Low-carbon scenario 2030	Avoided emissions 2010–2030
Urban freight	Road	Truck	Diesel	49,151	49,151	7.6	7.6	0.0
	Total urban freight			**49,151**	**49,151**	**7.6**	**7.6**	**0.0**
Urban passengers	Road	Bus	Diesel	730,799	308,538	43.1	17.5	215.5
		BRT		102,332	465,301	2.1	9.6	-72.3
		Car	Ethanol	364,894	446,579	-	-	0
		Car and motorbike	Gasoline	347,346	136,404	66.16	27.26	265.4
	Rail	Metro	Electric-ity	55,385	211,262	0.0	0.0	0.0
		Train		50,699	25,129	0.0	0.0	0.0
	Total urban passengers			**1,651,455**	**1,593,213**	**111.42**	**54.59**	**408.6**
GHG emissions from urban transport					-	**119.01**	**62.18**	**408.6**
Regional freight	Rail	Train	Diesel	552,364	703,854	6.6	8.3	-25.4
	Waterway	Boat		81,349	133,503	0.5	0.9	-4.5
	Pipeline	Pipeline		24,727	26,621	0.1	0.1	-0.1
	Road	Truck		1,274,440	1,113,926	77.3	65.6	115.1
	Total freight			**1,932,880**	**1,977,904**	**84.5**	**74.9**	**85.1**
Regional passengers	Road	Car	Ethanol	176,485	213,72	0.0	0.0	0
		Car and motorbike	Gasoline	97,031	37,781	5.23	2.44	19.9
		Bus	Diesel	276,915	266,675	7.3	6.8	2.9
	Air	Plane	Aviation kerosene	127,569	121641	28.7	28.0	8.3
	Train	TAV	Eletricity	-	21,092	0.0	0.0	0
	Total regional passenger			**678,001**	**660,909**	**41.23**	**37.25**	**31.0**
GHG Emissions from regional transport					-	**125.76**	**112.12**	**116.0**
TOTAL TRANSPORT-SECTOR EMISSIONS						**244.77**	**174.29**	**524.6**
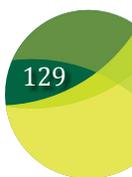
Implementing the proposed low-carbon scenario triggers two main challenges: (i) coordination and (ii) mobilization of additional financing. Because of the broad spectrum of public and private actors involved, harmonization of the many diverse initiatives represented requires federal government coordination. Furthermore, existing funding mechanisms may need to be supplemented by additional sources of financing to leverage the large volume of investment required by such capital-intensive infrastructure.

Improved coordination is needed for both urban and regional transport. For example, the Ministry of Cities could offer municipalities, which manage their own transport systems, incentives to adhere to broader mass-transport plans under the National Mobility Plan (PlanMob). For regional transport, the Ministry of Transport (MT), under the PNLT, could facilitate the integrated development of new infrastructure and transport-services concessions.

Chapter 6
Waste Sector: Reference and Low-carbon Scenarios

Waste treatment produces large quantities of greenhouse gases (GHGs), principally methane (CH_4), resulting from the anaerobic digestion of organic waste material. The incineration of solid waste also results in the release of carbon dioxide (CO_2) and nitrous dioxide (N_2O). In Brazil, waste treatment contributes 6.1 percent of CH_4 emissions and 3.8 percent of N_2O emissions.[95]

6.1 Method Overview

To estimate future GHG emissions from waste treatment, this study applied the method of the Intergovernmental Panel on Climate Change (IPCC 2000). The IPCC method was used to calculate both incineration emissions and landfill gas (CH_4) emissions (box 6.1, 6.2). The method distinguishes waste disposal and treatment categories according to the physical nature of the waste responsible for generating GHGs (i.e., solid waste or effluent). To calculate the potential for reducing future waste-sector emissions, a reference scenario was prepared to project the main variables for estimating emissions produced by various types of solid-waste and effluent treatment.

In the reference scenario, the key factors responsible for generating GHGs were climate, urban population growth, variations in the quantities of waste generated per inhabitant, and differences in waste composition (organic generating materials, potential CH_4 generators, and fossil materials). It is noteworthy that more heavily populated cities accounted for higher per capita waste output.

The study then explored the methods and technical possibilities for reducing GHG emissions. In addition, it identified the main barriers to adopting these mitigation options in the reference scenario and possible measures for overcoming them. Finally, the study prepared a low-carbon scenario for the waste sector based on the alternatives for mitigating GHG emissions.

The study scrutinized Brazil's current sanitation policies and consulted with various institutions responsible for defining and applying waste management policies at the federal level. The Ministry of Cities, Ministry of Environment, and Ministry of Science and Technology were approached with a view of obtaining the largest possible amount of data and other relevant information to assist in defining the low-carbon reference scenario for the year 2030.

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95   See Brazilian First National Communication, November 2004.

Box 6.1: Calculating Incineration Emissions

This study used the IPCC (2000) method to calculate incineration emissions. This method estimates the mass of carbon dioxide (CO2) and nitrous oxide (N2O) generated each year from the various types of incinerated waste. It also estimates the carbon contained in each type of waste, the fraction of fossil carbon in this waste, the combustion efficiency of the incinerators, and the N2O emissions factor. The following equations were used.

$$Q_{CO_2} = \sum_i (IW_i . CCW_i . FCF_i . EF_i \, 44/12)$$

$$Q_{CO_2} = \sum_i (IW_i . CCW_i . FCF_i . EF_i \, 44/12)$$

Equation 1: Estimate of CO_2 produced by solid waste incineration

where:

$Q_{CO_2} \; Q_{CO_2}$ = *Amount of CO_2 generated per year [$GgCO_2/yr$]*

i	=	*RSU: domestic solid waste*
		HW: hazardous waste
		CW: clinical waste
		SS: wastewater sludge
IW	= *mass of incinerated waste by type i*	*[Gg/yr]*
CCW	= *carbon in waste type i*	*[dimensionless]*
FCF	= *fraction of fossil carbon in waste type i*	*[dimensionless]*
EF	= *combustion efficiency of incinerators for waste type i*	*[dimensionless]*
44/12	= *conversion of C to CO_2*	*[dimensionless]*

$$Q_{N_2O} = \sum_i (IW_i . EF_i).10^{-6}$$

$$Q_{N_2O} = \sum_i (IW_i . EF_i).10^{-6}$$

Equation 1: Estimate of N_2O produced by solid waste incineration

where:

$Q_{N_2O} \; Q_{N_2O}$ = *Amount of N_2O generated per year [GgN_2O/yr]*

i	=	*RSU: domestic solid waste*
		HW: hazardous waste
		CW: clinical waste
		SS: wastewater sludge
IW	= *mass of incinerated waste by type i*	*[Gg/yr]*
EF	= *emission factor i*	*[kgN_2O/Gg]*

Future GHG emissions in the solid-waste management sector depend on the types of waste treatment applied and the types of emissions resulting from the modus operandi of these treatments. To construct the reference scenario, the study (i) inventoried the various types of waste treatment, (ii) surveyed the evolving roles of each treatment method, and (iii) estimated the corresponding emissions generated.

6.1.1 Waste Management Methods in the Reference Scenario

In accordance with the IPCC (2000) method, the study examined a variety of possible solid-waste management methods (figure 6.1).

Figure 6.1: GHG Sources Resulting from Solid-waste Disposal and Treatment

```
                          ┌─────────┐
                          │   RSU   │
                          └────┬────┘
                               │        ┌──────────────┐
                               ├────────│  Reduction   │
                               │        └──────────────┘
                               │        ┌──────────────┐
                               ├────────│  Recycling   │
                               │        └──────────────┘
         ┌─────────────┬───────┴───────┬─────────────┐
  ┌──────────────┐ ┌──────────────┐ ┌──────────────┐ ┌──────────────┐
  │ Incineration │ │   Sanitary   │ │  Composting  │ │ Not collected│
  │              │ │   landfill   │ │              │ │              │
  └──────────────┘ └──────────────┘ └──────────────┘ └──────────────┘
  Produces fossil   Produces CH₄    No emissions     No method
  CO₂ and N₂O                                        involved
```
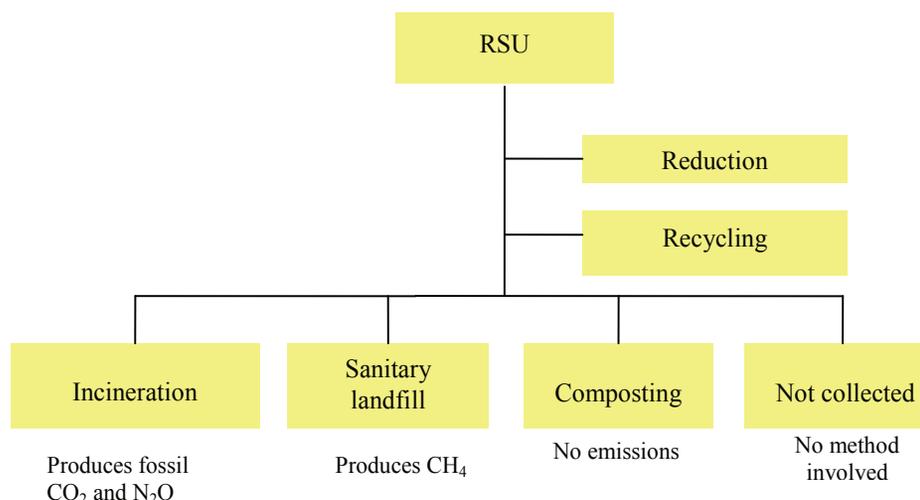
6.1.1.a Sanitary Landfills

Disposal sites for urban solid waste can be classified as sanitary landfillsand unmanaged landfills with a depth of more or less than 5 m. At such sites, the organic matter contained in the waste releases CH_4 for periods of 30–50 years; thus, familiarity with the disposal record of the particular landfill site is needed in order to estimate future emissions. It is noteworthy that improvement in disposal site operations can bring about an increased generation of GHGs. According to the IPCC (2000), the concentration of GHGs generated by the same quantity of waste in a sanitary landfill site would be reduced by 80 percent for an unmanaged landfill of 5-m depth and by 40 percent for one of less than 5-m depth.

The treatment of solid waste in sanitary landfills is based on the anaerobic (absence of oxygen) digestion of the organic waste material by bacterial action until it is stabilized or rendered inert. Biogas, a product of this anaerobic digestion process, is a mixture of gases, principally methane (CH_4), carbonic gas (CO_2), hydrogen (H_2), and sulphuric acid (H_2S); CH_4 represents an average of 50–90 percent of the total volume of this mixture, while CO_2 accounts for 5–10 percent. The composition of biogas is similar to that of natural combustible gas and can be used as a valuable alternative for producing energy (Alves 2000). In Brazil, few landfills use biogas for burning or energy generation; rather, it is common practice to allow the gas to escape directly into the atmosphere through the collector drains.

6.1.1.b Composting

Composting is an aerobic (presence of oxygen) process that removes the organic material from the landfill to produce high-quality organic compost. No GHGs are produced, and generation of CH_4 emissions is thus avoided. While composting is not included in the methods for estimating emissions, wider use of this practice could result in potential reductions in the quantities of waste for dumping in landfills.

6.1.1.c Incineration

Incineration is a treatment method based on thermal decomposition through oxidation that

makes the waste less bulky, less toxic, atoxic, or, in certain cases, eliminates it altogether (CETESB 1993). Waste treatment via incineration requires the use of systems to treat polluting gases generated by the combustion process of certain components of the solid waste. In the majority of cases, fabric or electrostatic filters are used.

In Brazil, the level of waste treatment via incineration is insignificant. The waste burning that does occur may or may not be accompanied by the use of heat recovery and electricity-generation technologies.

6.1.1.d Recycling

Reducing overall waste, reusing and recycling waste, and modifying patterns of consumption can contribute significantly to reducing the need for energy inputs, raw materials, and natural resources.

6.1.2 Projecting Solid-waste Volume in the Reference Scenario

To construct the reference scenario, it was necessary to project waste production, the evolution of its characteristics, and how it might mirror the various waste-management modalities. Using the above-mentioned methods, it was possible to calculate the emissions arising from the mix of modalities defined in this scenario.

The study applied the 2030 National Energy Plan (PNE 2030) to estimate future waste volume. In addition to population trends, projected waste volume depends on the per capita rate of waste generated by the population. Therefore, the study also used per capita generation data obtained from the CETESB (1998) and ABRELPE (2008), which focused on the 1970–2005 period; data for subsequent years were estimated using the continuing growth rate of the urban population and per capita waste generation.

Encouraging the reduction of "at-source" waste generation through environmental education programs, waste-generator pay charges, and recycling schemes could reduce overall waste generation by 10 percent or more. Commercial waste generators would have an economic incentive to reduce discarded waste when having to pay directly for waste collection. However, improving waste-collection services could result in an increase of up to 15 percent of the quantity of waste collected (currently 85 percent of urban waste is collected). Additional factors that could contribute to increasing the amount of waste collected are rising personal incomes and higher consumption patterns (figure 6.2).

Figure 6.2: Evolution of Waste Collection: Simulation Results, 1970–2030
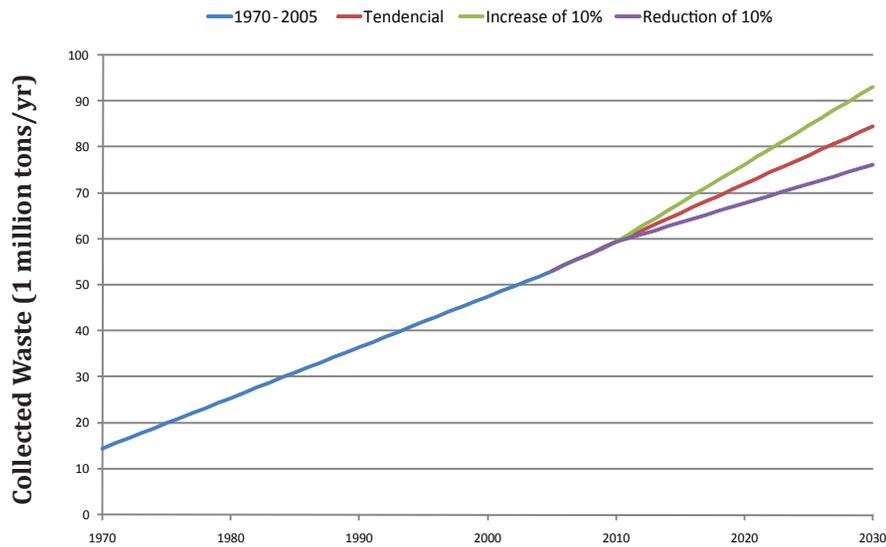
In the case of sanitary landfills, GHG emissions depend on the potential of the particular waste type to generate CH_4. To determine the potential of solid-waste landfills to generate CH_4, the study used a sample consisting of 95 analyses of types of waste collected in 47 municipal areas between 1970 and 2005. This data was used to prepare estimates of the behavioral variation of the waste over a period of time. The reference scenario is represented by the continuing reduction of this potential observed between 1970 and 2005. Scaling up the factors that produced this reduction could result in a reduction of about 10–20 percent (figure 6.3).

Figure 6.3 Potential Methane Generation, 1970–2030
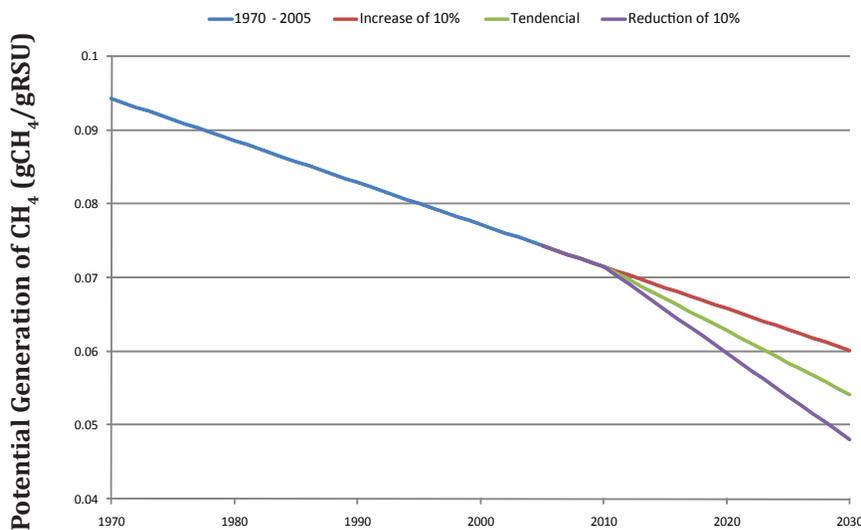
Waste emissions, moreover, depend on the characteristics of the disposal site. This study encompassed four site categories, in ascending order of quality: (i) unclassified garbage dump, (ii) unmanaged landfill less than 5 m deep, (iii) unmanaged landfill more than 5 m deep, and (iv) sanitary landfill. More CH_4 is emitted from the same quantity of garbage on better-managed sites, indicating that the burning of CH_4 is an essential ingredient for avoiding GHG emissions.

In the reference scenario, it was assumed that municipalities with fewer than 200,000 inhabitants in 2030 would continue to have unmanaged waste disposal sites of less than 5-m depth. For municipalities with more than 200,000 inhabitants in 2030, it was assumed that they would have evolved from "worst baseline condition" in 1970 to "intermediate status" in 1990, and, from 2010 on, would possess a sanitary landfill.

The future timeframe was defined by simply continuing the trends observed in the past. Higher concentrations of fossil carbon fractions can be verified as a result of the intensification of current practices involving packaging, logistics of food and beverages distribution, and price reductions affecting consumer goods produced by the petrochemical industry.

The same data was used to determine the fossil carbon fraction of the waste for 1970–2005. This fraction is particularly important for calculating the GHG emissions released via incineration since only the emissions resulting from burning the fossil portion contribute to increasing atmospheric concentrations of GHGs.

6.1.3 Estimating Solid-waste Emissions in the Reference Scenario

In the reference scenario, it was assumed that present waste-handling methods would continue. These consist of disposing waste in landfills, with no alteration in the role of other technologies, which are currently insignificant (and remain so in this scenario). As explained below, there are many barriers to implementing changes to improve Brazil's current waste-disposal situation, particularly in light of their costs and the need for introducing a broad-based, waste-separation-at-source education program.

GHG emissions of the corresponding reference scenario, expressed in terms of CO_2e per year, signify a continuation of current practices, enhanced by ongoing population growth, a persistent rise in the rate of waste generation, and evolution of waste composition. In this scenario, CH_4 emissions increase from 55 Mt CO_2e in 2010 to more than 74 Mt CO_2e by 2030 (figure 6.4).

Figure 6.4 Reference Scenario for the Waste Sector, 2010–30
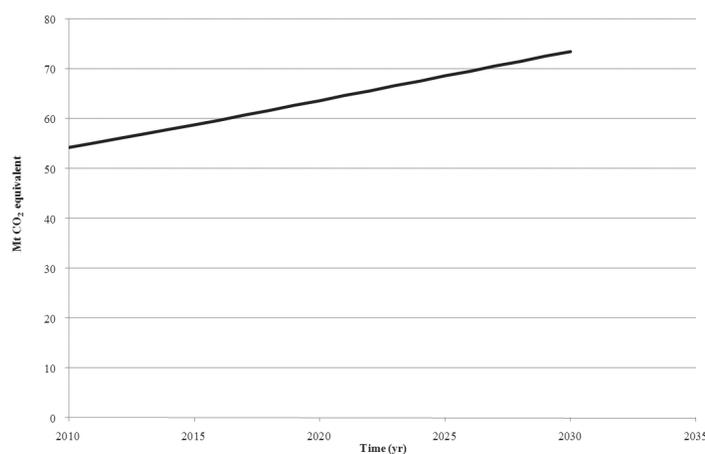
The study also calculated the amount and percentage distribution of urban waste-management services for the reference scenario over the 2010–30 period (figure 6.5,). An average rate of 15 percent was assumed for uncollected waste.

*Figure 6.5: Distribution of Solid-waste Management Services
and Treatment in the Reference Scenario, 2010–30*

■ **Uncollected** ■ **Landfills open air** ■ **Landfills without Gas Recapture**
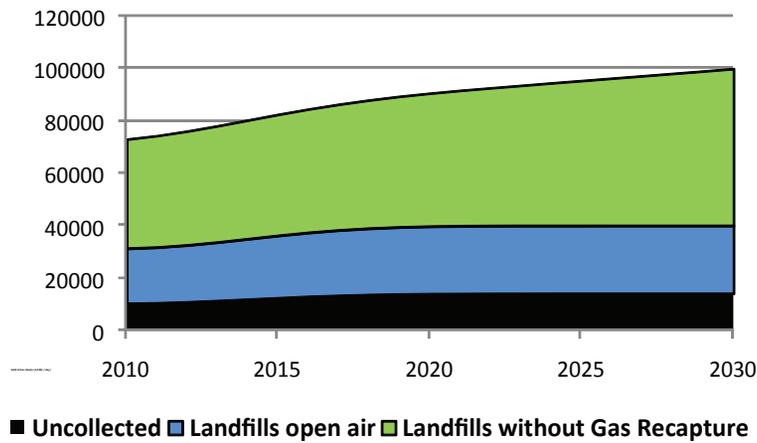
6.2 Reference Scenario for Liquid Effluents

In the effluent management sector, future GHG emissions depend on the treatment types to be used and the emissions resulting from their modus operandi. Construction of this reference scenario involved an initial survey of the treatment types used, a follow-up review of the evolution of their use, and an estimate of the emissions linked to such treatments.

6.2.1 Methods for Managing Liquid Effluents in the Reference Scenario

Potential ways to manage effluents, in accordance with the IPCC (2000) method, are described below (figure 6.6, box 6.2).

Figure 6.6: Sources of GHG Emissions from Effluent Treatment
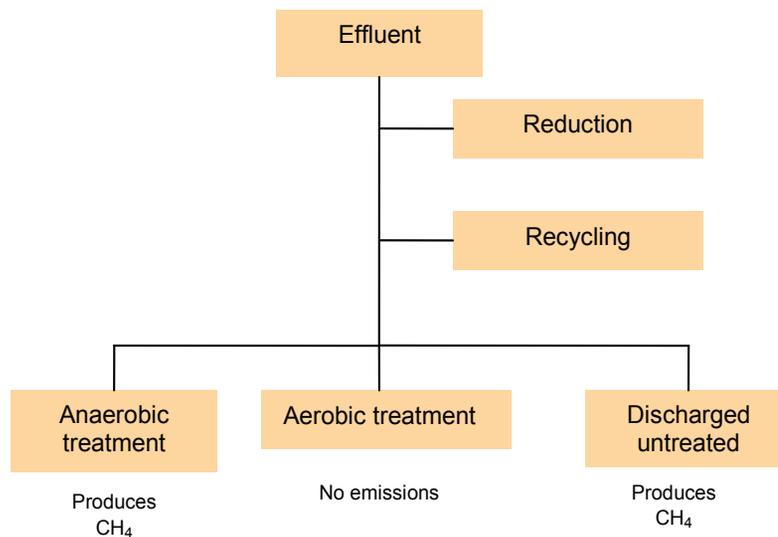
Box 6.2: Calculating Emissions from Various Forms of Effluent Treatment

The reference scenario includes an estimate of CH_4 emissions from the anaerobic degradation of organic loads that occur in sewage treatment plants (ETE) using either anaerobic reactor and stabilization lagoon processes or both aerobic and anaerobic processes, including anaerobic sludge digestion. The emissions generated via anaerobic degradation of organic loads occurring in seas, rivers, and lakes—as well as processes identified as on-site treatment, such as pit latrines and septic tanks—were not estimated.

The equations used to estimate GHG emissions, adopted from the IPCC (2000), are as follows:

$Emissions = TOW . EF –R$

Equation 1: Estimate of CH_4 emissions resulting from anaerobic treatment of sewage and effluents

where:

Emissions	= amount of CH_4 generated per year	[GgCH₄/yr]
TOW	= total organic sewage or effluent	[kgDBO yr]
TOW_dom	= total organic domestic sewage	[kgDBO/yr]
TOW_ind	= total organic industrial sewage	[kgDBO/yr]

$TOW_{dom} = P.D_{dom}$

Equation 2: Estimate of total organic sewage and effluents

where:

P	= population \\\\	[1.000 persons]
D_dom	= organic degradable component of domestic sewage	[kgDBO/1.000 persons. yr]

$TOW_{ind} = Prod.D_{ind}$

Equation 3: Estimate of total organic sewage and effluents

where:

Prod	= industrial production	[a product/ yr]
D_ind	= organic degradable component of industrial effluent	[kgDBO/a product] or

In addition, anaerobic treatment of wastewater and effluents is divided into various options (figure 6.7).

*Figure 6.7: Sources of Sewage and Effluents, Treatment Systems, and
Potential Methane Emissions*

```
                    ┌─────────────────────────────────┐
                    │ Domestic and industrial effluents│
                    └─────────────────────────────────┘
                       /                          \
              ┌───────────┐                    ┌──────────────┐
              │ Collected │                    │ Not collected│
              └───────────┘                    └──────────────┘
              /           \                      /            \
      ┌──────────┐   ┌─────────┐      ┌──────────────┐  ┌──────────┐
      │ Untreated│   │ Treated │      │On-site       │  │ Untreated│
      └──────────┘   └─────────┘      │treatment,    │  └──────────┘
           │              │           │latrine, and  │    /        \
   ┌──────────────┐   ┌──────┐  ┌──────────┐ │septic tank│
   │Dumped in     │   │ ETE  │→ │Stagnated │ └──────────────┘
   │lakes, rivers,│   └──────┘  │in network│  ┌───────────┐ ┌──────────┐
   │seas, and     │    /    \   └──────────┘  │Surface    │ │Dumped in │
   │ocean         │ ┌──────┐ ┌──────────┐     │disposal   │ │lakes,    │
   └──────────────┘ │Aerobic│ │ Anaerobic│    └───────────┘ │rivers,   │
                    └──────┘  └──────────┘                   │seas, and │
                       │       /        \                    │ocean     │
                   ┌──────┐ ┌────────┐ ┌───────┐             └──────────┘
                   │Sludge│ │Reactor │ │Lagoon │
                   └──────┘ └────────┘ └───────┘
                    /     \
           ┌──────────┐ ┌──────────┐
           │Anaerobic │ │Spread on │
           │digestion │ │surface   │
           └──────────┘ └──────────┘
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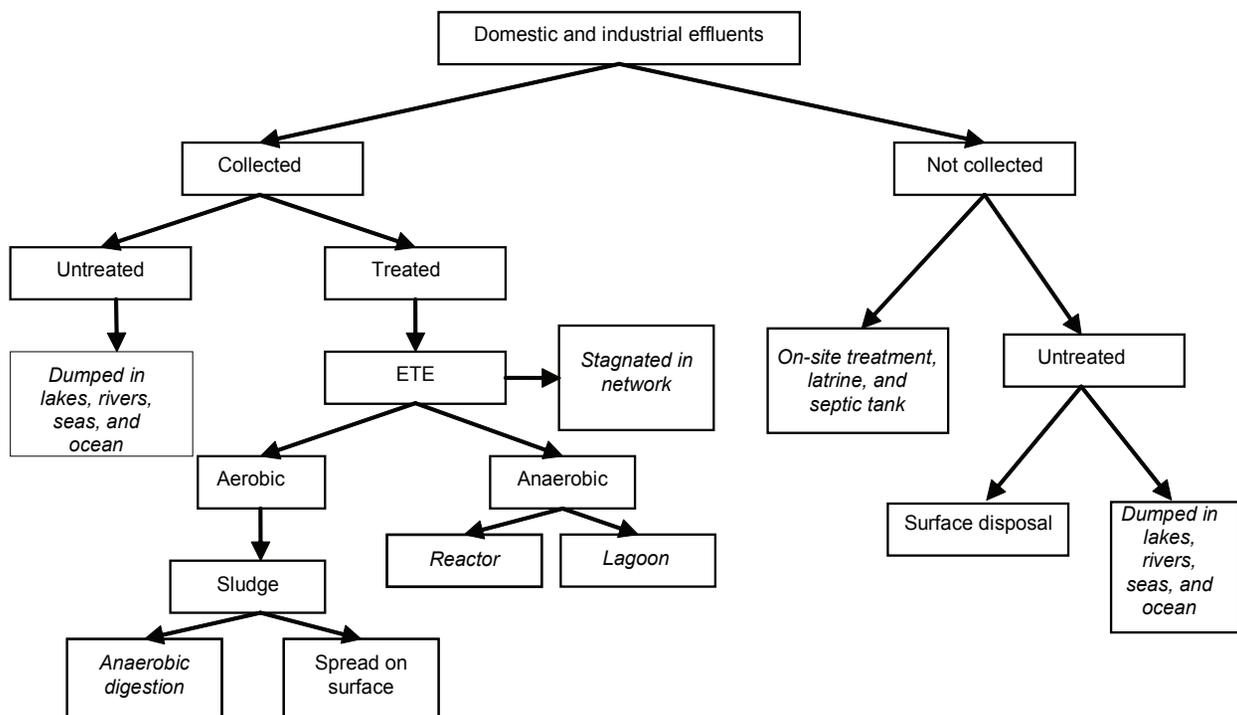
6.2.2 Liquid Effluents Projected in the Reference Scenario

To construct the reference scenario, it was also necessary to project the production of liquid effluents, the evolution of their characteristics, and their representation of the various waste-management modalities. Using the above-mentioned methods, it was then possible to calculate the emissions arising from the mix of modalities defined in this scenario.

The projection of effluent mass depends on population development and the rate of organic load generation per capita (based on this population), which remains constant over time. This study adopted the population development trends of the PNE 2030.

Scenarios were developed for treatment of (i) domestic effluents and (ii) commercial and industrial effluents. The reference scenario reflects the implementation of the Government's Basic Sanitation Plan[96] which foresees the universalization of collection and treatment services by 2030. Approximatley 33% of the residential and commercial effluents would be reduced through an aerobic process, while the remainder through anaerobic reactors, with the final sludge being sent to landfills for final disposal. Currently, there are many barriers to reaching universalization, particularly with regard to the costs of establishing and operating sewage services and wastewater treatment systems.

Current collection rates for domestic effluents are about 50 percent, while indexes of treatment are low (about 10 percent) (figure 6.8).

In the case of industrial effluents, organic composition varies considerably, depending on the

industrial sector. For example, such sectors as food and beverage have been burning the biogas associated with anaerobic treatment since the 1980s.

Figure 6.8: Residential and Commercial Effluents, 2010–30
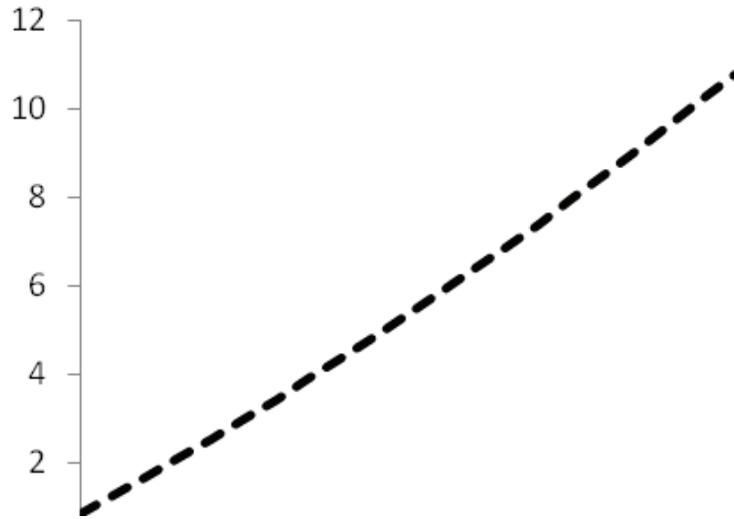
Over the 2010–30 period, GHG emissions from industrial effluents in the reference scenario, expressed in terms of CO_2e, reflect a continuation of biogas generation and burning, with treatment indexes of about 20 percent (figure 6.9).

Figure 6.9: Reference Scenario for the Industrial Effluents Sector, 2010–30 (MtCO2e/year)
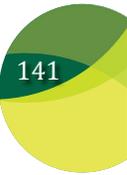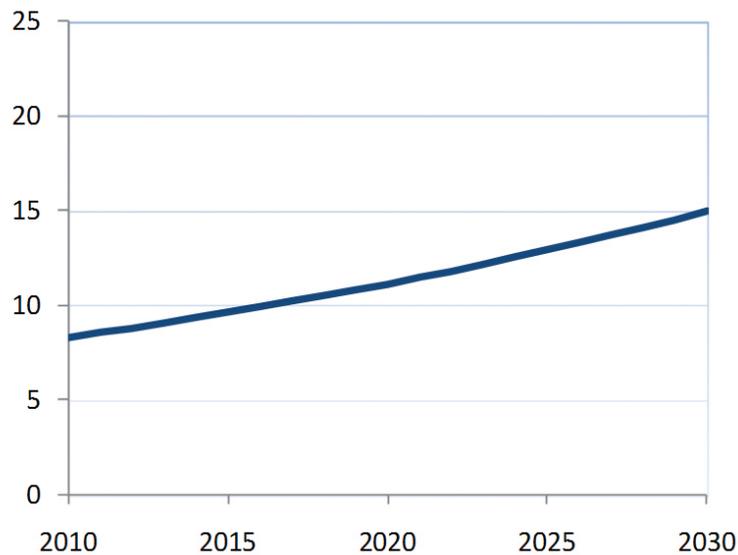
6.3 Low-carbon Scenario for the Solid-waste and Effluents Sector

The low-carbon scenario for the solid-waste and effluents sector is represented by the destruction or use of CH_4 for energy-producing purposes. In landfills, capture and burning in incinerators can lead to a 75-percent reduction in currently estimated emission levels (based on CDM projects, in the absence of national publications confirming this data). In anaerobic sewage treatment plants (ETEs), emissions can be avoided entirely.

6.3.1 Low-carbon Scenario for Solid-waste Management

In Brazil's waste sector, two imperative needs governed preparation of the low-carbon scenario: (i) improved sanitation and (ii) introduction of practices to reduce GHG emissions.[97] Practices that could lead to avoiding emissions are also desirable from the perspective of improving waste management. It is both necessary and possible to find solutions combining these two objectives.

Solid waste is not always comprehensively collected in all of Brazil's municipalities, which presents health and sanitation problems in many Brazilian cities and towns. It follows that disposing of larger quantities of waste at appropriate sites, thereby minimizing the pollution problems caused by uncollected waste, will lead to improved sanitary conditions in Brazil.

6.3.1.a Barriers and Proposals

In the reference scenario, a variety of barriers restrict the adoption of sound practices for sanitary landfills and incineration measures (table 6.1).

Table 6.1: Barriers in Sanitary Landfills and Incinerators and Suggested Mitigation

Type of mitigation measure		
Preventive	*Corrective*	*Governance*
Sanitary Landfill		
Technical-environmental		
Encourage awareness of consumption patterns and the need to undertake reverse logistics and selective waste collection in the context of the life cycle of the entire waste-generation productive chain.	Increase selective waste collection substantially via systematic forging of partnerships with cooperatives and nongovernmental organizations over the next 20 years.	Introduce mechanisms for waiving taxes throughout the productive chain where reverse logistics and selective waste collection are practiced, especially with regard to the fossil component.

97   By contrast, the reference scenario retains a major socio-environmental liability.

Incineration

Technical-environmental

Lack of technological know-how

Encourage opinion makers and sector specialists to acquire technical know-how and information on the environmental fallout from incineration system operations.	Increase awareness-raising and training of interested parties and agents involved in the application and operation of systems; take special account of the adverse effects on public health and the environment via atmospheric emissions that release potentially toxic substances with synergic effects.	Involve environmental agencies and licensing organizations in technical aspects of the question, analyzing these from the viewpoint of sustainability in large cities and metropolitan regions.

Economic-legal

Required substantial investment

Prepare feasibility studies for appropriate treatment systems restricted to urban areas with populations of over 3 million.	Propose introduction of advanced technology in systems with similar objectives by introducing systems capable of delivering a high level of efficiency with regard to the discharge, control, and mitigation of emissions of atmospheric gases and effluents.	Expand long-term planning and project development capacity in municipalities..

Required legal mechanisms to facilitate charges/tax collection

Propose new measure and follow-up mechanism to quantify per capita waste generation.	Modify the charging and payments system for waste collection and treatment services.	Expand both public and private sector capacities/ working knowledge of existing legal structures, regulations and procedures required for access to available financing resources (i.e. within appropriate stipulated timeframes, etc.)

6.3.1.b Solid-waste Management Optimized for Reducing GHG Emissions

The low-carbon scenario for solid waste is defined by the ongoing practice of depositing waste in landfills, reducing current environmental and health problems, and introducing systems for CH_4 capture and burning. Among the mitigation or capture options, reducing the source of waste generation appears to be the most important factor in terms of sustainability. This mitigation option is certainly the most desirable, although it can be associated with various sociocultural factors that often do not depend on either environmental or technical-economic solutions. There is little doubt that this approach should be awarded priority, which

implies an educational component to bring about changes in habits and customs and a reversal of current development model paradigms.

With regard to reducing or substituting for raw materials and inputs, a key question is which technological innovations are capable of generating new products and materials originating from ethanol and other renewable sources (e.g., biomaterials, biopolymers, and bio-plastics no longer regarded as fossil waste after discard).

The question of recycling should also be considered as a key mitigation or capture option, especially when it concerns primary or secondary recycling of consumer goods and materials originating from non-renewable sources. Particular attention needs to be paid to the recycling of materials based on polymers originating from oil and gas that generate fossil waste. This category includes a variety of plastics, foams, polystyrene, automobile parts, rubber, candles, and paraphins. Recycling, as well as reducing and substituting waste considered as fossil waste, can contribute considerably to a low-carbon scenario when the treatment option is incineration or high-temperature thermal treatment or even anaerobic composting (energy-producing anaerobic biogester).

6.3.1.c Low-carbon Scenario for the Solid-waste Sector

The low-carbon scenario for the waste sector can be represented by reductions in solid waste, compared to the reference scenario (figure 6.10).

Figure 6.10: Low-carbon Scenario for Solid Waste: Burning Methane with 75-percent Collection Efficiency at Landfill Site, 2010–30
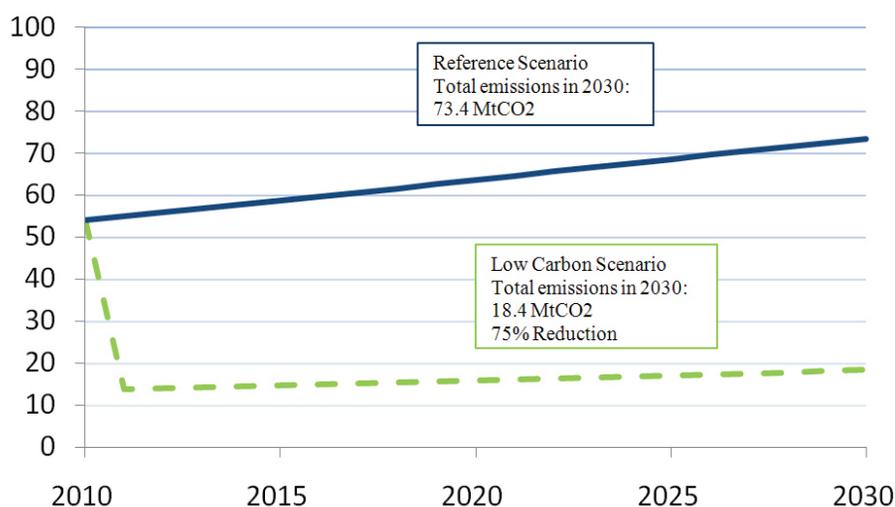
The option of burning biogas was first introduced in Brazil after the Kyoto Protocol entered into force. In April 2009, the Inter-Ministerial Commission on Global Climate Change began to examine CH_4 burning for 27 Clean Development Mechanism (CDM) projects. All other features of the reference scenario were retained, with the exception of 75 percent CH_4 destruction of total landfill collection capacity. This is a basic guideline governing CDM projects, although this information has not yet been communicated in any Brazilian publications.

As expected, in the low-carbon scenario, GHG emissions are reduced by 75 percent of the total verified (without this practice) and expand in line with population growth and other factors defined in the reference scenario; by 2030, GHGs are reduced from 73 Mt CO_2e to 18 Mt CO_2e, corresponding to 75 percent of the CH_4 burnt.

In terms of final disposal method, the low-carbon scenario for the solid-waste sector is unique. In the reference scenario, 100 percent of collected waste must be hauled to landfills. Similarly, in the proposed low-carbon scenario, all waste must be sent to landfills, but it also includes the capture and burning of CH_4. The other technologies evaluated have demonstrated less efficiency (table 6.2). Over the 2010–30 period, the daily waste generated per capita is expected to increase from about 0.95 kg to more than 1.05 kg (figure 6.11).

Table 6.2: Summary of Evolution in Waste Distribution in the Low-carbon Scenario (2010–30), by Method

Method	2010 (%)	2020 (%)	2030 (%)
Uncollected	14.3	15.6	14.3
Landfill without biogas recapture	45.5	22.4	0.0
Landfill with biogas recapture	11.4	33.6	59.8
Landfill, open-air	28.8	28.4	25.9
Total	**100**	**100**	**100**

Figure 6.11: Per-capita Waste Generated: Scenario 2010–30

Waste generated per capita
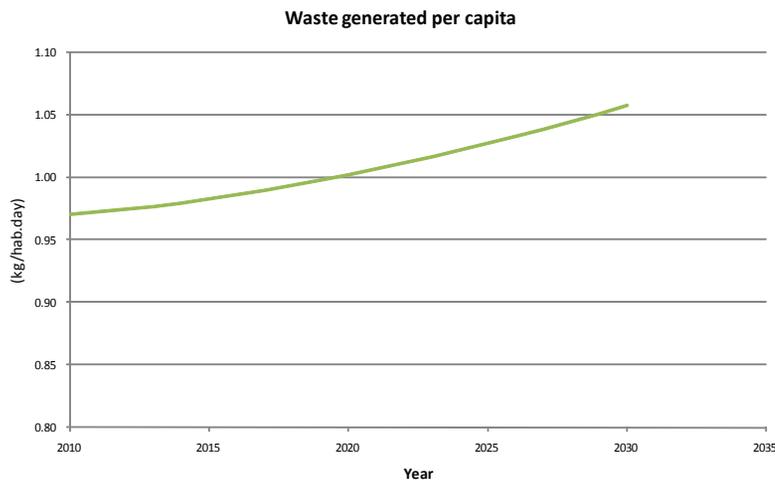
The increasing practice of biogas collection and flaring in landfills is projected to reach 100 percent by 2030. Growth is projected as linear, from 0 percent in 2010 to 100 percent by 2030 (figure 6.12).

Figure 6.12: Distribution of Waste Treatment and Services in the Low-carbon Scenario, 2010–30
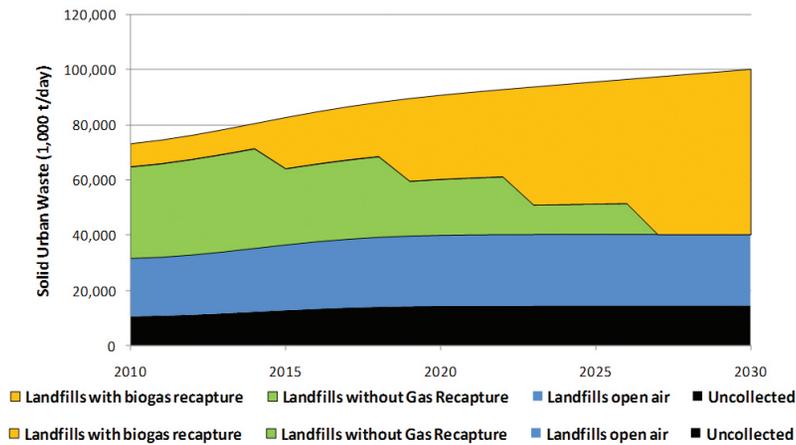
The percentage distribution of the waste treatment during 2010–30 was also estimated for the low-carbon scenario (figure 6.13).

Figure 6.13: Percentage Distribution of Waste Treatment in the Low-carbon Scenario, 2010–30
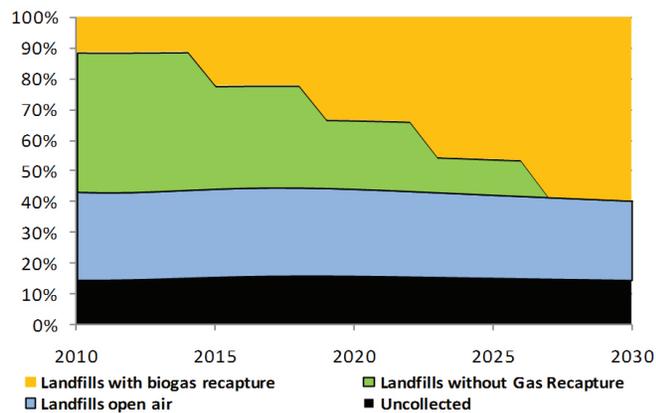
6.3.2 Low-carbon Scenario for Effluents Management

The precarious state of wastewater services and the virtual non-existence of treatment facilities are well-known features of Brazil. Raw sewage is dumped into water bodies, constituting a hazard for fishing. In turn, water used for domestic drinking supplies and agricultural purposes is contaminated, and entire urban areas located close to polluted beaches, lakes, and rivers are ruined.

Measures to expand and improve sewage treatment are needed; indeed, these constitute part of any country's development process. Employing aerobic technology can lead to increased electricity consumption and a consequent rise in the level of GHGs, as well as the wholesale generation of sludge, yet another source of GHGs (given the technology used in siting or treatment). Anaerobic technology primarily involves low energy consumption, alongside energy that can be generated from CH_4 produced in the anaerobic process. When it reaches the atmosphere, however, CH_4 can significantly increase GHG emissions. Retention, destruction, or

use of CH_4 for energy production can mitigate this serious environmental problem.

Like solid-waste management efforts, introducing practices that improve public-sanitation conditions and, at the same time, reduce GHG emissions may conflict with measures to improve public sanitation that also generate increased GHGs as a side-effect.

6.3.2.a Barriers and Proposals

In the reference scenario, the socio-environmental liability is retained for the effluents sector. Barriers limiting the adoption of sound practices in effluent treatment systems are summarized below (table 6.3).

Table 6.3: Barriers to Adopting Effluent Treatment Systems and Suggested Mitigation Measures

Barrier type	Preventive measure	Corrective measure	Governance
Technical-environmental			
Lack of technical treatment in systems for biogas collection, burning, and recovery and use in energy production.	Exchange in know-how between specialized bodies and operating systems with similar objectives (Brazilian and international companies, government agencies, and nongovernmental organizations).	Manage efficient and effective systems with a view to ensuring economic and environmental sustainability.	Propose a series of technical requirements to be followed by environmental bodies and agencies handling the execution and operation of environmental licensing procedures for systems with similar objectives.
Economic-legal			
Low investment and lack of economic resources.	Upgrade concepts related to treatment systems involving the generation of gases and develop systems for the collection, burning, recovery and use of biogas for producing energy.	Substantial and systematic increases in the value of investments over the next 20 years.	Control and enforcement regarding the acquisition and disbursement of funds within the range of existing programs and projects.
	Encourage re-use of water and use cleaner production techniques to enhance the supply capacity of water bodies.	Scale up control over water losses significantly and encourage more rational use of water to ensure its future sustainability.	Develop tax-incentive mechanisms for implementing techniques that focus on water re-use and cleaner production.

6.3.2.b Liquid Effluents Management Optimized for Reducing GHG Emissions

Among the mitigation and capture options, at-source reduction of effluents generation is the most important factor in terms of sustainability.

The aim of the proposed low-carbon scenario is to encourage the use of anaerobic technology that involves low energy consumption and the generation of CH_4, which possesses sufficient calorific power for use as a fuel to replace natural gas, gasoline, or diesel. Establishing wastewater treatment systems and reducing the organic load of effluents would help solve the serious environmental problem currently experienced by all large Brazilian cities and towns located close to areas where effluents are discharged.[98] The proposed low-carbon scenario aims to lessen this environmental problem without worsening GHG emissions, given that each sewage treatment plant (ETE) would be fitted with a system for containing and burning biogas.

The proposed low-carbon scenario in this study involves the widespread implementation of anaerobic sewage treatment systems, appropriately fitted with the respective CH_4 retention and destruction systems. Reducing current levels of GHG concentrations would go a long way toward resolving the related environmental problems currently experienced throughout Brazil (table 6.4).

Table 6.4: Evolution of Various Effluent Treatment Methods, 2008–30

Method	2008 (%)	2010 (%)	2020 (%)	2030 (%)
Anaerobic treatment	50	100	100	100
Untreated discharge	50	0	0	0
Total	**100**	**100**	**100**	**100**

6.3.2.c Low-carbon Scenario for the Effluents Sector

The respective low-carbon scenarios for domestic wastewater and industrial effluents were compared with those in the reference scenario (figures 6.14, 6.15). In the domestic wastewater low carbon scenario, there are zero emissions, as 100% of the biogas is burnt while service is universally provided.

Figure 6.14: Comparison of Low-carbon and Reference Scenarios for Domestic Wastewater, 2010–30 (100% of biogas is burnt)

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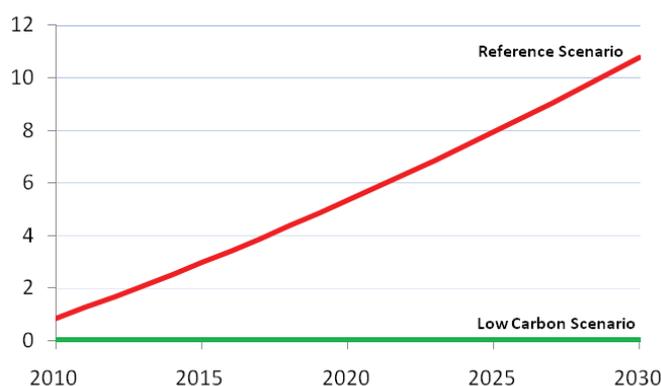
98   Examples include cities that use water from the polluted Tietê River in São Paulo or the cities around the Bay of Guanabara in Rio de Janeiro.

Figure 6.15: Comparison of Low-carbon and Reference Scenarios for Industrial Effluents, 2010–30 (100% of biogas is burnt from 2010 on)
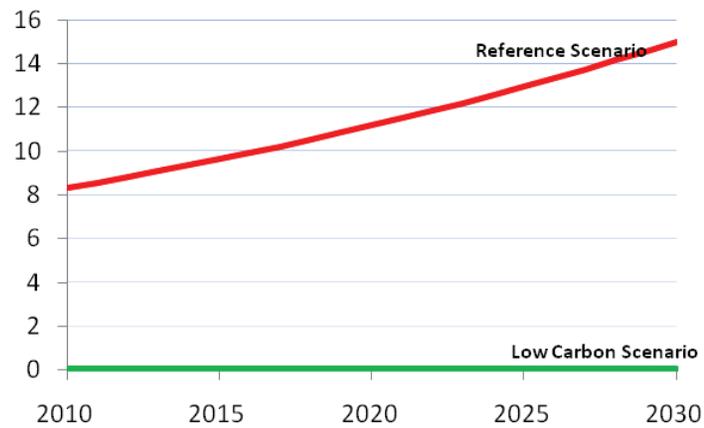
Projected Emissions in the Low-carbon Scenario

The low-carbon scenario for waste management demonstrates the possibility of avoiding emissions to levels 80 percent lower than what are projected in the reference scenario by 2030. In that year, emissions in the reference scenario are expected to reach 99 Mt CO_2e and to fall to 18 tCO_2e in the low-carbon scenario, for a cumulative total of avoided emissions of 963 Mt CO_2e (figure 6.16).

Figure 6.16: Comparison of Reference and Low-carbon Emissions Scenarios, 2010–30
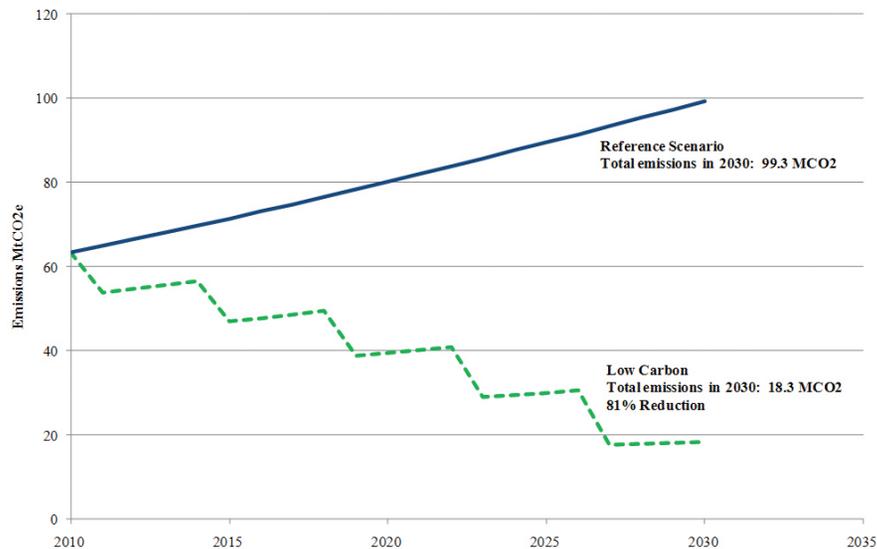
The activity with the most significant avoided emissions is the burning of CH_4 generated by sanitary landfills.
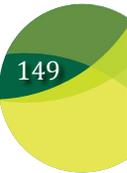
6.4 Conclusion

This significant reduction would occur primarily through the burning of CH_4 generated in controlled sanitary landfills. Meanwhile, associated emissions related to effluents reaching 25 Mt CO_2e by could be reduced to zero through sewage treatment and the capture and burning of the CH_4 generated. Although not considered in this study, methods to decrease waste production (e.g., alterations in disposable packaging, waste disposal, and recycling), are also recommended since waste-sector emissions are directly linked to the quantity of waste and effluents generated.

As a result, over the next 20 years, Brazil would require significant investments in its waste collection and treatment infrastructures. An estimate of these investments is presented in chapter 9 (section 905). It should be noted, however, that the priority of these investments is improvement of sanitary conditions, while at the same time contributing to the avoidance of emissions. Thus, the co-benefits from decreasing or avoiding emissions from the waste sector can be perceived as more important than the potential emissions reduction itself.

Chapter 7
Economic Analysis

An economic analysis of the low-carbon scenario serves to inform both the government and society of the economic costs and benefits of moving toward a lower carbon-development pathway. It also helps one to appreciate the conditions under which the proposed mitigation and carbon uptake options could be effectively implemented. At the same time, there is no unique method for analyzing these options. Various perspectives can be used to inform a broad range of audiences and agents about the economic conditions under which a low-carbon scenario could be put in place.

This study conducted economic assessments at two levels:

1. **Microeconomic**. This cost-benefit analysis enabled comparisons between individual options in the low-carbon scenario and between the overall set of low-carbon and reference-scenario options. Complementary societal and private-sector approaches were developed.

2. **Macroeconomic**. An Input-Output (I-O) based macroeconomic model was used to compare the set of low-carbon mitigation and carbon uptake options (i.e., the low-carbon scenario) against the reference-scenario to explore the macroeconomic sustainability of shifting to the low-carbon scenario.

It is important to note that an exhaustive and consistent economic analysis of all externalities across all sectors is not possible. Although the key co-benefits of certain mitigation and carbon uptake options considered under the low-carbon scenario could be measured in physical terms to explore their sustainability, the number and diversity of the sectors involved virtually preclude an exhaustive analysis of the externalities. Inevitably, ensuring homogeneity of the analysis means limiting it to direct and measurable costs and revenues, thus omitting important co-benefits that nevertheless may be key in shaping the decision-making process.[99]

In addition, this analysis developed a specific method for mitigation options related to land-use change since those proposed to avoid emissions from deforestation differ inherently from others, such as those avoiding emissions from energy and transport activities, which substitute GHG-emitting technologies with less polluting ones to meet the same need. The proposed mitigation options for deforestation involve systemic interventions that eliminate the need for more land, which would otherwise cause further deforestation and GHG emissions. Therefore, applying the same principles for the microeconomic assessment requires additional development.

In this chapter, Section 7.1 presents the microeconomic method used to assess the mitigation and carbon uptake options considered in the proposed low-carbon scenario. Cost-benefit analyses using social and private-sector approaches are presented in subsections 7.1.1 and 7.1.2, respectively; subsection 7.1.3 then calculates the costs associated with reduction of emissions from deforestation and carbon uptake via forest restoration; subsection 7.1.4 presents estimates of development co-benefits associated with mitigation options in the transport sector; a sensitivity analysis against oil price variations is presented in section 7.1.5, with a focus on ethanol. Section 7.2 assesses the macroeconomic effects of the GHG mitigation options on GDP and employment, as well as the four major emitting sectors considered in this study.

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99   For transport, the main benefits are less congestion and local pollution, rather than GHG mitigation; therefore, the study conducted a separate exercise to estimate these benefits (see subsection 7.1.4).

7.1 Microeconomic Assessment Method

A joint assessment of the many measures considered is especially challenging since they are implemented in diverse contexts. Some are in the sphere of the public economy and are implemented by local or federal government; others are conducted by the private sector. Some generate revenue (e.g., energy generation), others savings (e.g., energy conservation), and still others co-benefits and externalities (e.g., transport, waste management, and measures to avoid deforestation). Some are capital-intensive with a timeframe beyond 2030, while others involve short-term changes in operational conditions (e.g., switching to flex-fuel vehicles). The assessment could vary significantly, depending on whether the perspective is public or private sector. To better inform decision-makers, the study team conducted the cost-benefit analysis using both social and private-sector approaches.

The social approach provided a basis for making a cross-sectoral comparison of the cost-effectiveness of the 40 mitigation and carbon uptake options considered in the study. A social discount rate was used to calculate the Marginal Abatement Costs (MACs). The MACs of all proposed mitigation and carbon uptake measures were sorted by increasing value and plotted along a single graph to facilitate a quick cross-sectoral comparison of their costs and the volume of emissions they could reduce or sequester.

The private approach assessed the conditions under which the proposed measures could become attractive to economic agents deciding whether to invest in low-carbon alternatives in lieu of the more carbon-intensive options found in the reference scenario. This approach followed the same principles as the carbon finance transactions of the cap-and-trade approach adopted under the Kyoto Protocol: Such carbon-finance transactions provide additional revenue to economic agents who opt for solutions that are less carbon-intensive than baseline options. The private approach adopted in this study estimated the economic incentive that economic agents would need in order for the proposed mitigation measure to become attractive. If the incentive were provided through the carbon finance market, the private approach indicates the minimum carbon price, expressed in US\$ per tCO_2e, needed to make the low-carbon option attractive enough for implementation. This does not necessarily mean that the corresponding economic incentive must be in the form of carbon revenue through the sale of carbon credits; capital subsidies for low-carbon technologies or a combination of incentives could be used. Financing conditions and tax credits can sometimes be far more effective in channeling the corresponding incentive to make the low-carbon option preferable to project developers.

7.1.1 The "Social Approach": Building the Marginal Abatement Cost Curve

Using the social approach, the costs and benefits of the option implemented in the reference scenario over the 2010–30 period were subtracted year by year from the costs and benefits of the proposed low-carbon option implemented over the same period. Then the 2009 net present value (NPV) of the annual incremental costs and benefits were calculated to determine the weighted average per tCO_2e avoided or MAC over the period. The NPV was calculated using a social discount rate of 8 percent. This is the value used in the PNE 2030 for Brazil's long-term National Energy Plan and is generally used for projects financed by the Brazilian Development Bank (BNDES).

To reiterate, this analysis could not account for externalities because it was not possible at this stage to quantify all of the major ones associated with every proposed measure. If externalities

for some, but not all, measures were accounted for, the comparison would be considered biased and irrelevant. Therefore, in the analysis presented below, only monetary costs and revenues are taken into account. At the same time, the study team acknowledged that certain externalities may be key in the decision-making process.

The study built a marginal abatement cost curve (MACC) of GHG mitigation. Used extensively to analyze GHG mitigation policies, the MACC represents in graphic form the economic attractiveness of a given mitigation option against its potential mitigation size. The abatement cost curves are constructed at the level of technology/activity or sector/program. At the technology/activity level, a bottom-up, engineering economics approach (e.g., cost-benefit analysis or levelized cost analysis) is used to generate the abatement cost curves. At the sector/program level, they are generated by comparing portfolios of technology mitigation options under abatement and reference scenarios.

In this study, activity-level mitigation measures were analyzed individually. Portfolios of these measures were then elaborated at the sectoral level to build a low-carbon scenario; the associated potential for each mitigation option was adjusted to ensure internal consistency at the sectoral level to avoid double counting of emissions reductions.[100]

The study used pair-wise comparisons of GHG mitigation and baseline technologies to generate the abatement cost curves. This type of approach usually compares the NPVs of the investment and operations and maintenance costs and revenue for the technologies implemented in the reference and abatement scenarios. But the objective of this analysis was not limited to comparing abatement and baseline technologies in a static fashion; it also aimed to develop a low-carbon development path with feasible penetration scenarios for the abatement technologies and measures. Because such an approach usually assumes that the series of investments made could extend beyond the period considered, the study team used an annuity or levelized cost approach to calculate the abatement cost of each alternative. Since decision-makers may have to choose between alternatives that differ markedly in terms of costs and benefits distribution in time, particularly with regard to investment costs, 2009 present values were used for calculations and comparisons (box 7.1).

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100 For example, measures for energy conservation and shifting to renewable energy cannot claim displacement of the same fossil fuel–based power generation at the same time.

This study used an incremental cost approach to calculate marginal abatement costs. The approach can be expressed mathematically as follows:

$$AC_n^{Activity} = \frac{ANC_n^{abatement} - ANC_n^{base}}{AE_n^{base} - AE_n^{abatement}} \tag{1}$$

where,

$AC_n^{Activity}$ = Abatement cost of GHG mitigation activity/technology for year n
$ANC_n^{abatement}$ = Net annual cost of the abatement technology (2009 values) for year n
ANC_n^{base} = Net annual cost of the technology in the reference scenario (2009 values) for year n
$AE_n^{abatement}$ = Annual GHG emission with the abatement technology for year n
AE_n^{base} = Annual GHG emission with the technology in the reference scenario for year n

$$ANC_n = \frac{INV.r.\frac{(1+r)^t}{(1+r)^t - 1} + AOMC_n + AFC_n - AREV_n}{(1+r)^{(n-2009)}} \tag{2}$$

where,

ANC_n = Net annual cost of the mitigation technology or of the technology used in the reference scenario (2009 values) for year n
INV = Total investment or capital cost of the mitigation technology or of the technology used in t he reference scenario
$AOMC$ = Annual operations and maintenance cost of the mitigation technology or of the technology used in the reference scenario
AFC = Annual fuel cost of the mitigation technology or of the technology used in the reference scenario
$AREV$ = Annual revenue generated by the the mitigation technology or by the technology used in the reference scenario
r = Discount rate
t = Lifetime of the technology
n = year

The abatement costs thus calculated could differ by year because of the variatio n in cost-benefit streams across years. For a given technology over the study period, annual abatement costs are weighted with the corresponding annual GHG mitigation to calculate the average annual abatement cost. The method used can be expressed as fol lows:

$$AAAC^{Activity} = \frac{\sum_n AC_n^{Activity} \times MIT_n^{Activity}}{\sum_n MIT_n^{Activity}} \tag{3}$$

where,

$AAAC^{Activity}$ = Annual average abatement cost of GHG mitigation activity/technology in 2010 –30 period
$AC_n^{Activity}$ = Abatement cost of GHG mitigation activity/technology in year n
$MIT_n^{Activity}$ = GHG mitigatio n from activity/technology in year n

The alternatives and their respective emissions-abatement potential were used collectively to build the abatement cost curves. The same projected prices for fuels and

electricity as used in the PNE 2030 were applied.

For the abatement options considered in this study, a discount rate of 8 percent was used for calculating the MAC. This is the value that is considered the social discount rate for projects in Brazil. For purposes of comparison, the study also conducted sensitivity analyses for discount rates of 4-percent and 12-percent. It was assumed that mitigation measures with major collective benefits, such as reduced traffic congestion or less local pollution (e.g., bullet train, metro investment, and waste management), would be implemented independent of their MACs or levels of emissions reduction, despite their higher cost. Potential emissions mitigation and carbon uptake over the 2010–30 period totaled nearly 11.7 Gt CO_2 (including avoided emissions from ethanol for export and the Brazil-Venezuela transmission line (table 7.1).

The MACC, using an 8-percent social discount rate, was constructed for mitigation options with MACs of less than US$50 per tCO_2e (figure 7.1a). Similar curves could be constructed for sensitivity analysis (social discount rates of 4 percent and 12 percent). Each plateau in figure 7.1a corresponds to a GHG mitigation option with its mitigation potential. GHG mitigation potentials below the X-axis imply that they are economically attractive at an 8-percent discount rate.

The total emissions mitigation or carbon uptake potential associated with the measures with MACs of less than US$50 per tCO_2e is 11.3 billion tCO_2e over the 2010–30 period. If mitigation options above US$50 per tCO_2e are included, the total rises to 11.7 billion tCO_2e. On average, the annual mitigation potential is 560 million tCO_2e over the study period.

The more striking characteristic of the MACC for Brazil is that, unlike those of most other countries, it appears flat, owing to the large emissions-reduction potential from reducing deforestation. This option alone represents more than 6 Gt CO_2 or more than half of the entire mitigation and carbon uptake potential of the proposed low-carbon scenario. Assessing the costs associated with this major option is not easy; thus, special caution is warranted. For this reason, subsection 7.1.3 provides details on how this study calculated these costs.

The mitigation measures with the lowest MACs are residential lighting, sugar-cane cogeneration, and steam-recovery systems, with negative costs of US$120, $105, and $97 per tCO_2e, respectively. Measures with the lowest MACs are primarily related to energy efficiency (residential/commercial and industrial). These measures have significant economies of cost due to reduced energy-consumption costs, resulting in overall negative MACs.

More capital-intensive options related to transport, waste management, and energy have the highest MACs. These options include the bullet train, at US$360 per tCO_2e; industrial wastewater treatment, at US$103 per Mt CO_2e; and existing refineries at US$95 per tCO_2e.

To better view the MACs for the mitigation options other than deforestation and restoration, the same type of curve as depicted in figure 7.1a was constructed excluding these two options (figure 7.1b).

Table 7.1: Mitigation Potential and Marginal Abatement Cost of Various Alternatives, Based on Three Discount Rates

Mitigation option	% emissions reduction (2010–30)	Emissions reduction (Mt CO2) (2010–30)	Abatement cost (US$/tCO$_2$)		
			8%	4%	12%
Residential lighting	0	3	(120)	(164)	(92)
Sugarcane cogeneration	1	158	(105)	(219)	(43)
Steam recovery systems	0	37	(97)	(157)	(62)
Heat recovery systems	0	19	(92)	(147)	(60)
Industrial lighting	0	1	(65)	(122)	(36)
Solar thermal industrial energy *	0	26	(55)	(89)	(35)
Commercial lighting	0	1	(52)	(104)	(27)
Electric motors	0	2	(50)	(154)	(6)
Combustion optimization	1	105	(44)	(71)	(28)
Refrigerators (MEPS)	0	10	(41)	(151)	5
Recycling	1	75	(35)	(53)	(24)
Transmission line Brazil-Venezuela	0	28	(31)	(32)	(29)
Furnace heat recovery system	3	283	(26)	(49)	(13)
Natural gas displacing other fuels	0	44	(20)	(53)	(4)
Other energy efficiency measures	0	18	(14)	(24)	(8)
Ethanol displacing domestic gasoline	2	176	(8)	(15)	(2)
Wind	0	19	(8)	(162)	64
Optimizing traffic	0	45	(2)	(4)	0
Gas to liquid (GTL)	1	128	(2)	(7)	1
Reducing deforestation + livestock	53	6.041	(0)	(4)	1
Scaling up no tillage cropping	3	355	(0)	(1)	(0)
Investing in bike lanes	0	17	1	(2)	3
Ethanol exports displacing gasoline abroad	6	667	2	(15)	9
New industrial processes	1	135	2	(53)	26
Landfill methane destruction	9	963	3	4	2
Solar heater - residential *	0	3	4	(186)	84
Existing refineries (energy integration)	0	52	7	(5)	11
Wastewater treat. + methane destruction (res. & com.)	1	116	10	14	8
New refineries	0	52	19	21	16
Renewable charcoal displacing non renewable charcoal	5	567	21	14	32
Investing in railroad and waterways vs. roads	1	63	29	21	15
Reforestation	10	1.085	39	39	39
Total (MAC < US$50)	**100**	**11.294**			
Mitigation Options with MAC > US$50/tCO$_2$e					
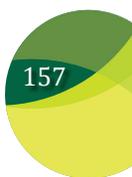
Existing refineries (incrustation control)			7	73	121	46
Existing refineries (advanced controls)			7	95	112	79
Wastewater treat. + methane destruction (ind.)			238	103	140	80
Investing in metro			174	106	100	83
Bullet train: Sao Paulo and Rio de Janeiro			12	400	358	331
Total (MAC > US$50)			**438**			

Note: The assumption for oil prices is that of the PNE 2030 (US$45 per barrel on average), which is low compared to current prices ($70 per barrel); thus, a sensitivity analysis is required, particularly for options that avoid oil and gas (e.g., gasoline substitution with bio-ethanol) (see subsection 7.1.4).

[*] Positive MACs for residential solar heater versus negative costs for industrial solar-thermal substitution reflect the lower carbon content of residential electricity generation (mainly hydropower) versus the higher carbon content of industrial thermal energy generation (gas, diesel, coal).

Figure 7.1a: Marginal Abatement Cost Curves for Mitigation Measures with MACs below US$50 per tCO$_2$e (8-percent social discount rate)
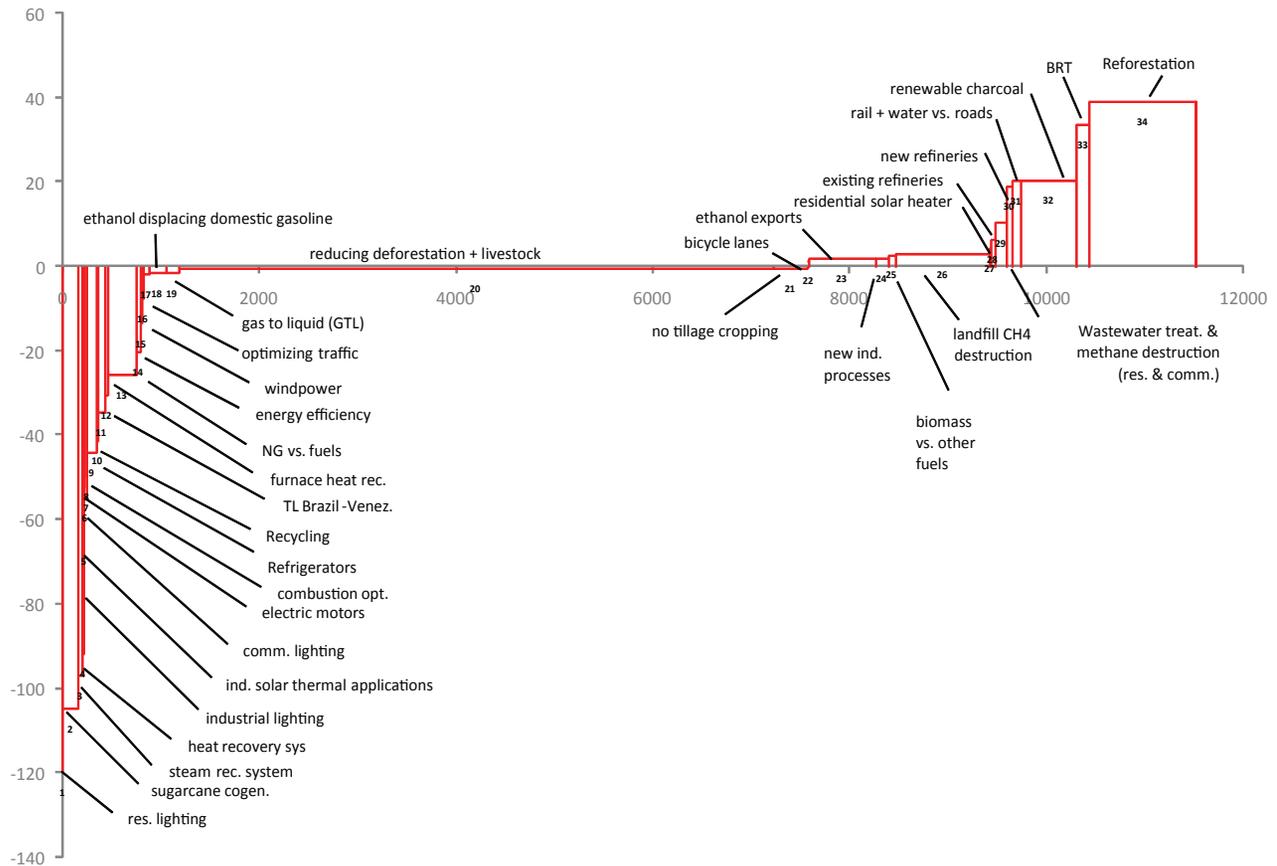
Note: The assumption for oil prices is that of the PNE 2030 (US$45 per barrel on average), which is low compared to current prices ($70 per barrel); thus, a sensitivity analysis is required, particularly for options that avoid oil and gas (e.g., gasoline substitution with bio-ethanol) (see subsection 7.1.4).

Figure 7.1b: Marginal Abatement Cost Curves for Mitigation Measures below US$50 per tCO2e, Excluding Deforestation and Reforestation (8-percent social discount rate)
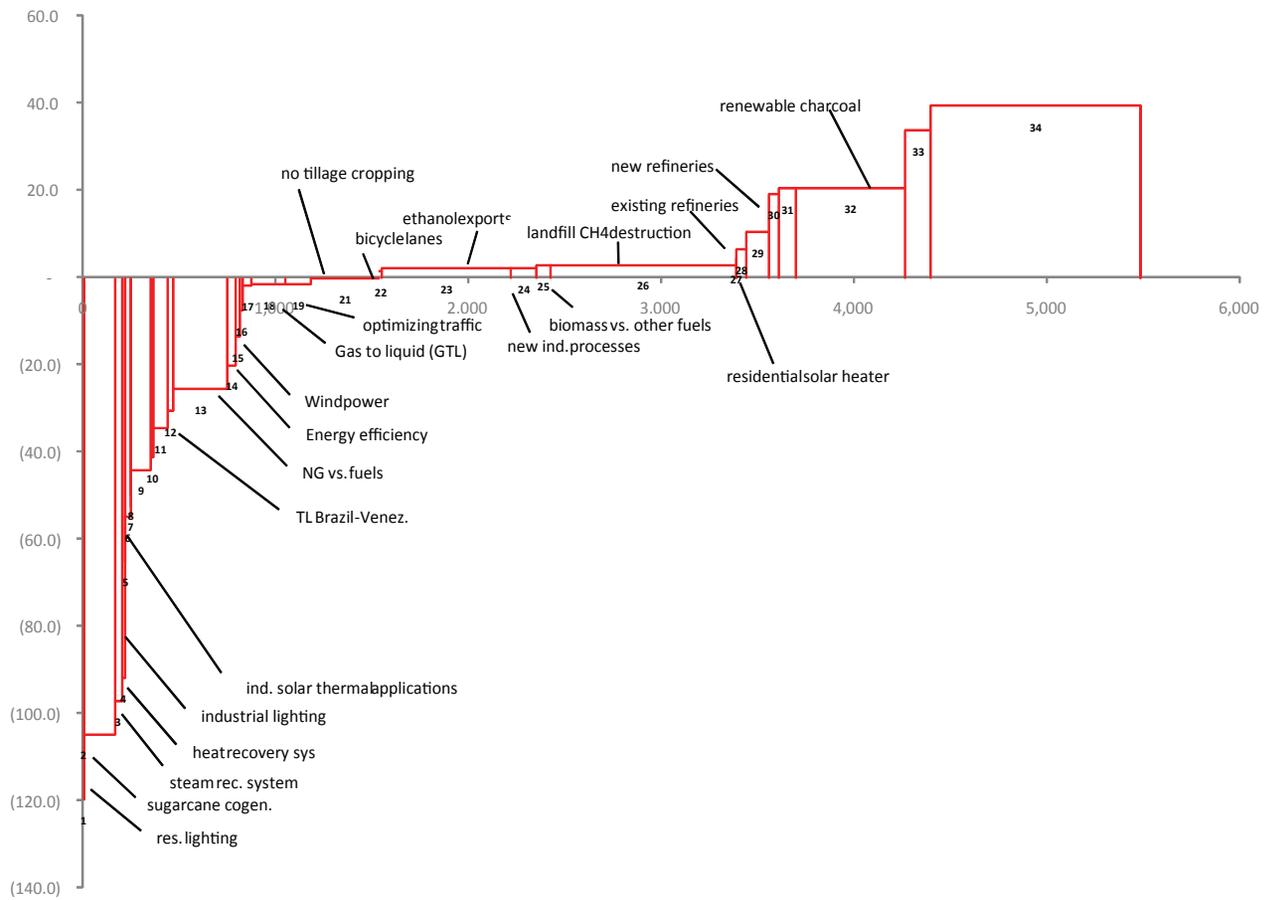
The MACCs for mitigation options with MACs above US$50 per tCO2e were also constructed. Although these options have higher MACs and represent only about 5 percent of total potential for avoided emissions, the likelihood of their being implemented depends more on their co-benefits rather than their emissions mitigation potential (figure 7.1c).

Figure 7.1c: Marginal abatement Cost Curves for Mitigation Measures above US$50 per tCO2e (8-percent social discount rate)
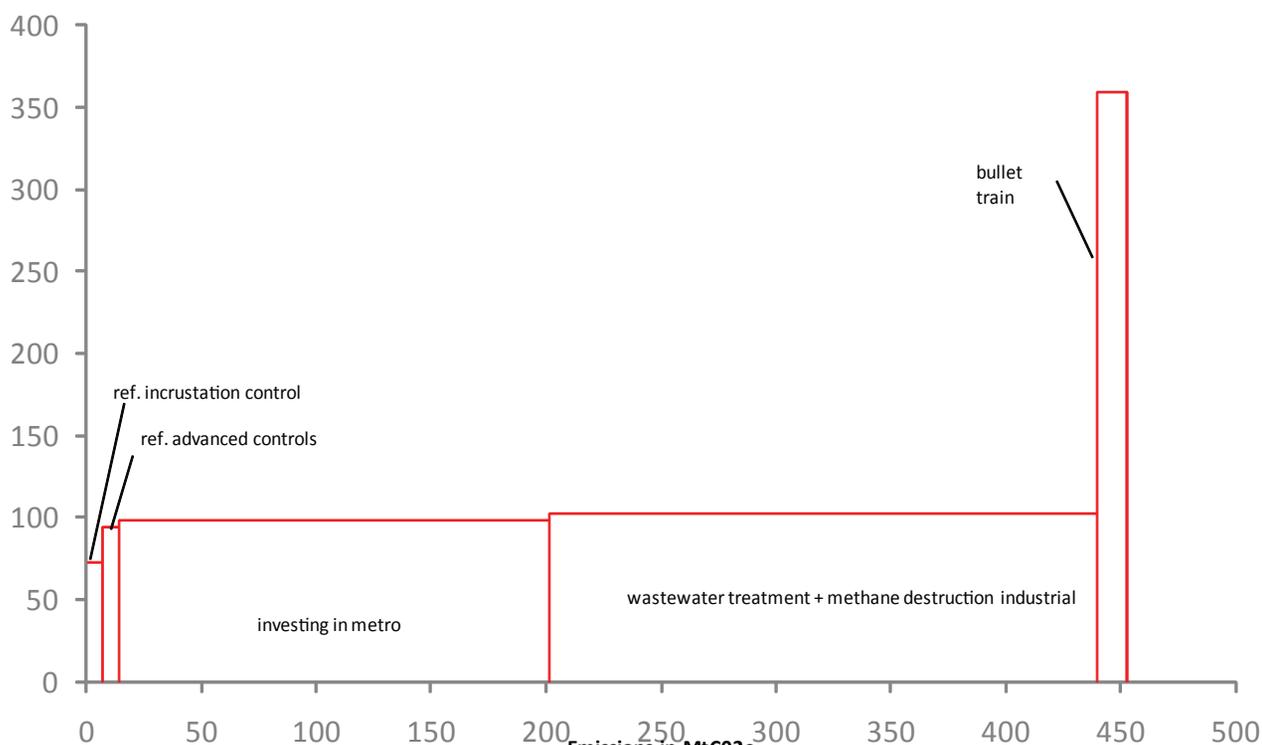
7.1.2 The "Private Approach": Determining the Break-even Carbon Price

To assess the feasibility of implementing the mitigation and carbon uptake options from a private-sector perspective, the study team calculated the incentives that would be required for the proposed measures to become attractive to Brazil's economic agents. The team applied a two-part method. First, it estimated the minimum internal rate of return (IRR) that Brazil's economic agents could expect in the subsector where the proposed mitigation measure is implemented. Second, it estimated the required minimum incentive as the perceived revenue per tCO_2 avoided that would make shifting from the reference option to the low-carbon option attractive; that is, the resulting IRR, including the incentive, would at least equal the benchmark IRR.

Because the risk levels investors perceive differ by technology type, investor strategies may vary according to observed market conditions in particular subsectors; required rates of return, in turn, may differ across technologies.[101] To establish such a benchmark IRR, the study team consulted the various institutions in Brazil that finance projects in the subsectors considered, as well as significant players and entrepreneurs in the field. While issues of confidentiality prevented these institutions from disclosing detailed information through this report, consistency of the data provided gave the project team a sense of the robustness of the estimates thus established.

This data was compiled to arrive at a consensus on the rates used and observed in practice; yet these benchmark IRRs remain indicative. At the same time, they differ markedly from the social discount rate used to calculate the MAC and can change from one sector or subsector to another,

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101 It is important to note that, in practice, certain proposed mitigation options are components of projects and cannot be separately financed; thus, for these options, the IRRs for overall projects were used.

confirming that the MAC presented in the above section should not be used as a proxy for the market incentive to be provided at the project level.

The market incentive was determined as the dollar value per tCO_2 that would make the NPV of the incremental costs and benefits equal to zero, using the benchmark IRR as a private discount rate. In this sense, the incentive can be viewed as the break-even carbon price. It should be noted that neither the MAC nor the break-even carbon price took into account the nonmonetary externalities (positive or negative) that the low-carbon option could generate.

For most sectors, the consensus benchmark IRR was 15 percent. But for certain mitigation measures, other values were applied based on an expected mix of significant public-sector financing (e.g., waste management) or greater private-sector involvement (e.g., cogeneration or major transport infrastructure). For gas-to-liquid (GTL) projects, a benchmark IRR of 25 percent was used, while sugar-cane cogeneration projects applied a rate of 18 percent (table 7.2.a).

GHG mitigation projects with IRRs above benchmark IRRs are expected to attract market investors; conversely, those with IRRs below benchmark IRRs will likely require added incentives, such as carbon credits or other mechanisms, to attract private financing. The level of such incentives is interpreted as the break-even carbon price because it represents the size of the incentive that will equate benefits and costs to achieve the required benchmark IRR. If the break-even carbon price for a GHG mitigation option is negative, implementation of such a measure is, for the most part, already attractive, and its IRR is, in most cases, even higher than the sector's IRR benchmark and no incentive is needed. However, if the break-even carbon price is positive, the option is not attractive as it cannot generate the required benchmark IRR without incentives in the amount of the break-even cost.

Interestingly, for certain mitigation options, the value of the Marginal Abatement Cost (MAC), which uses the social discount rate of 8 percent, was less than zero; but the break-even carbon price, which uses private-sector discount rates, such as the indicative benchmark IRR, was positive (e.g., cogeneration from sugar cane, fuel substitution with natural gas, electric lighting and motors, or GTL). Corresponding options, which appeared economically attractive under a social approach, are no longer attractive when using a private-sector approach. Other mitigation options, already considered expensive when viewed with the social discount rates, would have much higher costs when assessed from the private-sector perspective (e.g., residue mitigation options, bullet train, or Metro implemented by private sector).

Table 7.2.a: Comparison of Sector Benchmark IRRs and Break-even Carbon Prices for Various Mitigation Options (8-percent social discount rate)

Mitigation option	Abatement cost (US$/ tCO$_2$) (8% social discount rate)	Carbon incentive-incremental approach (US$/ tCO$_2$)	Benchmark IRR (%)
Residential lighting	(120)	(243)	15
Steam recovery systems	(97)	(228)	15
Heat recovery systems	(92)	(220)	15
Industrial lighting	(65)	(173)	15
Solar thermal industrial energy *	(55)	(123)	15
Combustion optimization	(44)	(104)	15
Recycling	(35)	(91)	15
Furnace heat recovery system	(26)	(41)	15
Other energy efficiency measures	(14)	(22)	15
Scaling up no tillage cropping	(0)	0	8
Optimizing traffic	(2)	4	15
Reducing deforestation + livestock	(0)	6	10
Landfill methane destruction	3	7	12
Sugarcane cogeneration	(105)	8	18
Natural gas displacing other fuels	(20)	10	15
Reforestation	39	12	10
Ethanol displacing domestic gasoline	(8)	24	15
Investing in bike lanes	1	25	15
Wastewater treat. + methane destruction (res. & com.)	10	33	12
Gas to liquid (GTL)	(2)	34	25
Ethanol exports displacing gasoline abroad	2	48	15
Electric motors	(50)	72	15
Existing refineries (energy integration)	7	75	15
Wind	(8)	93	10
Renewable charcoal displacing non renewable charcoal	21	95	15
Investing in railroad and waterways vs. roads	29	97	17
New refineries	19	106	15
Commercial lighting	(52)	122	15
New industrial processes	2	174	15
Existing refineries (incrustation control)	73	209	15
Transmission line Brazil-Venezuela	(31)	216	15
Refrigerators (MEPS)	(41)	223	15
Wastewater treat. + methane destruction (ind.)	103	251	12
Investing in metro	106	371	17
Existing refineries (advanced controls)	95	431	15
Solar heater - residential *	4	698	15

Bullet train: Sao Paulo and Rio de Janeiro	400	7.787	19

Many of the mitigation options with negative MACs would also not require incentives from the private-sector perspective (e.g., most energy-conservation options in the industry). These would generate such great economies of energy that implementation, even from a private-sector perspective, would be considered a win-win situation. In such cases, mandatory standards may be an option to harvest such "low-hanging fruits."

Obviously, not all mitigation options would be tackled solely from a private-sector perspective; otherwise, government incentives may be provided for reasons other than GHG emissions reductions. Nonetheless, this perspective is valid to demonstrate where incentives might be better placed or most required and where other tools, such as regulation and standards, may be more appropriate than carbon finance.

In theory, every measure whose break-even carbon price falls below the market carbon price would be implemented as a result of the action of market forces; the corresponding cumulative, emissions-reduction potential would be read directly on the horizontal axis at the point where the carbon price crosses the curve. However, as mentioned above, the corresponding economic incentive would not necessarily be in the form of carbon revenue through the sale of carbon credits; other incentives, such as financing conditions or tax credits, could be used (figure 7.2a-c). An estimate of the total volume of incentives needed over the study period would amount to US$445 billion or US$21billion per year on average. Transport mitigation options would require the greatest amount of average annual incentives at approximately $9 billion, followed by energy at $7 billion, waste at $3 billion and LULUCF at $2.2 billion (Table 7.2b). Almost all of the mitigation options would require financial incentives, with the exception of energy efficiency measures.

Table 7.2b: Volume of incentive required (undiscounted) in order to achieve the emissions reductions considered in the Low-carbon Scenario over 2010-2030

	Emissions Avoided (MtCO2e)	Total Incentive Required (US$ MMs)	Annual Incentive Required (US$ MMs)
Energy	1,721	142,892	6,804
Transport	487	185,018	8,810
Waste	1,317	70,256	3,346
LULUCF	7,481	46,769	2,227
Total	**$ 11,006**	**$ 444,935**	**$ 21,187**

Various financing mechanisms already in place could be used to finance some of the mitigation activities proposed in the low-carbon scenario. However, few of these target climate change–related activities specifically; moreover, the availability, reach, and configuration of such mechanisms may be limited. Chapter 9 explains in detail the financing mechanisms already in place for the various sectors.

Like the MACC, the shape of the break-even carbon price is determined largely by the enormous emissions-reduction potential from reducing deforestation. For this reason, special caution is warranted in calculating the MAC and break-even carbon price for these mitigation options. Subsection 7.1.3 describes in detail the cost-assessment assumptions and methods used.
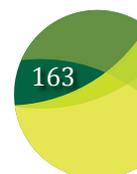
Figure 7.2a: Break-even Carbon Price of the Mitigation and Carbon Uptake Measures with MACs below US$50
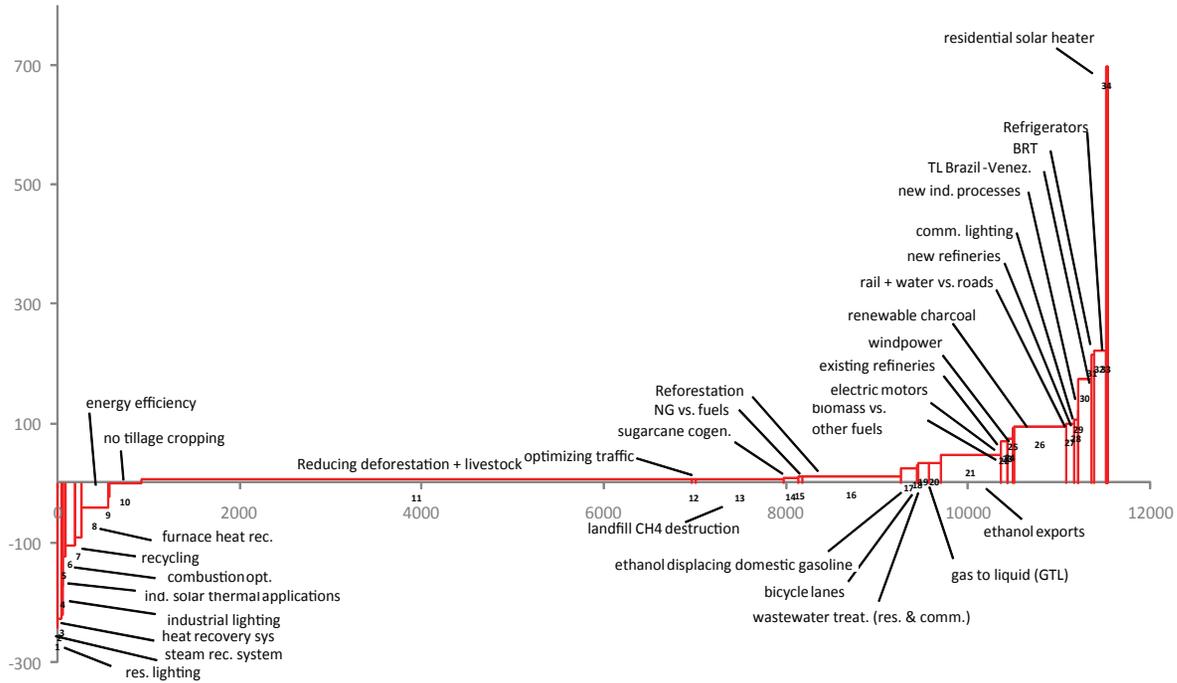
Figure 7.2b: Break-even Carbon Price for Mitigation and Carbon Uptake Measures with MACs under US$50 (Excluding Deforestation and Reforestation)
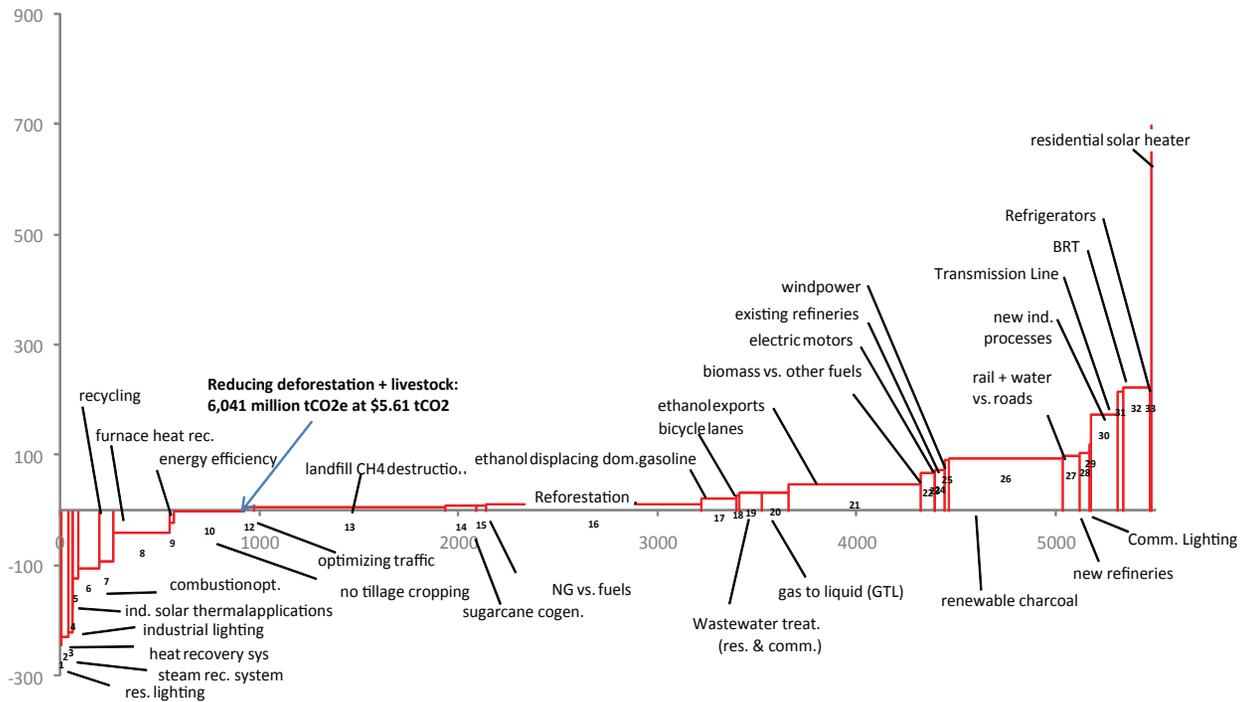
Note: A negative break-even carbon price means that no carbon incentive is needed for the considered option to be attractive from a private-sector perspective.

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Figure 7.2c: Break-even Carbon Price for Mitigation and Carbon Uptake Measures with MACs above US$50 (Excluding Deforestation and Reforestation)
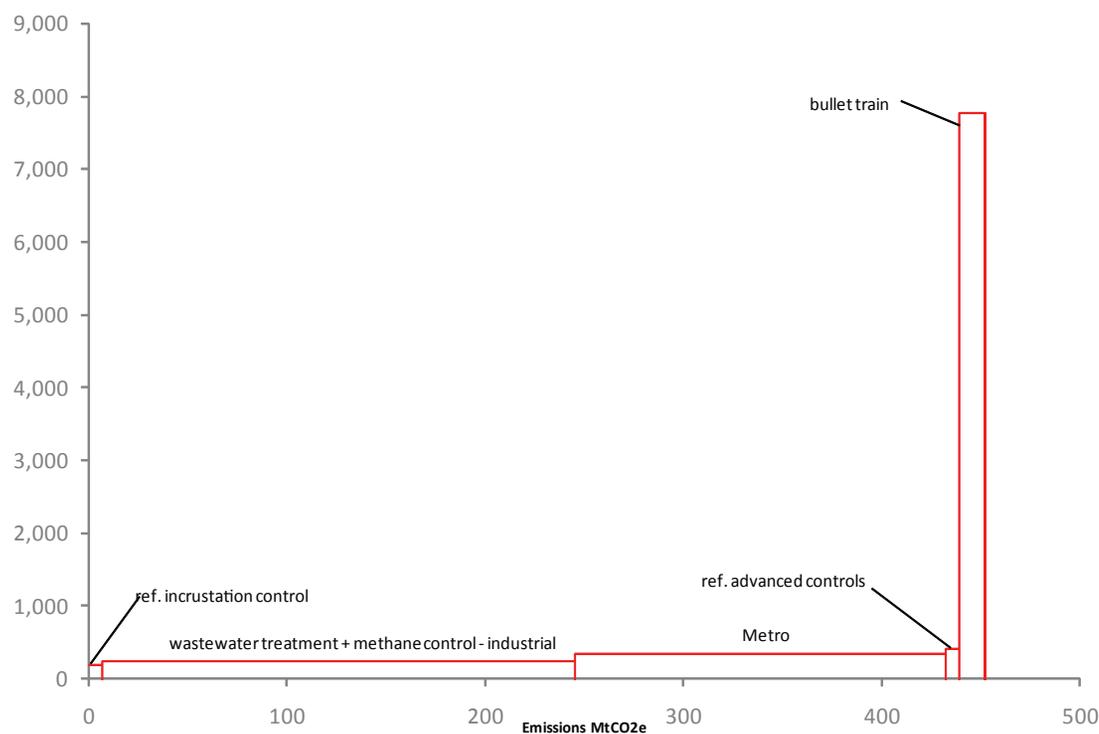
7.1.3 Costs of Reducing Emissions from Deforestation

The two largest emissions mitigation and carbon uptake options identified in this study are (i) avoiding deforestation, estimated at 9.8 Gt CO_2e over the 2010–30 period and (ii) carbon uptake via restoration of legal forest reserves, estimated at about 1.0 Gt CO_2e over the same period. The subsections that follow analyze the costs of transitioning from the LULUCF reference scenario to the proposed low-carbon scenario to harvest the potential of these two major mitigation and carbon uptake measures.[102]

7.1.3.a Avoiding Deforestation

To quantify the costs involved in avoiding deforestation, two key measures were analyzed in terms of investment and financing needs. These measures are (chapters 2 and 3):

- **Improving livestock productivity** to free up land required for other activities. It is reckoned that this measure would lead to a 70-percent reduction in deforestation, declining from an annual average of 19,500 km² to roughly 4,780 km² per year (a figure slightly below the government target of 5,000 km²).

- **Preserving forests.** This complementary set of measures aims at protecting the forest where deforestation is illegal.[103]

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102 More details are found in the LULUCF technical report and those of consultants on related topics.
103 Other measures to prevent deforestation in areas where it is still legally possible were not computed in this analysis. Measures currently being discussed in Brazil and internationally include financial incentives, sometimes called payment for environmental services, offered to economic agents to compensate for the opportunity cost of forfeiting the right to deforest.

7.1.3.a.i Improving Livestock Productivity

Livestock production is achieved through four categories of production systems: two of lower productivity (degraded and extensive pasture) and two of higher productivity (feedlot and mixed crop-livestock). In the reference scenario, degraded and extensive pasture account for more than 90 percent of the land used for livestock activities. In the low-carbon scenario, these lower-productivity systems are gradually replaced by the feedlot and mixed crop-livestock systems until these higher productivity systems reach approximately 60 percent of the total land required by livestock production by 2030. The increased share of beef production in the higher productivity systems would reduce the need for pasture, resulting in land released for other uses. In turn, this would reduce pressure on forests, resulting in lower GHG emissions.

As discussed in chapter 3 (table 3.4), 70.4 million ha of additional land would be made available: 16.8 million ha for crops, production forests, and pasture expansion under the reference scenario and 53.4 million ha for new mitigation and carbon uptake activities under the low-carbon scenario (44.3 million ha for restoring the environmental liability of legal forests, 6.4 million ha for additional ethanol production, and 2.7 million ha for production forests).

Compared to the lower productivity systems, higher productivity systems require significantly greater financial resources for investment and expenses and offer higher returns. In terms of production costs over the 2010–30 period, recovery of degraded pasture via adoption of the crop-livestock system would require an added investment of R$2,925 per ha (US$1,330 per ha), plus another R$21,300 per ha (US$9,682 per ha) to cover expenses. Adoption of the feedlot system over the same period would require R$1,144 per ha (US$520 per ha) in additional investment and R$4,869 per ha (US$2,213 per ha) for added expenses (table 7.3).

Table 7.3: Investment and Expenditures for Prototypical Livestock Systems (2009-30)

Production system	Gross R$ per ha*			Additional R$ per ha*		
	Investment	Expense	Total	Investment	Expense	Total
Degraded pasture	2,124	2,594	4.717	-	-	-
Extensive pasture	2,775	4,644	7.419	651	2,051	2,702
Feedlot	3,267	7,463	10.730	1,144	4,869	6,013
Crop-livestock	5,049	23,894	28.943	2,925	21,300	24,225
* Exchange rate is R$2.20 = 1US$.						

Based on the relative prices considered, the higher productivity systems (feedlot and crop-livestock) generate dramatically higher IRRs (7.50 percent and 15.47 percent, respectively) than those of the lower productivity systems (degraded and extensive pasture) (table 7.4).

Table 7.4: Economic and Financial Performance of Prototypical Livestock Systems (2009–30)

System	NPV* (R$ per ha)	IRR (%)
Degraded pasture	(1,857)	NC**
Extensive pasture	(1,128)	0.56
Feedlot	(95)	7.50
Crop-livestock	1,953	15.47

* Based on an 8-percent social discount rate.
** NC = non-calculable sufficiently negative value.

As a result, the economics of the reference and low-carbon scenarios differ markedly. The per-hectare cost under the low-carbon scenario is far higher than that of the reference scenario. Over the 20010–30 period, the per-hectare cost difference would amount to R$3,139 on average (table 7.5).

Table 7.5: Investment and Expenses in the Reference and Low-carbon Scenarios

Scenario	Total investment expenditure (gross R$ per ha)			Total investment expenditure (additional R$ per ha)		
Reference	2,688	5,020	7,708	2,688	5,020	7,708
Low-carbon	2,996	7,849	10,845	308	2,829	3,137

Source: EMBRAPA.

The economic performance of the livestock sector is far better in the low-carbon scenario than in the reference scenario. Using an 8-percent social discount rate, the overall NPV of the investment and corresponding cash flows of the reference scenario over the 2010–30 period result in –$R18 billion (US$8 billion). By contrast, the NPV of the low-carbon scenario results in R$14 billion (US$6.5 billion). Compared to the reference scenario, the average IRR for the livestock sector in the low- carbon scenario increases from a negative value[104] to 11.24 percent (table 7.6). It is important to note that the NPV and IRR calculated here refer only to new investments made from 2010 onward in both scenarios. Neither investments made before that date nor related expenses and revenues were taken into account.

Table 7.6: Comparative Economic and Financial Performance of the Livestock Sector

Scenario	NPV (2010–30) (R$ billion)	IRR (%)
Reference	(17.782)	NC*
Low-carbon	14.335	11.24

* NC = noncalculable, sufficiently negative value.

These difference in economics are accompanied by differences in environmental performance: The low-carbon scenario for LULUCF does not require additional land for land use and therefore does not contribute to deforestation and, in turn, its associated GHG emissions.

7.1.3.a.ii Forest Protection

Although the low-carbon scenario for land use offers solutions for bringing the need for additional land virtually to zero, it is expected that complementary forest-protection measures would also be required for two major reasons. First, the legal limit for deforestation (up to 20 percent of properties located in the Amazon region) has not yet been reached. Thus, where the complex dynamic of deforestation is powered by the financial value of the wood or cleared land (along with the need for cropland, pasture, and production plantations), deforestation would continue. Second, there may be a significant delay between the time demand for cropland, pasture, or production forests is reduced and the time one could effectively observe a behavioral

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104 The illegal appropriation of public areas for specutlative purposes may explain why an seemingly not economically attractive activities still happen. The land titling issue, which the program "Terra Legal" is aimed at addressing, could not be included in the scope of this study.
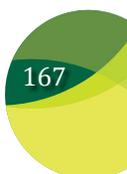
change among deforestation agents at the frontier (i.e., since they may continue to speculate on demand that has already dried up far upstream in the land market chain).

Table 7.7: Projection of Forest Protection Costs in Areas Where Deforestation is Illegal (million US$)

year	Conservation Units winvestment	Conservation Units expense	Indigenous Reserves investment	Indigenous Reserves expense	Road Network Control investment	Road Network Control expense	Remote Sensing Monitoring	Total Annual Cost
2010	516	430	1,680	372	112	93	1	3,205
2011	0	430	43	381	0	93	1	949
2012	0	430	43	391	0	93	1	958
2013	0	430	43	400	0	93	1	968
2014	0	430	43	410	0	93	1	977
2015	0	430	43	419	0	93	1	987
2016	0	430	43	429	0	93	1	996
2017	0	430	43	438	0	93	1	1,006
2018	0	430	43	448	0	93	1	1,015
2019	0	430	43	457	0	93	1	1,025
2020	0	430	43	467	0	93	1	1,034
2021	0	430	43	476	0	93	1	1,044
2022	0	430	43	486	0	93	1	1,053
2023	0	430	43	495	0	93	1	1,063
2024	0	430	43	505	0	93	1	1,072
2025	0	430	43	514	0	93	1	1,082
2026	0	430	43	523	0	93	1	1,091
2027	0	430	43	533	0	93	1	1,101
2028	0	430	43	542	0	93	1	1,110
2029	0	430	43	552	0	93	1	1,120
2030	0	430	43	561	0	93	1	1,129
Total	516	9,035	2,539	9,797	112	1,963	21	23,983

Therefore, the low-carbon scenario proposes to implement additional forest-protection measures in forested areas where deforestation is illegal. Given the many ongoing programs and abundant literature available on this topic, including the Plan of Action for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM), this study limited itself to reviewing existing proposals (chapter 3). We present here, in order of magnitude, the results of a preliminary analysis of the additional costs that could arise from the need for additional forest-protection activities. These aim to ensure that the full potential of deforestation reduction would be achieved via the release of pasture land and livestock productivity gains, as proposed in the low-carbon scenario.

To assess investment costs and expenditures for managing and enforcing the protection of conservation units where deforestation is illegal, the study used the Minimum Conservation

Investment (IMC) tool developed by the Working Group on Financial Sustainability of the National System of Conservation Units (SNUC), created by the Ministry of Environment.[105] Using the IMC tool, the study assessed the costs associated with four protection activities over the 2010–30 period: (i) protection of indigenous reserves, (ii) protection of conservation units, (iii) control along the road network, and (iv) remote sensor monitoring. These activities aim to prevent intrusion into and deforestation of these areas, as well as forbidding the transport of products resulting from illegal deforestation. Over the period, protection costs would total US$24 billion, or $1.14 billion per year on average (table 7.7).

It should be emphasized that the mitigation options considered under the low-carbon scenario do not include additional measures to prevent deforestation in areas where it is still legally permitted. Elaboration and quantification of such proposals were beyond the scope that could be achieved under this study. If such additional measures, like for instance payments for compensating landowners for forfeiting their rights to deforest, were to be added, additional costs and benefits would have to be integrated into account in analysis, leading most probably to higher marginal abatement costs.

7.1.3.a.iii Calculating the Marginal Abatement Cost from the Social Viewpoint

Three calculations are required to determine the MAC. The first calculation is the year-over-year incremental cost of the low-carbon scenario for livestock in relation to the reference scenario (annual differential between the net results of the two scenarios). Next, the incremental costs for each year are calculated in current 2009 values, using a social discount rate of 8 percent. Finally, the weighted average based on the annual emissions reduction volume (from deforestation) is calculated. The volume of emissions avoided corresponds to a deforested area, in the reference scenario, equivalent to the area of pasture freed-up in the low-carbon scenario to accommodate the expansion of other activities.

As previously mentioned, the proportion of higher productivity systems is greater in the low-carbon scenario than in the reference scenario, which results in a positive NPV of the incremental results of R$14.3 billion, versus –$18 billion NPV in the reference scenario. The overall IRR for the low-carbon scenario is 11.24 percent, whose calculation is based on the incremental costs of the implementation and expansion of the higher productivity (more cost intensive) systems and their related returns.

The result of the calculation indicates a marginal negative cost of US$2.5 per tCO_2 avoided. This suggests that adoption of more productive systems, versus existing predominant extensive and degraded pasture systems, should produce economic gains for the beef sector in addition to mitigating GHGs. While the projected productivity gains in the low-carbon scenario would almost certainly have positive economic outcomes, this initial "social viewpoint" analysis could prove misleading for those keen on learning what the real costs would be to get livestock breeds to adopt more productive systems. In reality, the conclusions differ markedly when perceived from a private-sector point of view, as shown by the following preliminary results regarding the break-even carbon price (section 7.1.3.a.iv). When the costs of forest protection over the 2010–30 period are included—US$24 billion—the MAC increases to –US$0.48 per tCO_2 avoided.

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105 The IMC (*Investimento Minimo de Conservação*) tool is based on the financial module of the Minimum Conservation System (MICOSYS) developed by D. Vreugdenhill; see D. Vreugdenhil, "MICOSYS, Application Honduras 'National Parks Model'," Evaluation Spreadsheet in MS Excel, prepared for PPROBAP, COHDEFOR Project/UNDP/World Bank/GEF (2002).

7.1.3.a.iv Calculating the Break-even Carbon Price from the Private-sector View

Transitioning from predominantly lower productivity systems, particularly feedlot and crop-livestock systems, would require higher levels of investment and operations and maintenance disbursements of more than US$430 billion over the 2010–30 period or US$22 billion per year. Although the low-carbon scenario results in an IRR of 11.24 percent, these more efficient production systems—particularly the feedlot system, with a 7.5-percent IRR—may not be remunerative enough to be implemented at a significant scale initially.

Thus, in the case of livestock production, it would be particularly important to complement an economic analysis from the social viewpoint (i.e., social discount rate) with an analysis from the private-sector perspective. The main justification is this: While the social viewpoint does not oscillate between the reference scenario and the low-carbon scenario, the private-sector view changes dramatically because Brazil's livestock sector has limited access to banking finance and depends heavily on its own capital resources for investing in livestock-related technologies. The productivity of more traditional livestock systems, which often produce returns of only about 0.5 percent or less, is generally insufficient to defray the costs of banking credit.

Promoting a transition from lower to higher productivity systems could contribute to increasing the rate of return for these businesses. However, the adoption of higher productivity systems presupposes substantially higher investments that require access to banking credit. It follows that the rate of return for these businesses must at least equal the credit costs plus expected profits to provide livestock breeders an adequate incentive. Therefore, IRRs have to be far higher in the low-carbon scenario than in the reference scenario.

The sum total of the expected rate of return, plus financing costs (i.e., the long-term interest rate [TJLP] + percent spread ~ 10 percent +) is generally higher than the rates of return that certain productive modes recommended for the low-carbon scenario can achieve (i.e., about 0.56 percent for extensive systems, 7.5 percent for feedlot systems,).

The social approach does not explain why higher productivity systems would need substantial incentives to operate, while traditional producer systems, which produce less profit, would tend to expand on their own. What at first glance appears as a win-win situation—less land needed and thus less pressure to clear forests and expand the agricultural frontier on the one hand and a better biological and economic performance for the livestock breeder on the other—may not be an accurate portrayal.

In short, the expected IRRs or private discount rates related to livestock breeding in the reference scenario are low (approaching 0.5 percent), while those considered in the low-carbon scenario are significantly higher (at least 10–12 percent). If bank loans, which benefit from lower charges (e.g., Banco da Amazônia [5–8.5 percent] or BNDES [5.75–6.75 percent]), are needed only to finance part of the overall sum required, it could be reckoned that, under the low-carbon scenario, a producer would need to achieve an average IRR of at least 10 percent, which is a rather conservative value. This study used this benchmark IRR to produce an initial estimate of the incentives a low-carbon scenario would require to generate substantial productivity gains in the livestock sector resulting in the release of needed pasture land to accommodate growing alternative activities without inducing pressure on forests. It should be emphasized that this study is a first attempt to gauge the level of incentives required. To tackle the issues more thoroughly, further studies are clearly warranted.

To calculate the break-even carbon price, the only incremental costs considered were those associated with the implementation and expansion of higher productivity systems. Given that the feedlot system has an IRR of 7.5 percent, which is less than the benchmark IRR used in this study (12 percent), the break-even carbon incentive required was calculated to ensure that this system would reach an IRR equal to the benchmark rate. The calculation indicates that this incentive should be about US$1.47 per tCO_2e, or approximately US$9 billion over the 2010–30 period in order to avoid 6 Gt CO_2e and ensure an IRR of 12 percent. When the costs of forest protection over the same period are taken into account—US$24 billion—the incentive to implement the overall strategy to reduce deforestation by approximately 80 percent of the historical observed rates rises to US$6 per tCO_2e or US$36.5 billion to avoid 6 Gt CO_2e (figure 7.3). Using a higher IRR of 15%, the resulting break-even carbon incentives would be $1.88 and $6.64 including forest protection costs.

Figure 7.3: Marginal Abatement Cost (8-percent social discount rate) and Break-Even Carbon Price (considering an IRR of 12%) for Deforestation Avoidance Measures
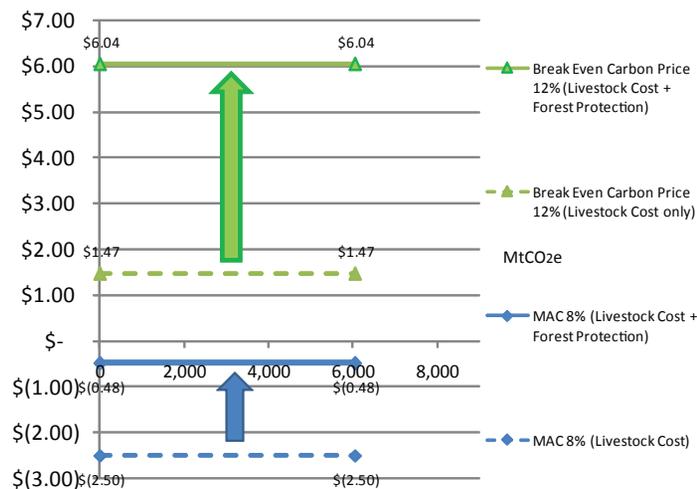
7.1.3.a.v Financing Requirements

To implement the higher-productivity, livestock-production systems in the low-carbon scenario, the required financing of investments and operations and maintenance would total R$946 billion (US$430 billion) over the 2010–30 period, with investments representing approximately 30 percent of total expenditures or about US$21.5 billion per year (table 7.8). In the reference scenario, a smaller amount would be required since these higher productivity systems are expected to expand in that scenario, albeit at a far more limited scale. Releasing an additional 70.9 million ha in the low-carbon scenario would require R$720 billion (US$327 billion) more in financing for higher productivity systems. This would represent about US$16 billion in added annual costs, equivalent to 72 percent of the gross value of beef production in 2008.[106] As a point of reference, Brazilian-government financing for the sector in 2007 was US$3 billion or approximately 10 percent of the estimated annual investment required by the reference

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106 Gross value of beef production in 2008 (based on figures for April 2008 by IGP-DI) was estimated by Brazil's National Confederation of Agriculture and Livestock (CNA) at R$49.59 billion (see Indicadores rurais XI (90 [Sept.-Oct.]):6.

scenario in 2010 (US$32.5 billion).

Financing requirements would be significantly lower if the low-carbon scenario were not to incorporate mitigation and carbon uptake measures that require additional land on top of expansion of agricultural land in the reference scenario (legal forest carbon uptake, ethanol for increased national consumption and for export, and production forests for the iron and steel industry). In the reference scenario, the additional land for agricultural and livestock production is 16.8 million ha, less than one-third of the total volume of land released under the low-carbon scenario (via high-productivity livestock production systems to accommodate both expansion of crops and all measures considered) (table 3.4). Without added mitigation and carbon uptake activities, the financing required in the low-carbon scenario for improved livestock production to release land for crop expansion would total US$238 billion—US$108 billion more than in the reference scenario—and US$262 billion when estimated forest protection costs are added.

Table 7.8: Livestock-sector Investment and Expenses To Release Land To Absorb Additional Land Needed in the Reference and Low-carbon Scenarios (2010–30)

Scenario	Pasture area released (millions of ha)	Cumulative investments in feedlot and crop-livestock systems (billion R$)	Cumulative expenses in feedlot and crop-livestock systems (billion R$)	Total investment in feedlot and crop-livestock systems (billion R$)
Reference	0	92.075	134.351	**226.426**
Reference (absorption of additional land needed)	16.8[*]	107.699	356.397	**464.095**
Low-carbon	70.4[**]	225.322	721.124	**946.446**

[*] *Additional land needed for expansion of crops, pasture, and forests.*
[**] *Absorption of additional land needed for expansion of crops, pasture, and forests in the reference scenario, plus land needed for proposed mitigation and carbon uptake options in the low-carbon scenario.*

7.1.3.b Forest Recovery: Legal Forest Reserves

Forest-restoration costs can be divided into the following components, all of which include a labor cost component:

- *Fencing-off.* Costs are estimated at R$1,500 to R$2,000 per ha.

- *Ground preparation.* Includes costs for fertilizers, elimination of weeds and sauba ants, and digging of appropriate holes for planting saplings; total cost is estimated at R$1,000 and R$5,000 per ha.

- *Planting.* Includes costs for saplings and labor; costs are estimated at R$1,200 to R$2,300 per ha.

- *Maintenance of restored areas.* Includes regular weeding and periodic application of fertilizers where needed. These costs could account for as much as 50 percent of total costs.

The final per-hectare costs of forest restoration would depend on the extent to which the

environment has deteriorated and the levels of intervention necessary to re-establish vegetation cover. Four levels of interventions correspond to four scenarios, as follows:

- *Minimum:* The area to be restored possesses significant potential for natural regeneration; hence, it requires only fencing-off to permit re-establishment of the vegetation cover.

- *Light:* In addition to fencing-off, the area requires planting of tree species used in the forest-restoration exercise.

- *Moderate:* The ground is highly compacted from years of livestock grazing and is completely colonized by gramineous plants. Required interventions include fencing-off, ground preparation, elimination of weeds and ants, and extensive planting of saplings; machinery could be used to contain costs.

- *Major:* In addition to the conditions described above, the ground is extremely degraded and eroded and thus unsuitable for machinery; owing to ecological degradation, such an area would likely continue in a low-carbon state indefinitely.

It should be noted that intervention costs can vary considerably, primarily due to the costs of manual labor in rural areas and the purchase of inputs for machinery, whose prices tend to vary, even within the same state (figure 7.4). Owing to the inability to spatialize forest-restoration costs geographically, abatement and investment costs in the Legal Scenario were simulated using the moderate-intervention scenario. The carbon removal rate was equivalent to the average absorption level for the Cerrado and Atlantic Forest biomes (98.3 tCO_2 per ha in 2030).

Figure 7.4: Variation in Forest-restoration Costs, by Intervention Scenario
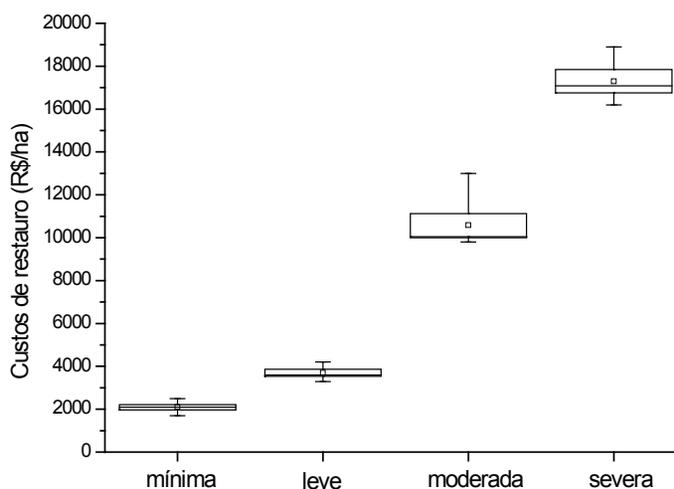
Note: Values are average costs.
Sources: Various forestry restoration budget reports and specialized literature.

In the Legal Scenario, the incremental cost equals the cost of forest restoration, given that this scenario presupposes that no economic activity would occur in such areas. Therefore, the average marginal cost would total US$39.3 per tCO_2, while the break-even carbon price would equal US$50.52 per tCO_2 (figure 7.5).

Figure 7.5: MAC and Break-even Carbon price for CO$_2$ Removal via Legal Forest Restoration
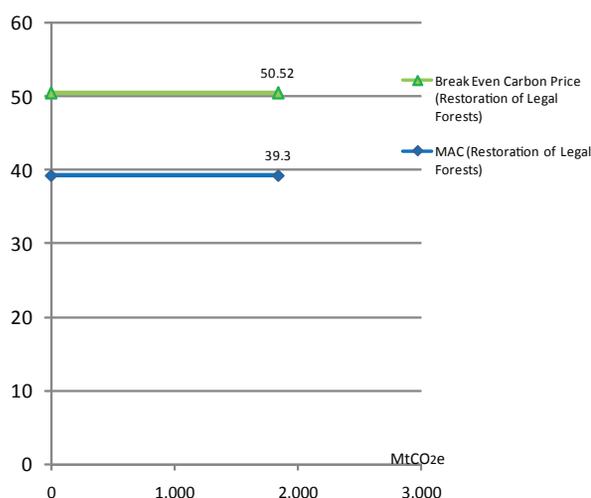
Considering that the total volume of forest restoration would equal 44 million ha, the total non-discounted cost, based on the above-mentioned marginal cost, would equal US$54 billion over the 2010–30 period. The average annual cost over the period would equal US$2.7 billion.

7.1.4 Internalization of Development Benefits

Ensuring homogeneity of the cost-benefit analysis of mitigation and carbon uptake options across sectors has meant limiting it to direct and measurable costs and revenues, thus omitting significant co-benefits that may be key in shaping the decision-making process. This is especially important in sectors where such development benefits cannot be easily internalized by private agents. In the transport and waste-management sectors, for example, internalization of benefits relies on public policies formulated at various levels of government; thus, it should be reflected in the social-approach calculation. Over the years, significant progress has been made in the public economy, and various techniques have been developed to estimate certain such benefits in monetary terms. Such quantification, where possible, can significantly change the net results of the cost-benefit assessment of the proposed mitigation measures, thus better informing the public decision-making process.

This study calculated three major categories of co-benefits associated with the mitigation options considered for the transport sector: (i) travel time savings, (ii) accident reduction and (iii) reduced local pollution. All these three co-benefit categories contribute to improving transport services. To calculate travel time savings, the study used data generated by the Corredor T5 Project, a BRT project implemented in the city of Rio de Janeiro. The data indicate an average travel time value of R$1.08 (U$0.5) per passenger and per hour for collective transport and R$12.07 (U$5.5) per passenger and per hour for individual transport. To calculate accident reduction, the study used data generated by several World Bank–financed projects, including the CBTU Decentralization Programs for Urban Train Systems in Rio de Janeiro, São Paulo, Belo Horizonte, and Recife. To calculate the reduction of local pollution, the study used data generated by Reductions of Negative Scale Effect Associated with the Improvement of Public Transportation, a 1998 study coordinated by the Institute for Applied Economic Research (IPEA) and the National Public Transportation Association (ANTP) that analyzed annual losses from transport-system inefficiencies in 10 cities (box 7.2).

Not surprisingly, when transport improvement benefits are factored in, the net MACs of certain transport mitigation options are lowered significantly. The effect is especially clear for BRT, the main urban-transport change proposed in the low carbon scenario; in this case, the MAC changes from slightly positive (+0.31 per tCO$_2$e) to clearly negative (–$24 per tCO$_2$e). But the high-speed rail co-benefits that could be internalized using this method are not enough to compensate for the high monetary MAC related to the corresponding modal shift (figure 7.6).

Box 7.2: Calculation of Transport Improvement Co-benefits

To calculate the major co-benefits of the mitigation options considered for the transport sector, this study used the following methods:

1) Benefits related to reduction of accidents:

For each transport mode, the following equation is applied:

RCAccid= ((Pass x km NP – Pass x km WP) x N Acid x C Accid / PF– Supp) x Days / year

with:

RCAccid = Reduction of Accidents Costs

Pass x km NP = Total of passengers x km in peak period for the situation without the project (no project)

Pass x km WP = Total of passengers x km in peak period for the situation with the project

N Acid = Number of Accident per passengers x km

PF – Supp = Peak Factor for Supply

C Accid = Unitary Accident Cost

Days / year = Total number of days equivalent in the year

2) benefits related to travel time reduction

TTR = ((Pass x hours NP – Pass x hours WP) x VT / (PF - Dem.)) x Days / year

with:

TTR = Travel Time Reduction

Pass x hours NP = Total passengers x hours at peak period for the situation without project (no project)

Pass x hours WP = Total passengers x hours at peak period for the situation with project

VT = Value of Time

PF – Dem = Peak Factor for demand

Days / year = Total number of days equivalent in the year

2) benefits related to reduction of local pollution

RPollution = ((Vehic x Km NP – Vehic x Km WP) x UCPollution / (PF - Dem.)) x Days / year

Onde:

RPollution = Reduction of health care expenses related to pollution.

Vehic x Km NP = Total of Vehicles x km at peak time for the situation without the project (no project)

Vehic x Km WP = Total Total of Vehicles x km at peak time for the situation with the project

UCPollution= Unitary Cost in health care related to vehicles pollution

PF – Dem = Peak Factor for demand

Days / year = Total number of days equivalent in the year

Figure 7.6: Effect of Transport Improvement Benefits on the MAC
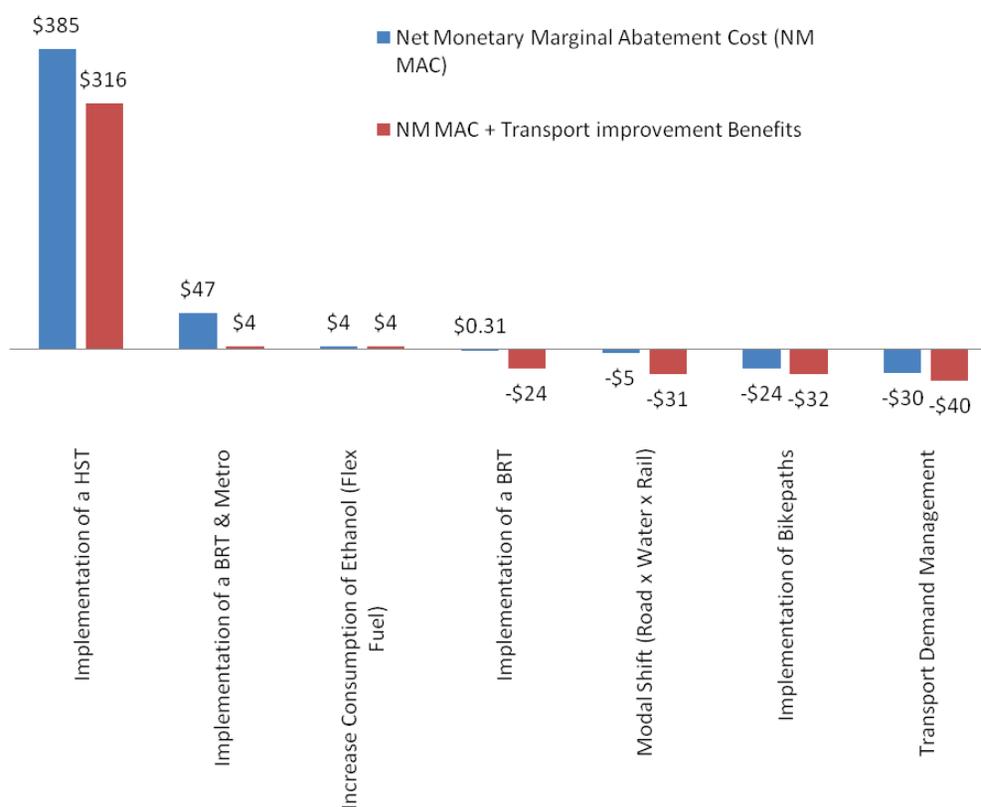
7.1.5 Sensitivity Analysis against Oil Price Variations

Results of the cost-benefit analysis for mitigating emissions from fossil fuels in industry and the transport sector are particularly sensitive to the price of oil. The higher the oil price, the greater the avoided costs, which are counted as a benefit and thus lower the MAC and break-even carbon price. As mentioned previously, MAC and break-even price calculations were based on the PNE 2030 assumption adopted for the price of oil (an average of US$46 per barrel [WTI] over the period). At the time the PNE 2030 was elaborated, this assumption was considered reasonable; however, it now appears low, given that oil prices have averaged more than $70 per barrel in the past three years (reaching over $100 in 2008), and are currently at $71 per barrel.[107] Thus, for all energy and transport mitigation measures, it is especially important to conduct a sensitivity analysis of the results presented above against oil price variations.

In the case of gasoline substitution with bio-ethanol from sugar cane, results indicate a positive break-even carbon price for ethanol for both export and domestic consumption (US$34 per tCO$_2$ and $48 per tCO$_2$, respectively), suggesting that ethanol exports may not be competitive against gasoline without a significant carbon incentive. But the sensitivity analysis shows that, when oil prices rise, break-even carbon prices quickly turn negative for both ethanol for export and domestic consumption. When oil prices reach about $50 per barrel (assuming constant prices of

107 As of September 2009.

sugar and other production variables), the break-even carbon price is reduced to zero;[108] above that price, the MAC and the break-even carbon price of gasoline substitution with bio-ethanol are negative for both domestic and international markets. At the current oil price of $71 per barrel, the break-even carbon price is about –$80 per tCO$_2$ (figure 7.7).[109]

Figure 7.7: Sensitivity Analysis of MAC and Break-even Carbon Price for Ethanol against Oil Price
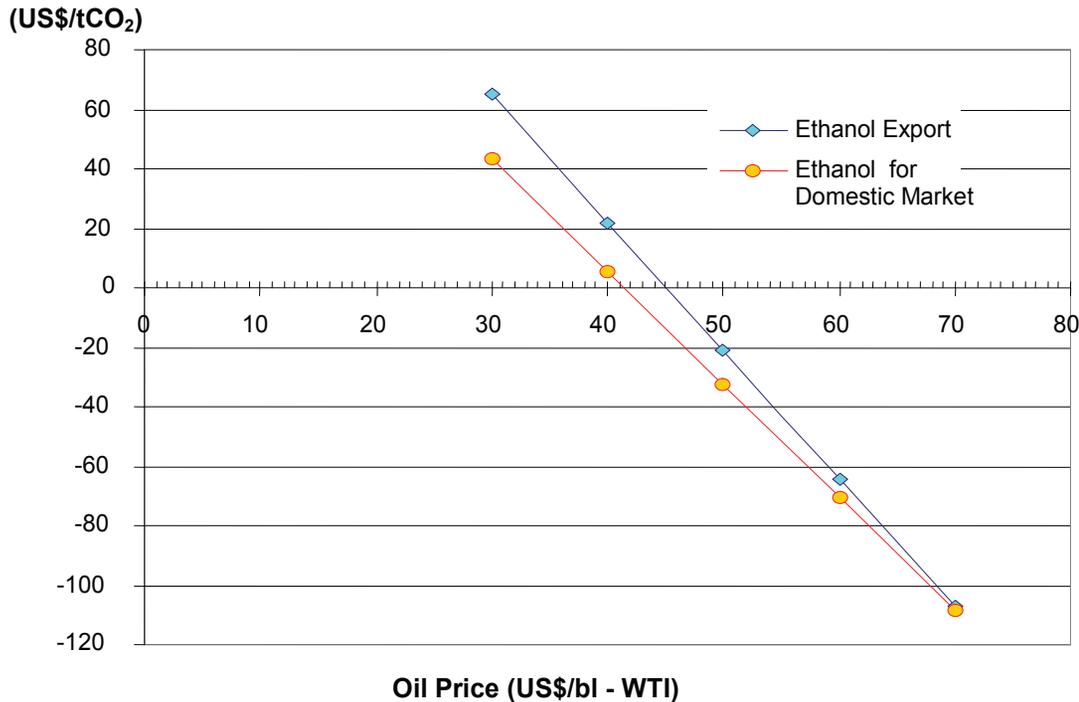
The sensitivity analysis shows that other mitigation measures are also strongly affected by changes in oil prices, from both a social and private-sector perspective (figure 7.8). For example, the break-even carbon price for all options related to energy efficiency becomes even more negative, indicating low-hanging fruits that should be harvested quickly. However, options related to electricity savings are not significantly affected, which is consistent with the limited fossil-fuel content of the energy mix in the power sector.

108 More precisely, the break-even carbon price is reduced to zero when the price of oil reaches US$49 per barrel for domestic ethanol consumption and $51 per barrel for ethanol export. The higher cost of ethanol for export versus domestic consumption results primarily from the lower avoided emissions factor used due to emissions related to ethanol transport. In reality, a variety of factors would affect the production of ethanol, including the cost of ethanol production, competition for raw materials, and the price of oil. This simulation primarily illustrates the impact of the price of oil, including when oil prices rise above the PNE scenario of US$46 per barrel.

109 That is, the net present value of avoided gasoline cost becomes higher than that of the ethanol cost when oil prices exceed US$50 per barrel.

Figure 7.8: Sensitivity of Break-even Carbon Price of Mitigation Measures in the Energy and Transport Sector
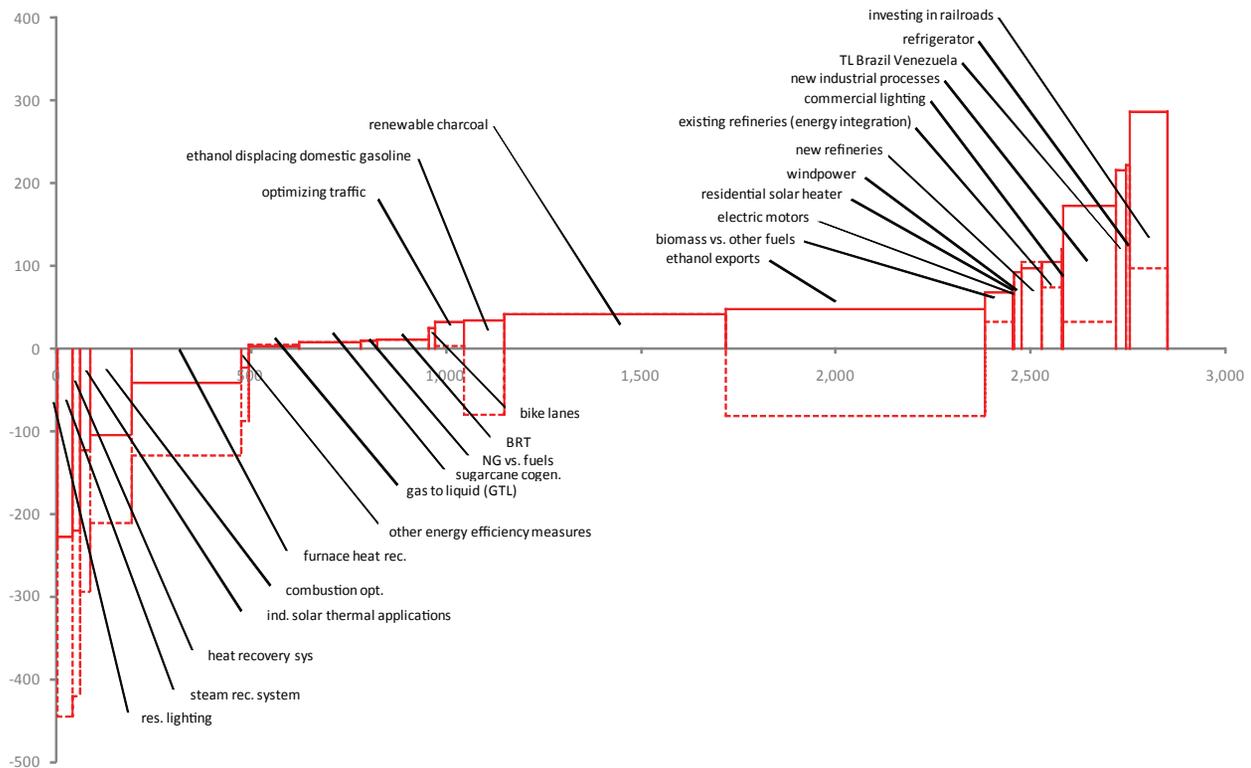
7.2 Macroeconomic Benefits Assessment

GHG mitigation options are often evaluated at a project or program level; however, such evaluations do not capture the indirect effects of the measures on other sectors of the economy. Indeed, economic sectors and industries are closely linked. For example, decreased electricity consumption resulting from energy-efficiency improvements leads to a reduction in the fuels produced for electricity generation. Furthermore, decreased fuel demand might cause job cuts not only in the fuel industry but also in the pipeline industry. Moreover, a mitigation option evaluated as attractive at the project level might prove less so if its effects on the overall economy were taken into account. Conversely, an option evaluated as less attractive at the project level may provide more spin-off benefits at the level of the overall economy and thus would be more attractive in that larger context. Thus, it is always desirable to assess GHG mitigation options based on their effects on the overall economy.

7.2.1 Methodological Background

Various methods and approaches can be used to estimate economy-wide impacts of GHG mitigation options. The most common method is a top-down approach involving computable general equilibrium models, which simulate the effects of carbon constraints or, alternatively, carbon tax. Some studies have also incorporated bottom-up measures, such as demand-side management and fuel substitution, into top-down models. models.[110]   While such a linkage

110 See, for example, G. R. Timilsina and R. M. Shrestha (2008), "A General Equilibrium Analysis of Potential Demand Side Management Programs in the Household Sector in Thailand," International Journal of Energy

could have been ideal for this study, this approach was not implemented due to budget and time constraints. Instead, the study team used an input-output (I-O) modeling approach to assess the macroeconomic impacts of GHG mitigation options. Therefore, these results should be used with caution; they are indicative only, suggesting the order of magnitude of the impact of the mitigation and carbon uptake measures considered in the low-carbon scenario.

In the framework this study used to assess macroeconomic impacts, the cost analysis performed to calculate the marginal abatement costs provides the change in investments and fuel consumption (and change in outputs of any other sector) when shifting from the reference scenario to the low-carbon one. Depending on the mapping of the abatement options onto the economic sectors available in the I-O table, changes in investments and outputs are allocated to various sectors. For example, the incremental investment for energy-efficiency measures that replace inefficient electrical appliances with their efficient counterparts are treated as increased output of the electromechanical sector of the I-O table. Similarly, a reduction in electricity consumption resulting from the energy-efficiency programs is treated as a reduction in electricity-sector output. Since imported goods do not produce economic spin-offs outside the countries where they are manufactured, the study team considered only the domestic fraction of the total demand change due to the GHG mitigation options. These changes in domestic demand for goods and services were then multiplied by I-O coefficients to determine the gross-output impacts of the mitigation options. Finally, two ratios—(i) GDP to gross output and (ii) employment to gross output—were used to calculate the respective effects of the mitigation options on GDP and employment (figure 7.9).

Figure 7.9: Framework for Assessment of Macroeconomic Impacts
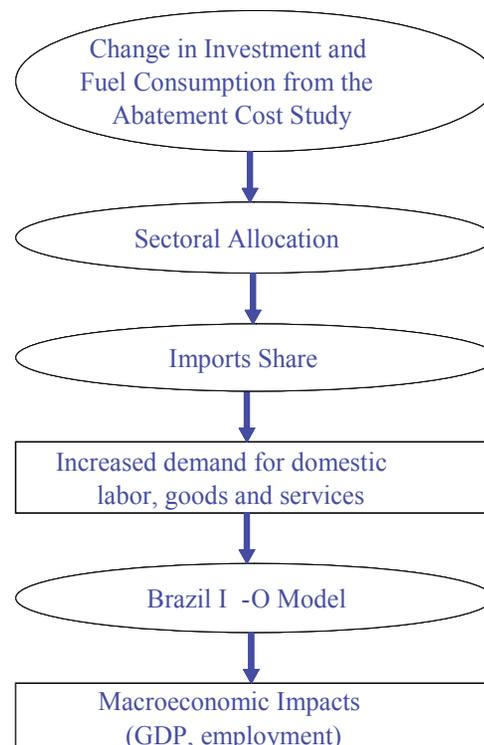
This approach is limited by its lack of constraints on supply of goods and labor. In addition, it is possible that the I-O coefficients projected for future years might be inaccurate. Nonetheless, the approach is simple and easy-to-understand, and its popularity extends from developing countries to such industrialized countries as the United States and Canada.[111]

7.2.2 Effects on GDP and Employment

Since the GHG mitigation options considered in the study require substantial investment, the green investment would generate spillover to other sectors of the economy and thus generate additional employment opportunities and value added. The effects, however, would be relatively small, with 1.8 percent value added in the low-carbon scenario in 2010 and 0.2 percent in 2030 (figure 7.10.a). The GDP impacts would decrease overtime because the national GDP in the reference scenario grow rapidly, whereas the size of green investment either remains stagnant or increase slowly. Similarly, in the low-carbon scenario, the green investment would add 1.13% in average to the total national employment compared to the reference scenario (Figure 7.10.b).

The positive effects of green investment on the economy, while perhaps surprising, are not uncommon in existing studies that use an I-O approach, which does not incorporate resource constraints. A Computable General Equilibrium (CGE) model is preferable for assessing the macroeconomic impacts of GHG mitigation policies. Even so, some current studies that use the CGE model also demonstrate that GHG mitigation options could increase GDP and generate added employment (Roland-Holst and Kahrl 2009; Van Heerden et al 2006; Timilsina and Shrestha 2006).

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Figure 7.10: Cumulative Effects of GHG Mitigation Options on the Brazilian Economy, 2010–30

% change from the baseline
2010   1.85%
2015   1.27%
2020   0.74%
2025   0.44%
2030   0.21%

- - - Low Carbon   ⸺ Reference

a) Effects on GDP (billion US$ at 2009 price)
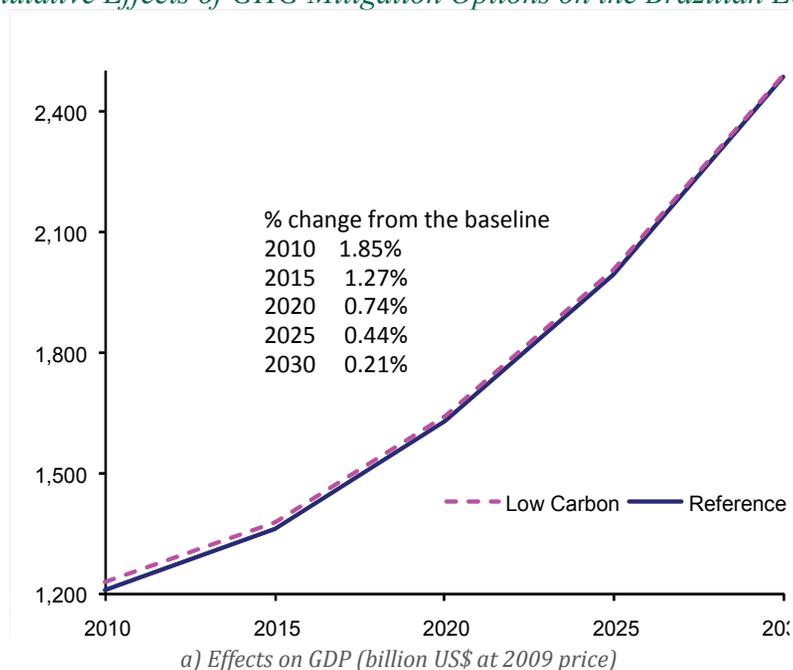
111 G. R. Timilsina, N. LeBlanc, and T. Walden (2005), *Economic Impacts of Alberta's Oil Sands*, Canadian Energy Research Institute, Calgary; N. Parra, C. Horin, M. Ruth, K. Ross, and D. Irani (2008), *Economic Impacts of Climate Change on Kansas*, The Center for Integrative Environmental Research, University of Maryland.
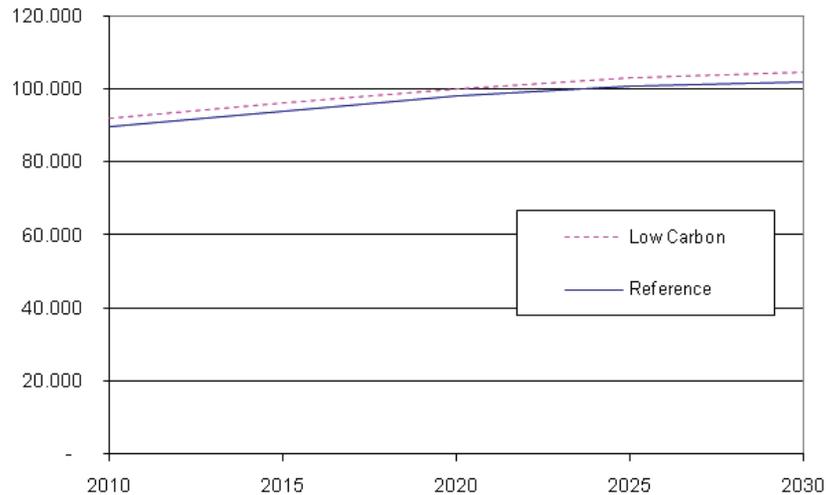
b) Effects on Employment (thousand person-years)

7.2.2.a Effects on Land Use: Agriculture and Forestry

For Brazil's land use–related sectors of agriculture and forestry, it is estimated that GHG mitigation activities would generate annually, in average, US$3.7 billon value added (GDP) and 952 thousand person-years of employment over the 2010–30 period (table 7.9). The employment effects of land-use activities are particularly notable since they tend to be labor-intensive.

Table 7.9: Macroeconomic Impacts of GHG Reduction Options: Land Use

Mitigation measure	Mitigation (2010–30) (Mt CO$_2$)	Investment (2010–30) (million US$)	Abatement Cost at 8% DR (US$/ tCO$_2$)	Impacts on GDP (2010–30) (million US$)	Impacts on employment (2010–30) (thousand person-yrs.)
Scaling up no tillage cropping	355	152	-0.33	-106	-30
Ethanol displacing domestic gasoline	176	20,158	56.22	4,127	1,095
Ethanol exported displacing gasoline abroad	666	19,680	2.10	4,948	2,845
Reforestation	1,084	54,140	39.31	29,611	7,020
Avoided deforestation	6,364	102,419	0.18	38,403	9,067

** Combines the cost for ethanol production for both domestic consumption
and export (MAC of ethanol for internal consumption is US$56.2).*

7.2.2.b Energy Sector

The overall economic impact of GHG mitigation measures on Brazil's energy sector could amount to US$851 million more per year in average in GDP over the 2010–30 period; in addition, about 142 thousand person-years of employment in average per year would be created. While energy efficiency options to reduce GHG emissions have negative economic impacts, other options have positive economic ones (table 7.10).

Table 7.10: Macroeconomic Impacts of GHG Reduction Options in the Industrial, Commercial, and Residential Sectors, 2010–30

Sector	Mitigation measure	Mitigation (2010–30) (Mt CO_2)	Investment (2010–30) (million US$)	Abatement Cost at 8% DR (US$/ t$CO_2$)	Impacts on GDP (2010–30) (million US$)	Impacts on employment (2010–30) (thousand person-yrs.)
Industry	Combustion optimization	105	2,215	-44	-5,279	-496
	Heat recovery systems	19	322	-91	-1,999	-206
	Steam recovery systems	37	818	-96	-4,131	-426
	Furnace heat recovery system	283	8,073	-25	-7,581	-839
	New industrial processes	135	7,995	2	8,116	1,922
	Other energy efficiency measures	18	827	-13	-258	6
	Solar thermal energy	25	1,481	-54	-2,149	-215
	Recycling	74	249	-34	-6,700	-676
	Natural gas displacing other fuels	43	4,087	-20	2,291	385
	Biomass displacing other fuels	69	12,357	3	2,175	442
	Renewable charcoal	566	8,794	2	11,349	1,621
	Electric motors	1	4,600	-49	366	23
	Industrial lighting	0	285	-65	-140	-11
Residential	Solar heater - residential	2	4,604	4	1,664	81
	Air conditioning (MEPS)	2	11,197	516	1,962	99
	Residential lighting	3	1,197	-119	-1,055	-52
	Refrigerators (MEPS)	9	48,875	-41	1,930	84
Commercial	Commercial lighting	1	747	-52	-330	-25
GTL	Gas to liquid (GTL)	128	6,985	-2	3,634	292

Refining	New refineries + CCS	51	120,907	19	1,719	116
	Existing refineries (energy integration)	52	4,027	6	3,416	170
	Existing refineries (incrustation control)	6	0	72	862	61
	Existing refineries (advanced controls)	6	1,491	95	1,019	51
Renewable energy	Sugarcane cogeneration	157	52,264	-104	28	2
	Wind	19	12,897	-7	4,418	429
	Transmission line Brazil-Venezuela	27	454	-30	2,532	139

7.2.2.c Transport Sector

The transport sector requires an investment of about US$150 billion over the 2010–30 period (table 7.11). In average, it would add US$1.9 billion value added and 210 thousand person year employment annually over the study period. Interestingly, GHG mitigation options in such sectors as industry appear attractive at the project or activity level since they have negative abatement costs. But from an economy-wide perspective, they may not be the best options. Conversely, transport-sector options, which appear less attractive at the project or activity level, are more attractive from a macroeconomic perspective. This is an important observation since most existing studies focus only on project-level abatement cost analysis and do not capture economy-wide impacts. Hence, policies and implementation strategies based on such limited analyses could be misleading.

Table 7.11: Macroeconomic Impacts of Transport-sector Mitigation Options

Sector	Mitigation measure	Mitigation (2010–30) (Mt CO$_2$)	Investment (2010–30) (million US$)	Abatement Cost at 8% DR (US$/ tCO$_2$)	Impacts on GDP (2010–30) (million US$)	Impacts on employment (2010–30) (thousand person-years)
Regional transport	Rail and waterways investment vs. roads	63	41,707	19	2,917	368
	Bullet train (São Paulo-Rio de Janeiro)	13	28,759	352	14,837	1,050
Urban transport	Bus rapid transit (BRT) investment	103	33,575	33	5,535	651
	Metro and BRT investment	174	42,620	91	17,869	2,433
	Traffic optimizaton	45	1,050	-1	-576	-78
	Bike lane investment	16	302	1	-33	-8

Note: This table excludes US$20 billion of investment costs in ethanol (included in the macroeconomic impacts of GHG reduction options for LULUCF).* Includes both investment costs for BRT and avoided GHG mitigation.
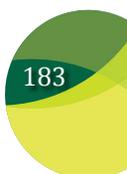
7.2.2.d Waste Management

GHG mitigation activities in the waste management sector are also expected to contribute positively to the economy, but to a lesser extent. The mitigation activities are estimated to add US$9 billion to GDP and 370,000 person-years of employment to the Brazilian economy over the 2010–30 period (table 7.12).

Table 7.12: Macroeconomic Impacts of Waste-management Sector Mitigation Options

Mitigation measure	Mitigation (2010-30) (Mt CO_2)	Investment (2010-30) (million US$)	Abatement Cost at 8% DR (US$/ t$CO_2$)	Impacts on GDP (2010-30) (billion US$)	Impacts on employment (2010-30) (thousand person-years)
Landfill methane destruction	963	5,687	2.87	2,224	125
Wastewater treat. + methane destruction (ind.)	238	36,569	103	40,807	2,152
Wastewater treat. + methane destruction (res. & com.)	116	41,678	10.4	48,737	2,748

7.3 Concluding Remarks

On the basis of this two-level economic analysis (micro and macro), this study selected the mitigation and carbon uptake options retained for the low-carbon scenario, presented in the next chapter. The criteria adopted were that the MAC, which represents the social perspective usually adopted in government planning exercise, should not exceed US$50, except for the options that would obviously be triggered more by the large co-benefits expected and for which a high MAC is expected to be largely balanced by these co-benefits and by positive macroeconomic impacts. This is typically the case for most of the proposed transport- and waste-sector measures.
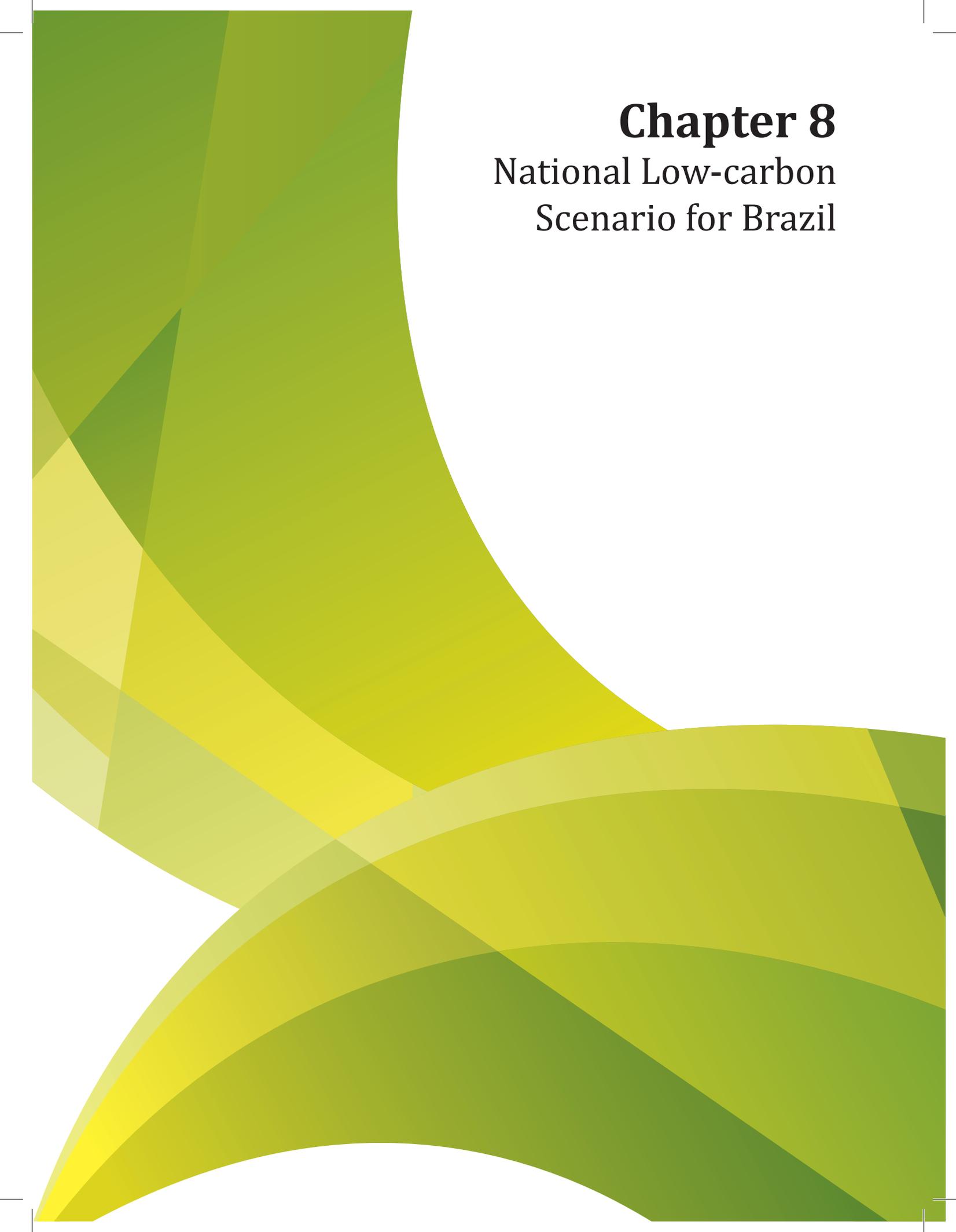
Chapter 8
National Low-carbon
Scenario for Brazil

The reference and low-carbon scenarios for Brazil's four main emitting sectors—land, land-use change, and forestry (LULUCF); energy; transport; and waste management—presented in the preceding chapters, were built in a coordinated and consistent manner. As a collective whole, they lay the foundation for establishing a national low-carbon scenario. This chapter aggregates the results from each of the four sectors into a single reference scenario and a proposed low-carbon scenario. It should be noted that these scenarios are not a projection of Brazil's full GHG emissions inventory and thus do not pretend to capture 100 percent of all sources of GHG emissions.[112] Rather, they present projections for the four sectors that offer the greatest opportunities for emissions mitigation and carbon uptake. The organization of this chapter, like that of chapters 3-6, begins with the reference scenario, followed by the proposed low-carbon scenario. The last section, which outlines the uncertainties intrinsic to any future prospective analysis, underscores that these results should be considered as indicative.

8.1 The Reference Scenario

To estimate Brazil's potential contribution to limiting the increased concentration of global GHG emissions, it is first necessary to determine the emissions that would have been generated without undertaking specific efforts to achieve that goal. Such a reference scenario is subject to many assumptions regarding the country's future economic and social development. **It is worth to note that such reference scenario is based on a different methodology than the one used by the Brazilian government in its national GHG inventory.** Moreover, having focused only on the areas where the most promising low-carbon options were identified, the reference scenario built by this study could not cover 100 percent of all emission sources of the country and therefore, should not be considered as a simulation of future national emissions inventories. This section first describes the method used to build the reference scenario, including the underlying principles, and follows with a discussion of the results and interpretation.

8.1.1 Method and Principles

Since the objective of this study is not to simulate the future development of the Brazilian economy or to question the government's stated development objectives, this study has adhered, to the extent possible, to existing planning documents and government plans to establish the reference scenario. Therefore, the 2030 National Energy Plan (PNE 2030), published by the MME in 2007, was adopted as the reference scenario for the energy sector. The study also took into account of Brazil's Government Accelerated Growth Plan (PAC) and the National Logistic and Transport Plan (PNLT), launched in 2007, and other policies and measures in other sectors that were already published by the time the reference scenario was established. To ensure full consistency across all sectors, the study adopted the same macroeconomic and demography assumptions found in the PNE 2030 (Annex A).[113] In short, the construction of the reference scenario considered an average annual GDP growth of 4.1 percent,[114] an average annual

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112 For example, industrial sources of nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and other non-Kyoto GHG gases are not accounted for here. Without a current complete inventory, it is not possible to determine precisely the share of other sources in the national GHG balance. However, based on the first Brazil National Communication (1994), it is expected that they would not exceed 5 percent of the total Kyoto GHG emissions.

113 Annex A provides a complete set of common assumptions.

114 In the context of the recent financial crisis, the Brazilian government has recently changed its planning prospects and is considering a lower GDP growth rate. Given the long-term nature of the study, it did not lower the average GDP growth rate.

population growth of 0.93 percent, and a set of fuel prices corresponding to an average WTI oil price of about US$45 per barrel.

For the other areas, official planning documents were either lacking or not detailed enough to estimate associated emissions. In these cases, the study built its own sector reference scenarios, using sector models developed or adjusted for the project,[115] always ensuring consistency with the same set of common assumptions. The building of the sector-specific reference scenarios involved close coordination so that all four would be fully consistent with each other and could thus be aggregated.

Key interfaces were addressed jointly, one example being the determination and integration of land needs for the production of solid and liquid biofuels, which have been considered in the transport and energy sectors, in the land-use modeling. On this basis, the study team was able to establish a national reference scenario for the main GHG emissions sources in Brazil over the coming two decades (2010–30).

8.1.2 Results and Interpretation

Under the reference scenario, total emissions increase by approximately one-third (32 percent) over the 2010–30 period, reaching nearly 1.7 Gt CO_2e per year in 2030[116], which may then represent about 2.7 percent of global emissions[117]. In cumulative terms, Brazil would emit nearly 26 Gt CO_2e over the period, slightly more than one year of emissions in Annex I countries.[118]

In terms of sectoral distribution, it is not surprising that deforestation remains the largest source of emissions over the period. While emissions from deforestation reach about 530 Mt CO_2e per year by 2030, their relative share is reduced from 41 percent of national emissions in 2008 to 31 percent by 2030. Energy emissions nearly double over the 2008–30 period (excluding the integration of transport emissions), becoming the second largest source of GHG emissions after deforestation. Transport, whose emissions increase by more than half, becomes the third largest source. Livestock, formerly the second largest emitting source, remains about constant, at a level similar to that of transport in 2030. Emissions from agriculture, the fifth largest emitting sector, nearly double over the period. Finally, waste-management emissions increase by nearly half. In sum, energy-related emissions from the energy and transport sectors grow faster than LULUCF sector emissions, although the latter remains dominant in both annual and cumulative terms (table 8.1, figure 8.1).

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115 More details can be found in the corresponding technical reports for each sector.

116 As a result of the methodology used to establish this reference scenario, it differs from the projections of national and sectoral emissions presented by the Brazilian Government together with the voluntary commitment to reduce emissions officially announced in 2009 and reflected in law Law 12.187. In a way, the difference between this reference scenario defined in this study and the one established by the Brazilian government on the basis of past trends reflects the positive impact in terms of emissions of the policies already adopted at the time the reference scenario of this study was established. Notably, the Reference Scenario was defined before the elaboration of the National Plan on Climate Change (PNMC) and the adoption of Law 12.187, which institutes the National Climate Change Policy of Brazil and set a voluntary national greenhouse gas reduction target.

117 Based on an estimate of global GHG emeissions of 61.5GtCO_2e by 2030 published by UNFCCC, 2007. The reference scenario presented in the UNFCCC consists of (i) energy-related CO_2 emissions provided by the International Energy Agency (IEA 2006); (ii) extrapolated baseline projections for non-CO_2 emissions from the U.S. Environmental Protection Agency (USEPA 2006); (iii) current CO_2 emissions related to land use, land use change, and forestry (LULUCF); and (iv) CO_2 emissions from industrial processes provided by the World Business Council for Sustainable Development (WBCSD 2002).

118 According to the United Nations Framework Convention on Climate Change (UNFCCC), global emissions would rise from 38.9 Gt CO_2e in 2000 to 61.5 Gt CO_2e in 2030, while emissions from Annex I countries would remain relatively stable at 21–22 Gt CO_2e per year. See UNFCCC (2007), *Investment and Financial Flows To Address Climate Change.*

Table 8.1: Sectoral Distribution of Gross Emissions in the Reference Scenario, 2008 and 2030

Emissions source	2008		2030	
	Mt CO$_2$e/year	%	Mt CO$_2$e/year	%
Deforestation	536	42	533	31
Energy	232	18	458	27
Transport	149	12	245	14
Livestock	237	18	272	16
Agriculture	72	6	111	6
Waste management	62	5	99	6
Total	**1,288**	**100**	**1,718**	**100**

Figure 8.1: Gross Sectoral Emissions in the Reference Scenario, 2008–30
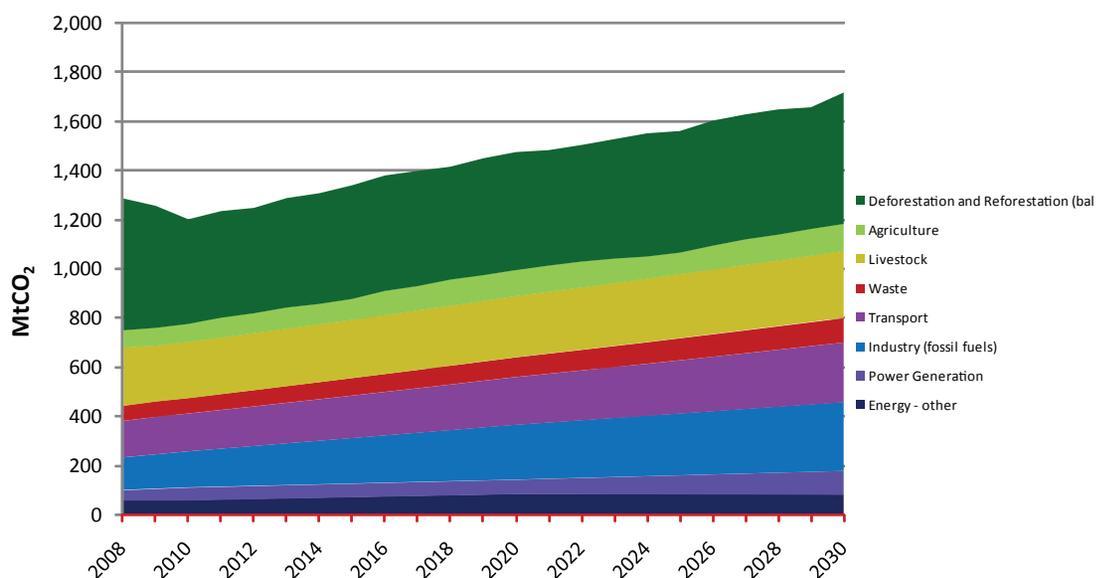
In the reference scenario, the rate of deforestation is expected to remain relatively stable. The Brazilian government has recently implemented various forest-protection policies and programs, which, along with changes in economic factors (e.g., drop in international meat and soybean prices), have the combined effect of decreasing the pace of deforestation (from about 27,000 km^2 in 2004 to 11,200 km^2 in 2007). This new level is on par with 2010–30 modeling results developed by this study, which are based on economic projections for crops and meat production and productivity tendencies. Thus, absent new policy changes, emissions from deforestation are expected to stabilize at about 400–500 Mt CO$_2$ per year. According to the modeling results, some decrease in the deforestation rate is expected until 2011—due to a small contraction in livestock activities observed over the past several years—after which time it is expected to stabilize and resume a slow but steady rise.

Energy-related emissions, related to either transport (singled out to better reflect the evolution of the sector's contribution) or other energy needs, represent more than two-thirds

(68 percent) of the total annual increase between 2008 and 2030. Transport activities and energy consumption are both functions of economic growth. While certain subsectors have already low carbon intensity—namely because of bio-ethanol fuel for vehicles and hydropower for electricity generation—others continue to rely on fossil fuels. This is the case for urban transport, which continues to rely on diesel power for bus and air transport and industrial thermal processes. As a result, urban-transport emissions grow automatically. Individual vehicles account for one-third of the growth in transport emissions, while trucks comprise another third. Without bio-ethanol, transport emissions would be inflated by 50 percent in 2030. Finally, waste-management emissions are expected to remain relatively stable at about 5-6 percent of gross emissions, although they will grow significantly in absolute terms (+59 percent) because of growth in waste volume and the corresponding rise in the disposal rate at landfills, where anaerobic fermentation results in the release of CH_4.

8.2 Proposed Low-carbon Scenario

Based on the in-depth technical and economic assessments of mitigation and carbon uptake opportunities, presented in chapters 3–6, a low-carbon scenario is proposed to further explore Brazil's contribution to the global effort to mitigate climate change over the next two decades. Like the national reference scenario, the national low-carbon scenario is an aggregate of the low-carbon scenarios for the four sectors analyzed: LULUCF, energy, transport, and water management. It has similarly been built in a coordinated manner to ensure full consistency among the four main areas considered.[119]

8.2.1 Method and Principles

Based on the best available expertise the World Bank could assemble, the proposed national low-carbon scenario targeted the reference scenario's development objectives using less carbon-intensive technologies deemed available for large-scale implementation over the 2010–30 period. For each of the four areas, the most significant mitigation and carbon-uptake opportunities were analyzed.

The proposed national low-carbon scenario combines the bottom-up, technology-driven approach, based on in-depth technical and economic assessments of feasible options in the Brazilian context and optimization at the sectoral level. Less promising options from a cost-effectiveness perspective, as well as those fully explored over the period analyzed in the reference scenario, were not further considered. A cut-off threshold of US$50 per tCO_2e was applied in order to discard those options with the highest marginal abatement costs (MACs), which would not be justified considering other major indirect benefits.

Rather than adding up independent assessed mitigation potentials associated with specific technologies, the proposed low-carbon scenario has been built using a systemic approach, enriched by iterative cross-sectoral coordination. Such a cross-sectoral approach was particularly helpful in identifying solutions to mitigate future deforestation, which could not have been achieved via analysis of individual activities. Indeed, in-depth analysis of the Brazilian livestock sector, together with geospatially explicit modeling of the land-use dynamic, enabled

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119 Three seminars were held (September 14–16, 2007, April 30, 2008, and March 19, 2009) to present and discuss the methodology, intermediary results, and near-final results with representatives of 10 Brazilian government ministries. Sectoral teams also interacted on various occasions with technical-area specialists and public-agency representatives.

this study to determine that a gradual shift from low-productivity livestock production systems to high-productivity ones would free up enough land to accommodate crops expansion and forest plantation and restoration at zero additional land demand compared to the base year of 2008. This includes avoiding potential carbon leakages that mitigation measures considered in various sectors (e.g., biofuels in the energy and transport sectors and carbon uptake activities in the forestry sector) could have induced by increasing national land demand and eventually fueling the progression of the pioneer frontier in the Amazon and Cerrado regions. As a result, consistent potentials for mitigation and carbon uptake were estimated for each of the four main areas and then consolidated at the national level to build the proposed low-carbon scenario.

This type of low-carbon scenario should be considered as modular rather than "take it or leave it," since the political economy may differ significantly by sector or region, making certain mitigation options, which initially appear more expensive, easier to harvest over the long run; the converse is also true. Given the many combinations that are possible over this period and the uncertainty that certain barriers, particularly those related to incremental costs and financing, will be removed, this low-carbon scenario should not be considered as the only possible one. Rather, it should be taken as a scenario aimed at informing decision makers about the order of magnitude of emissions reductions that could be achieved over the next two decades and associated measureable costs and benefits.

8.2.2 Results and Interpretation

Over the period considered, the proposed low-carbon scenario projects an emissions reduction from deforestation that would comply with the Brazilian government's voluntary commitment announced at Copenhagen in December 2009. In the year 2030, projected gross emissions in the low-carbon scenario are 40 percent lower than in the reference scenario (1,023Mt CO_2e versus 1,718 Mt CO_2e per year), while net emissions are 52 percent percent lower (810 Mt CO_2e versus 1,697 Mt CO_2e per year) (table 8.2)[120].

Table 8.2: Comparison of Annual Emissions Distribution in the Reference and Low-carbon Scenarios, by Sector

Sector	Reference 2008		Reference 2030		Low-carbon 2030	
	Mt CO_2e	%	Mt CO_2e	%	Mt CO_2e	%
Energy	232	18	458	27	297	29
Transport	149	12	245	14	174	17
Waste	62	5	99	6	18	2
Deforestation	536	42	533	31	196	19
Livestock	237	18	272	16	249	24
Agriculture	72	6	111	6	89	9
Total Gross Emissions	**1,288**	**100**	**1,718**	**100**	**1,023**	**100**
Carbon uptake	-29	-2	-21	-1	-213	-21
Total Net Emissions	**1,259**	**98**	**1,697**	**99**	**810**	**79**

120 When calculating national carbon inventories, some countries consider the contribution of natural regrowth towards carbon uptake; therefore, although this study does not compute this contribution in the carbon balance of LULUCF activities, it would be fair to add that information for comparison purposes. If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 112MtCO2 per year on average, thus reducing the net emissions.

The key driver for reducing emissions in the low-carbon scenario is a dramatic reduction in deforestation, which is far larger than the emissions reduction for all the other sectors combined. Reducing emissions from deforestation and carbon uptake via forest plantations and restoration are the two areas where the proposed low-carbon scenario succeeded most in reducing emissions (figure 8.2). Transport- and energy-sector emissions are less easily reduced as they are already low compared to international standards, mainly because of the large share of hydroelectricity and bio-ethanol in the current energy matrix (table 8.2, figure 8.3).

Figure 8.2: Emissions Reduction Potential in the Low-carbon Scenario, 2010–30, Compared to the Reference Scenario
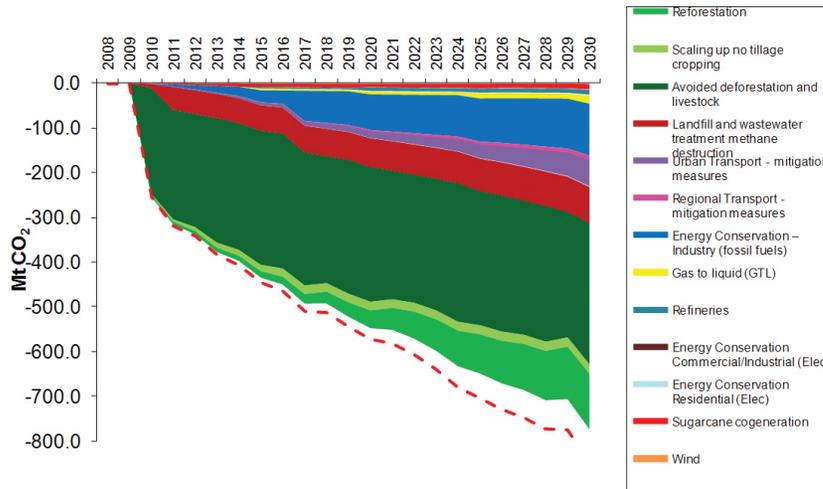
Figure 8.3: GHG Mitigation Wedges in the Low-carbon Scenario, 2010–30
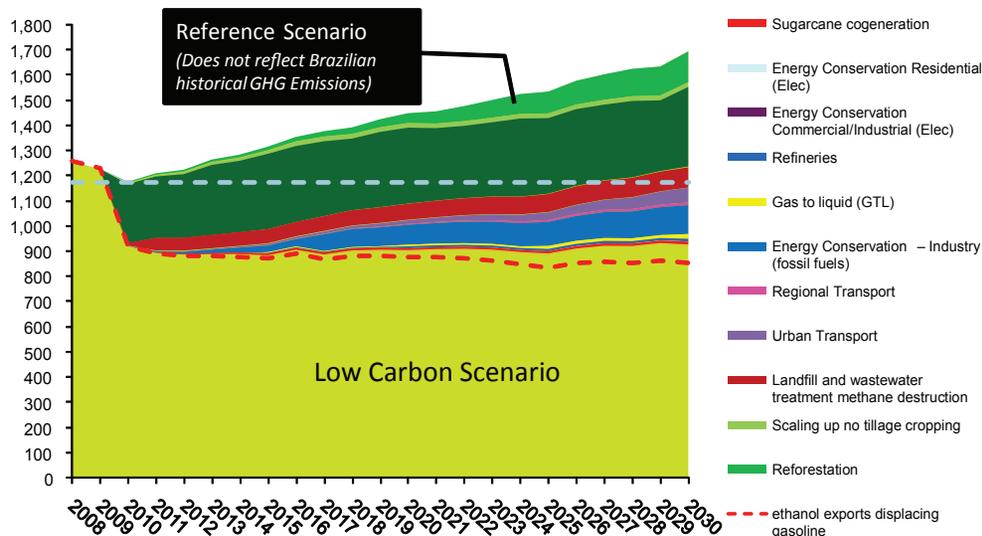
As a consequence, the distribution of GHG emissions among sectors in the low-carbon scenario differs significantly from the distribution observed in the reference scenario, mainly because the share of deforestation emissions is reduced to approximately 70 percent compared to the reference scenario (figure 8.4).

Figure 8.4: Gross Sectoral Emissions under the Low-carbon Scenario, 2010–30
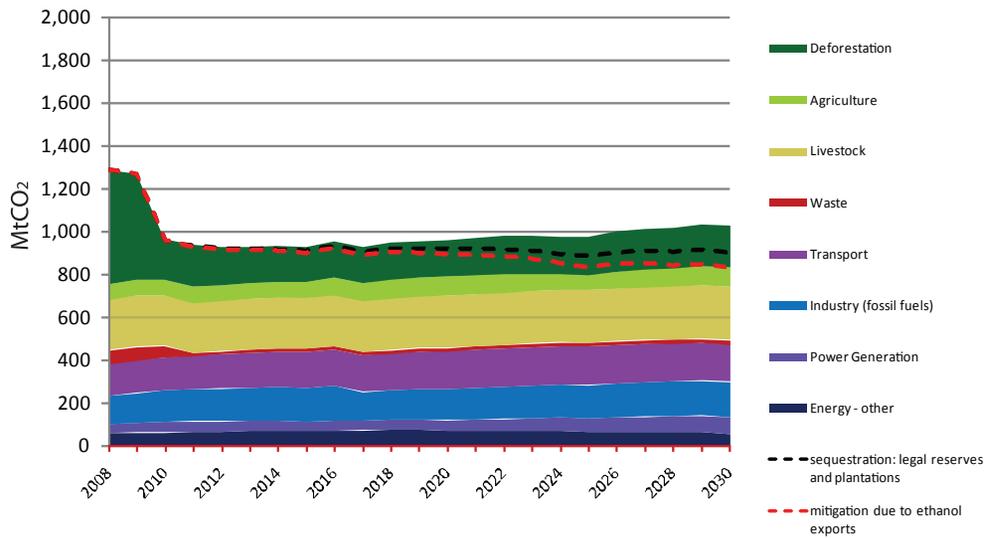
In 2030, the two main emitting sectors are energy (29 percent) and livestock (24 percent). Transport also increases its share from 14 percent in 2008 to 18 percent in 2030 (table 8.2, figure 8.5).

Figure 8.5: Comparisons of Gross Emissions Distribution among Sectors in the Reference and Low-carbon Scenarios, 2008–30
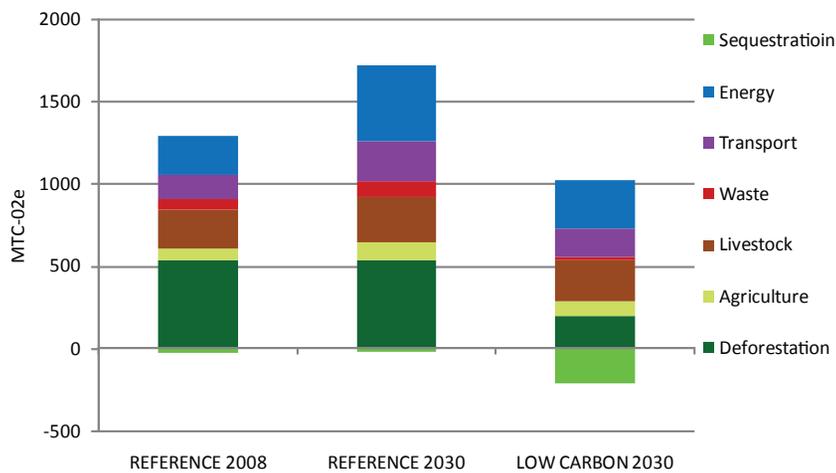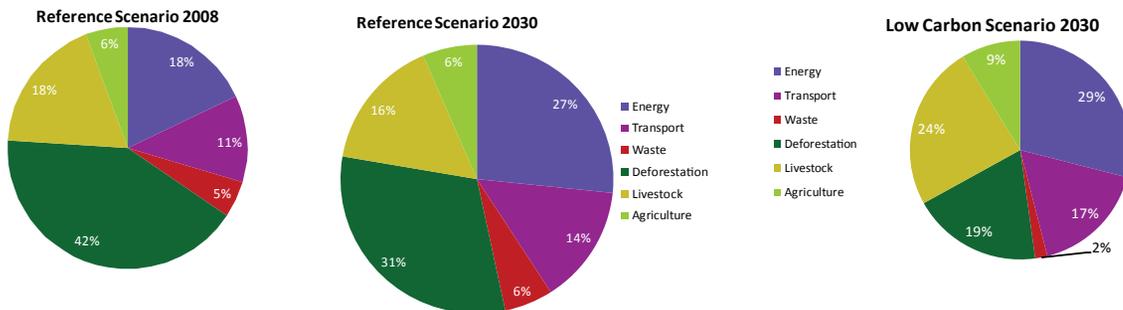
Similar changes are also reflected in the distribution of cumulative emissions among sectors over the 2010–30 period (table 8.3, figure 8.6): The relative share of LULUCF emissions is lower in the low-carbon scenario than in the reference scenario, while shares of energy- and transport-sector emissions are markedly higher in the low-carbon scenario.

Table 8.3: Comparison of Cumulative Emissions
Distribution among Sectors in the Reference and Low-carbon Scenarios, 2010–30

Sector	Reference scenario (2010–30)		Low-carbon scenario (2010–30)		Reduction		
	Mt CO_2e	% of total	Mt CO_2e	% of total	Mt CO_2e	% of total	% of Reference scenario (2010–30)
Land use	16.709	56	9.228	49	7.481	67	44
Waste	1692	6	375	2	1.317	12	78
Transport	4.101	14	3.610	19	487	4	13
Energy	7.587	25	5.765	30	1.821	16	24
Total	**30.089**	**100**	**18.982**	**100**	**11.106**	**100**	**37**

Figure 8.6: Comparison of Emissions Distribution among
Sectors in the Reference and Low-Carbon Scenarios, 2008–30
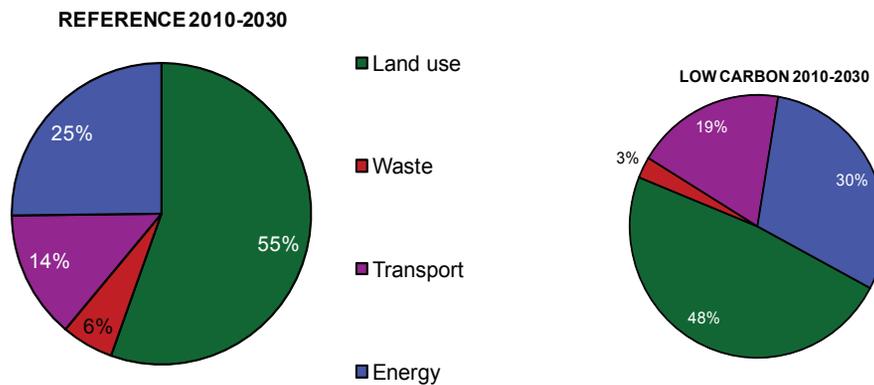
8.3 Key Uncertainties for Emissions Estimates

Since the reference and proposed low-carbon scenarios are subject to uncertainties, the results are indicative and should be used to inform stakeholders of future emissions if the study's assumptions, which were based on a broad and ongoing consultative process, are verified. Some of the uncertainties result from calculations related to either the reference or low-carbon

scenario, while others concern both. This section first outlines overall uncertainties for the four main areas and then addresses more sector-specific ones.

8.3.1 Macroeconomic Projections

For emissions-generating activities, both the reference and low-carbon scenarios depend heavily on the macroeconomic projections of the 2030 National Energy Plan (PNE 2030) published by the EPE in 2007. The plan's B1 scenario, adopted as the reference case, estimates the Brazilian economy's average growth rate at 4.1 percent annually. As a consequence of the recent financial crisis, the Brazilian government expects lower GDP growth, particularly in the near term. If so, decreased supply and demand for a variety of services and products would slow the pace of deforestation and energy consumption, including demand for transport services. However, given the longer-term timeframe of the study, medium-term projections for emissions growth under the reference scenario are less affected by the crisis and would remain about the same. The same short- and medium-term trends would apply to the low-carbon scenario.

8.3.2 Land-use Questions

With respect to uncertainties for projected land-use emissions, one must distinguish between the gross volume of emissions from GHG sources and the net emissions obtained after taking into account carbon uptake activities involving mainly production forests and native forest recovery. Uncertainties for gross emissions differ between the first and second stages of calculations: (i) projecting land use and land-use changes and (ii) converting the results into emissions.

The economic modeling developed for the first stage of calculations benefited greatly from the wealth of historical local data, which allowed for robust calibrations of the key parameters and equations (box 8.1). Based on the results, it was assumed that the main uncertainties are linked to the above-mentioned macroeconomic projections, which directly affect projections for expanded cropland and meat production and thus deforestation. If cropland and meat production expand more than expected under the reference scenario, then more effort would be required under the low-carbon scenario to release enough pasture; otherwise, the additional deforestation that would result would lead to increased emissions.

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Uncertainties inherent in the economic modeling of future land-use scenarios are related to the modeling of (i) domestic demand (a function of income, ultimately linked to macroeconomic projections and equilibrium prices determined by the modeling), (ii) exports (a function of macroeconomic parameters and prices), and (iii) production (a function of costs and productivity per hectare). Price elasticities were calibrated from a historical series (1996–2008), while production costs and per-hectare productivity for various crops were based on data from the National Supply Company (CONAB); the Brazilian Institute of Geography and Statistics (IBGE); and Agroconsulta and Scott Consultoria, two private firms that annually update estimates for the sector. Projections for Brazilian exports are exogeneous and were based on global projections of the Food and Agricultural Policy Research Institute (FAPRI), the same source used by the U.S. Department of Agriculture; FAPRI projections were used to calibrate export projections for 2009–18 and 2019–30.

Thus, it was assumed that the key uncertainties are linked to macroeconomic projections. Under the reference scenario, projections for meat exports and pasture are relatively conservative. With the exception of the Amazon region, where significant growth in pasture is expected, volume nationwide remains fairly stable, attributable to the continued stability in global meat demand. Stabilization in meat exports—or even a slight decrease, observed over the past several years—is difficult for Brazilian industry to reverse, following the impressive development of the previous decade (1997–2006).

Source: ICONE.

For the second stage of calculations, the main uncertainties are based on available data for soil carbon content and the vegetation converted, which drive the conversion of deforestation into GHG emissions. Estimates of the above- and below-ground carbon content of biomass depends on the accuracy of the data, which can only be improved by intensive field research. The uncertainty of the data used for this national study is estimated at about 20 percent, which mainly affects the reference scenario, since conversion of native vegetation is brought to very low levels in the low-carbon scenario.

Under the low-carbon scenario, an added uncertainty is the pace of releasing pasture for expanding agricultural crops to avoid deforestation and comply with the legal scenario adopted as a target for forest recovery–based carbon uptake. The rapid fall of deforestation-based emissions entails considerable efforts to improve livestock productivity to free up pasture for other activities. To the extent that the release of pasture keeps pace with the annual need for additional land for crops expansion, the conversion of native vegetation would no longer be needed; in theory, deforestation and related emissions would then be brought to zero. Key questions are whether the pace of pasture release and agricultural expansion will match and whether the necessary conditions will be created to ensure that the pace of agricultural expansion is not too rapid. Achieving the right pace on the livestock side and providing the right incentives—positive or negative—for forest protection are critical. If the required financing disbursements are not made on time, deforestation and its related emissions will continue.

Another uncertainty involves the expected effect of productivity gains on the growth of livestock. In the study, the Brazilian share of the international market is taken as an exogenous projection from FAPRI (box 8.1). Increased productivity could improve competition and thus spur increased production. Since productivity gains converge with less need for pasture area, such a rebound effect should not cause more deforestation, subject to the condition that such gains are limited to the areas of the former low-productivity systems.

Under the low-carbon scenario, the main carbon uptake potential resides in the recovery of legal forest reserves. Indeed, the proposed low-carbon scenario considered full compliance with the Forest Reserve Law—including an enormous effort to recover riparian and native forests—as a target for carbon uptake. This "Legal Scenario" would break with the past. A fully Legal Scenario may be difficult to implement; flexibility mechanisms are already being discussed, especially regarding legal reserves, which may reduce the net area reforested. For example, in such Amazon states as Rondônia and Pará, which have already developed economic and ecological zoning, the legal reserve can be reduced from 80 percent to 50 percent, particularly for rural properties located along the main roads. In exchange, landowners would commit to fully restoring the 50-percent legal reserve, with the abated 30 percent converted into "agriculture consolidation areas."

Therefore, the carbon uptake volume indicated in this study may be at the upper bounds of the range. Building flexibility into target setting would reduce the volume of carbon sequestered; at the same time, it would ease the effort of releasing the corresponding amount of pasture and thus mitigate the risk of inducing a carbon leakage. That is, conversion of native vegetation would occur somewhere else as a result of the domino effect triggered by the induced net reduction of land available at the national level for crop and livestock expansion. In terms of carbon balance, it is preferable to avoid releasing in the atmosphere the full carbon stock of one hectare of burned forest over the progressive removal of GHGs from the atmosphere through the restoration of one hectare of forest. Thus, it is essential to ensure consistency between efforts to release pasture and enforce the restoration of legal reserves.

8.3.3 Energy

Uncertainties for energy-related emissions depend on assumptions about available supply options over the reference scenario timeframe, as well as macroeconomic projections. In this respect, the PNE 2030 reflects some strategic choices of the Brazilian government; those with very low carbon intensity may involve significant implementation challenges. For example, scenario B1, adopted as the reference scenario for this study, assumes continued growth in hydropower capacity and development of biomass, wind, and nuclear energy that far exceeds trends observed in the recent past. Results of recent energy auctions show that hydropower faced difficulties and has not met earlier expectations, with a significant share of winning bids dependent on fuel oil, diesel, and even coal-based power generation. Corrective measures, including streamlining environmental licensing for hydropower plants[121] and GHG emissions compensation for more carbon-intensive options, are already under way, which should boost the future participation of renewable energy, targeted by government policies. Yet the carbon intensity of the power sector may increase beyond the amount projected in the reference scenario, at least over the initial few years of the period considered.

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121 See in particular: "Environmental Licensing for Hydroelectric Projects in Brazil: A Contribution to the Debate," Summary Report. World Bank Country Management Unit, March 28, 2008.

8.3.4 Transport

For transport-related emissions, major causes of uncertainty involve the share of bio-ethanol as a fuel substitute for gasoline and the pace of building transport infrastructure, as well as macroeconomic projections. Fuel switching depends on price comparisons between ethanol and gasoline at the final-consumer level, which is closely tied to international oil prices. Given the high volatility of international oil prices, the key element to reduce uncertainty and enable meeting a specific target would be an adjustment mechanism for the price of ethanol. The three-decade history of Brazil's PROALCOOL program shows that such a mechanism is feasible, although it can be especially costly when gasoline prices fall below ethanol production costs. Current prospects for high oil prices reduce this uncertainty considerably.

Building new transport infrastructure is key to enabling a modal shift to low-carbon transport modes and reducing congestion, which would allow for decreasing emissions in both the reference and low-carbon scenarios. Therefore, the reliability of transport emissions projections depends on the capacity of major stakeholders, particularly local and federal government and key financial institutions, to leverage adequate and timely financing.

8.3.5 Waste Management

Reference-scenario emissions for solid and liquid waste management, like transport-related emissions, grow according to macroeconomic parameters, including demography. But waste-management emissions are related mainly to progress made in solid waste collection and appropriate disposal in landfills, where additional emissions from methane (CH_4) result from anaerobic fermentation. Thus, uncertainty about waste-management emissions in the reference scenario is linked primarily to questions about financing and implementing waste-management projects at the municipal level. A secondary source of uncertainty involves technical assumptions in the emissions calculation, particularly regarding organic content, which would require further field research to refine estimates. Assuming that waste is effectively collected, the uncertainty regarding landfill gas emissions remains large, at about 40 percent.

In the low-carbon scenario, these emissions are destroyed via combustion in flares or small power plants. Since the Clean Development Mechanism (CDM), an existing international instrument, has demonstrated its effectiveness in fostering the destruction of landfill gas, it is expected that solid waste emissions under the low-carbon scenario will continue close to zero, independent of emissions levels in the reference scenario, subject to the continuation of the CDM over the period considered.

8.4 Looking Ahead

In summary, the major uncertainties that affect the relative success of the proposed low-carbon scenario involve a range of implementation challenges. Chapter 10 outlines ways to meet these challenges through better policy and institutional coordination and incentives, while the additional financing required is the subject of the next chapter.

Chapter 9
Financing the Low-carbon Scenario

The proposed low-carbon options for Brazil aims first and foremost to deliver products and services that support the country's sustainable economic development. These investment decisions secondarily help to avoid emissions usually associated with the production of the product or service in question either directly, by shifting to less carbon-intensive technologies, or indirectly, by increasing productivity gains to reduce global land demand. Thus, financing and investment decisions are guided by a blend of economic interest and altruism.

Brazil currently has an array of mechanisms in place to finance economic activities, yet few target climate change–related activities specifically. Those mechanisms that are not climate change–specific might apply equally to low-carbon and reference-scenario alternatives. Many proposed activities (e.g., integrated livestock and agriculture, rehabilitation of degraded pastureland for enhanced productivity, or scaled-up cogeneration of electricity with bagasse) support sustainable economic development within their sectors and can be financed through credit lines of Brazil's National Bank of Economic and Social Development (BNDES). But the availability, terms, and reach of such financing may be limited, especially when applied to unconventional alternatives.

This chapter reviews the volume of financing needed to implement the proposed low-carbon scenario for each of the sectors considered and assesses to what extent additional financing would be needed to fill potential funding gaps. For this purpose, the study team consulted various Brazilian financial institutions and reviewed existing public financing mechanisms. Since the 20-year period covered by the study is far longer than the time horizon most financial institutions use, the results presented in this chapter should be considered preliminary.

9.1 Overall Investment Requirements

The cumulative investment costs of the proposed low-carbon options are estimated at US$725 billion in nominal terms over the 2010-2030 period or approximately $34 billion per year on average.[122] The per-sector distribution is $344 billion for energy, $156 billion for land use, $141 billion for transport, and $84 billion for waste management.

For purposes of comparison, national investments in 2008 totaled US$250 billion which represents 19 percent of GDP. In 2008, the BNDES disbursed R$90.8 billion (US$41.2 billion) in loans, the bulk of which flowed to the industrial sector, followed by infrastructure. FDI in 2008 amounted to US$30 billion.[123] The Government Accelerated Growth Plan (PAC), launched in 2007, expects to spend US$503.9 billion over a four-year period (2007–10).[124]

The total investment difference between the low-carbon and reference scenarios over the 2010–30 period is US$389 billion or US$20 billion per year. The corresponding abatement

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122 Present value (2009) discounted at 8 percent is US$318 billion.
123 BMI.
124 The PAC envisions that R$503.9 billion will be spent on transport, energy, housing, and hydropower resources; the program also includes stimulus for credit and financing, improvement of the investment environment, and long-term fiscal measures. Planned investments over the 2007–10 period are divided into three types of infrastructure (i) logistical (highways, rail, ports, airports, and waterways) ($R58.3 billion), (ii) energy (generation and transmission; production; exploration and transport of oil, natural gas, and renewable fuels) ($274.8 billion), and (iii) social and urban (housing, metro, urban rail, and universal electrification and hydropower programs) ($170.8 billion [of which R$106 billion is for housing projects]). To achieve results more rapidly, the Brazilian government opted for infrastructure recovery projects, completion of ongoing projects, and initiation of projects with a strong potential to generate social and economic development. Investment plans include the construction and recovery of 45,000 km of roads and 2,518 km of rail, expansion and improvement of 12 ports and 20 airports, more than 12 GWs of new generation, construction of 13,826 km of transmission lines, and installation of four biodiesel refineries and 77 ethanol plants.

potential is 11.7 Gt CO_2e over the 2010-2030 period or an average of 560 Mt CO_2e annually (table 9.1) when including ethanol exports displacing gasoline abroad. While total investments are spread somewhat evenly over the period, it is difficult to anticipate long-term investments and implementation levels. In the case of transport, more than 50 percent of investments occur in the 2010–15 period; these are largely driven by infrastructure projects related to the 2014 World Cup event (e.g., metro and bullet train). For the energy sector, investment requirements are evenly spread over the period, with the exception of refrigerators, whose more energy-efficient models enter the market after 2015, and new refineries, which follow an independent construction schedule. Other investments are concentrated in the initial years of the period. For renewable charcoal, more than US$5 billion is spent in the first six years to prepare the soil and plant Eucalyptus trees. Some proposed activities involving not yet commercialized technologies have declining costs over the 20-year time horizon.

Although the overall costs for implementing a low-carbon development scenario may not seem exorbitant or detrimental to economic development, identifying resources and financing mechanisms for specific mitigation activities may not be easy; thus, appropriately defined programs or actions that promote their implementation would be required. Moreover, as detailed in chapter 7[125], mobilizing the additional investment required, in particular from the private sector, would require providing incentives to make low carbon options attractive when compared with more conventional options. The corresponding economic incentive would not necessarily be in the form of carbon revenue through the sale of carbon credits; other incentives, such as financing conditions or tax credits, could be used. Transport mitigation options would require the greatest amount of average annual incentives at approximately $9 billion, followed by energy at $7 billion, waste at $3 billion and LULUCF at $2.2 billion. However, most of energy efficiency measures would not require incentives.

Table 9.1: Comparison of Sectoral Investment Requirements for the Reference and Low-carbon Scenarios by Mitigation Option, 2010–30*

Sector/ abatement measure	Abatement potential (Mt CO2e)	Annual Abatement Potential (Mt CO$_2$e)	Reference-scenario investment (billion US$)	Low-carbon scenario investment (billion US$)	Low-carbon investment differential (billion US$)	Annual Differential (billion US$)
Land Use and Land-use Change						
Reforestation	1.085	52	-	54,140	54,140	2,578
Scaled-up zero-tillage cropping	355	17	0,215	0,153	(0,062)	(0,003)
Avoided deforestation plus livestock	6.041	288	41,845	102,420	60,575	2,885
Total land use and land-use change	**7.481**	**356**	**42,060**	**156,713**	**114,653**	**5,460**

125 See in particular section 7.1.2 The "Private Approach": Determining the Break-even Carbon Price.

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Energy

Electricity generation						
Transmission line (Brazil-Venezuela)	28	1	1,676	0,455	(1,221)	(0,058)
Sugar-cane cogeneration	158	8	16,756	52,264	35,508	1,691
Wind	19	1	4,287	12,898	8,611	0,410
Electricity conservation						
Residential solar heater	3	0	3,439	4,605	1,166	0,056
Residential lighting	3	0	0,903	1,197	0,294	0,014
Refrigerators (MEPS)	10	0	42,734	48,785	6,051	0,288
Commercial lighting	1	0	0,265	0,748	0,483	0,023
Electric motors	2	0	3,399	4,601	1,202	0,057
Industrial lighting	1	0	0,108	0,286	0,178	0,008
Recycling	75	4	-	0,249	0,249	0,012
Fossil-fuel production						
Gas-to-liquid (GTL)	128	6	2,310	6,986	4,676	0,223
New refineries	52	2	116,753	120,908	4,155	0,198
Existing refineries (energy integration)	52	2	-	4,028	4,028	0,192
Existing refineries (incrustation control)	7	0	-	-	-	
Existing refineries (advanced controls)	7	0	-	1,492	1,492	0,071
Fossil-fuel conservation						
Combustion optimization	105	5	-	2,215	2,215	0,105
Heat-recovery system	19	1	-	0,323	0,323	0,015
Steam-recovery system	37	2	-	0,819	0,819	0,039
Furnace heat-recovery system	283	13	-	8,074	8,074	0,384
New industrial processes	135	6	-	37,995	37,995	1,809
Other energy-efficiency measures	18	1	-	0,827	0,827	0,039
Fossil-fuel substitution						
Solar thermal energy	26	1	-	1,482	1,482	0,071
Renewable charcoal displacement of nonrenewable charcoal	567	27	-	8,794	8,794	0,419
Natural gas displacement of other fuels	44	2	-	4,088	4,088	0,195
Ethanol exports displacement of gasoline abroad	667	32	3,817	19,680	15,863	0,755
Total energy	**2.447**	**117**	**196,447**	**343,799**	**147,352**	**7,017**

Transport						
Regional						
Ethanol displacement of domestic gasoline	176	8	9,992	20,158	10,166	0,484
Rail and waterways investment vs. roads	63	3	32,074	41,707	9,633	0,459
Bullet train (São Paulo-Rio de Janeiro)	12	1	-	28,759	28,759	1,369
Urban		0				
Metro and bus rapid transit (BRT)	174	8	6,562	49,182	42,620	2,030
Traffic optimization	45	2	-	1,050	1,050	0,050
Bike lane investment	17	1	-	0,303	0,303	0,014
Total transport	**487**	**23**	**48,628**	**141,159**	**92,531**	**4,406**
Waste management						
Landfill methane destruction	963	46	1,984	5,687	3,703	0,176
Wastewater treatment plus methane destruction (residential and commercial)	116	6	40,075	41,678	1,603	0,076
Wastewater treatment plus methane destruction (ind.)	238	11	7,314	36,569	29,255	1,393
Total waste management	**1.317**	**63**	**49,373**	**83,934**	**34,561**	**1,646**
Total	**11.732**	**559**	**336,508**	**725,605**	**389,097**	**18,528**
Excludes Air Conditioning (MEPS) and BRT alone						

Sectoral financing requirements of the low-carbon and reference scenarios vary significantly by amount; availability of federal, state, and municipal resources; private-sector involvement; financial and fiscal incentives; and credit availability. Therefore, the study team analyzed the potential financing gap for the low-carbon scenario on a sectoral basis. The results, presented in Sections 9.2–9.5, are by no means exhaustive; further analysis would be required to assess whether the mechanisms are appropriate for the proposed mitigation options.

9.2 Land Use and Land-use Change Financing Needs

In the low-carbon scenario, the cumulative investment costs associated with LULUCF total US$156 billion, nearly $114 billion more than in the reference scenario (table 9.1). These costs include approximately $24 billion for forest protection over the 20-year period. Financing mechanisms already in place in the LULUCF sector include government-financed lines of credit for sustainable production and forestry, regional constitutional funds, private-sector financing, and such recently initiated mechanisms as The Amazon Fund. Agriculture- and livestock-specific financing includes annual and biannual government plans. The main government-linked financial institutions that back these sectors are Banco do Brasil (with 60 percent of all

rural credit), Caixa Econômica Federal (CAIXA), and BNDES. Such regional banks as Banco da Amazonia and Banco do Nordeste do Brasil (BNB) are dedicated to investing in development in the Northeast and Amazon regions.

The investment costs associated with zero-tillage cultivation in the low-carbon scenario total US$1.12 billion ($153 million plus $967 million for operations and maintenance costs) or $151 million less than in the reference scenario. Productivity is considered the same for both scenarios; cost reductions in the zero-tillage system result from less labor and fewer machine hours required. Barriers to shifting to zero-tillage production include a higher perceived risk in changing over to this system and limited knowledge of appropriate implementation.

Cumulative costs for higher-productivity, livestock mitigation options in the low-carbon scenario total R$946 billion (US$430 billion) over the 2010–30 period or approximately US$20.4 billion per year (including operations and maintenance costs). About three-fourths of total costs represent operations and maintenance expenditures, which must be financed. In the reference scenario, these costs can be considered additional since higher productivity systems account for only 10 percent of total production in that scenario.[126] However, in the low-carbon scenario, they account for 60 percent of total production by 2030.

BNDES has a financial stimulus program for sustainable practices related to agricultural and livestock production, including PRODUSA, which supports recovery of degraded pasture area for increased productivity and FINAME-Agricola, which supports the costs of agricultural machinery and installations. But historically, Brazil's livestock sector has had limited access to credit. Typically, producers have had to rely heavily on their own capital for investment. The more traditional production systems have low IRRs; 0.5 percent, which is at the high end of the range, is not enough to cover bank financing costs, even at subsidized rates of 5–8.5 percent (Banco da Amazonia) and 5.75–6.75 percent (BNDES). Promoting the transition from a lower to a higher productivity system can increase the IRR of the activity, but it requires greater capital investment, which, in turn, requires bank financing. This may present a barrier since the return from these investments would have to at least equal the financing costs plus an expected return for the investor.

The sector's limited access to credit is evidenced by research conducted in 2003 by Brazil's National Confederation of Agriculture and Livestock (CNA) (Conhecer Project); 54 percent of the producers interviewed said they did not have access to credit with rates lower than 8.75 percent per year due to bank-imposed and borrower debt requirements. An equal number of producers could not obtain financing through the National Program for Recuperation of Degraded Pastures (PROPASTO), as banks claimed lack of funding resources (Martha and Vilela 2007). Addressing such financing obstacles specific to the livestock sector is the most pressing challenge to ensuring that the proposed low-carbon scenario can effectively achieve the bulk of expected emissions reductions.

In addition to financing livestock productivity gains to release land for expansion of other activities and thus avoid deforestation, other forest protection measures may be needed. The primary reason is the significant lag between the time that land demand would be reduced through increased livestock productivity and the behavioral changes of deforestation agents at the frontier could be effectively observed; that is, they may continue to speculate on demand that would have already dried up. A second reason is that felling trees and using the land where they

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126 In the reference scenario, the estimated total annual investment in beef livestock (less productive and less remunerative), based on a total area of 204 million ha and current production systems, totaled approximately US$32 billion (EMBRAPA). In 2007, funding through government-linked financial institutions represented approximately 10 percent of the required costs.

stand typically have more economic value than maintaining the trees (chapter 3).

It is hard enough to avoid deforestation, much less restore areas where economic profits will be lost. Despite such challenges, Brazil's government-funded programs have historically attempted to curb deforestation, restore native forests, and recover degraded areas. It has often been mentioned that use of support lines for environmental projects, particularly those related to reforestation of legal reserves, have been underused; indeed, small entrepreneurs are unlikely to borrow to finance the restoration of legal reserves when this would simultaneously involve the loss of economic profits on currently used land and financing costs to restore it.[127]

The forestry-recovery costs associated with compliance with the Legal Reserve Law are estimated at US$54 billion (44.2 million ha) over the 2010–30 period. These costs are limited to forest recovery and do not cover the opportunity cost of lost income generated from the land. Some forest-recovery projects have obtained financing from the Global Environment Fund (GEF) and such private-sector initiatives as the AES Tiete Reforestation CDM project. Other projects result from the enforcement of legal obligations. Other initiatives aim to recover forests, although few are of the size and scale needed to generate a country-wide impact. While implementing forestry-recovery projects may be limited by ecological barriers, the main obstacle is lack of incentives for rural entrepreneurs to finance forest recovery while sacrificing the income the land currently generates.

Given the high volume of financing and level of public-sector involvement needed, projects that focus on reducing emissions from deforestation and increasing carbon uptake from forest recovery are likely to require international financing. One potential source is The Amazon Fund, which is designed to finance activities that prevent and monitor deforestation and promote sustainable forest use and conservation in the Amazon and other tropical biomes (section 9.6).[128]

Summing up, public-sector participation will likely predominate in the financing of LULUCF-sector projects. Given its policies, enforcement capacity, and dedicated funding sources, the public sector will be vital to the success of the proposed mitigation options via the allocation of national and international resources from The Amazon Fund. Agriculture- and livestock-related efforts should continue to receive significant government incentives and funding through dedicated programs. Given the significant level of emissions avoided via increased livestock productivity, appropriate attention should be paid to improving livestock-sector incentives and credit availability.

9.3 Energy Financing Needs

Mitigation options in the energy sector are some of the most costly as they involve significant capital investments compared to less capital-intensive options. In the low-carbon scenario, the cumulative investment costs associated with the energy sector total US$344 billion, $147 billion more than in the reference scenario (table 9.1).

Compared to the other sectors considered in this study, the energy sector has a long history of centralized financing through such large state-owned enterprises as Petrobras and Eletrobrás, as well as targeted programs, subsidies, and charges on electricity distribution companies. In

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127   Decree No. 6.514, altered by Decree No. 6.686, will impose penalties and daily fines on landowners who do not comply with the requirement of maintaining stipulated percentages of native vegetation within their territories by November 12, 2009; the bulk of these requirements affect the Amazon region, followed by the Cerrado and other biomes.

128   Such financial instruments as the CDM can be used in cases where the private sector may be more willing to participate.

addition, special regulations are in place for biodiesel production and consumption, energy efficiency, and long-term national energy plans, which facilitate sector planning and budgeting.

This study divides the additional financing requirements for energy-sector mitigation options in the low-carbon scenario into three areas: (i) electricity generation and conservation, (ii) fossil-fuels production, and (iii) fossil-fuels conservation and substitution. Mitigation options related to electricity generation and conservation would require US$126 billion in investments; fossil-fuels production would require $133 billion, while fossil-fuels conservation and substitution would need $84 billion. Most of the proposed low-carbon mitigation options would involve the scaling up of existing technologies, with the exception of GTL, which is a new technology. More importantly, financing mechanisms already in place could be used to implement most of these options.

One potential financing option uniquely suited to the energy sector is the proposed National Fund for Climate Change, which would fund Brazil's Policies and Climate Change Plan. This fund would use a portion of the resources generated via petroleum exploration and production to avoid or minimize the environmental damages caused by such activities. Based on projected production for Petrobras in 2010 and 0.05 percent of net income (2007 results), the fund could spend US$50 million per year on climate-change mitigation activities (Section 9.6).

9.3.1 Electricity Generation and Conservation

Electricity generation and conservation investments in the low-carbon scenario total US$126 billion, with $66 billion for generation and $60 billion for conservation. Electricity generation investments, totaling about $43 billion more than in the reference scenario, include the Brazil-Venezuela transmission line for hydropower generation, sugar-cane cogeneration, and wind energy. Electricity conservation investments, whose total is about $10 billion more than in the reference scenario, has an added cost of about $458 million per year. Energy-efficiency mitigation options range from residential solar heaters and refrigeration to residential, commercial, and industrial lighting; electric motors; and recycling. The major generation and conservation investments are described in the following subsections.

9.3.1.a Hydropower: Brazil-Venezuela Transmission Line

Although hydropower generation represents a large share of required future investments, this does not directly affect the additional financing needs assessed for the low-carbon scenario. The main reason is that the reference scenario already accounted for the corresponding low carbon-intensive energy potential (PNE 2030), and this study assessed that further hydroenergy development beyond that envisioned in the reference scenario over the 20-year time horizon would not be feasible. Therefore, hydropower generation costs are the same in both the reference and low-carbon scenarios. Construction of the 25 hydropower plants considered in the PNE 2030 and related transmission lines would require R$2,900 per kW or about R$32 billion (US$14.5 billion) per year.

Despite private-sector involvement, the Brazilian government offers consortia financing through BNDES, which traditionally invests in the energy sector (in 2006, it disbursed R$52.2 billion) and the Guarantee Fund for Electric Energy Projects (FGEE), created in 2008 (under temporary provision No. 450) to guarantee the participation (direct or indirect) of state-owned companies in electric power construction projects under the Government Accelerated Growth Plan (PAC).

9.3.1.b Sugar-cane Cogeneration

The cumulative cost for sugar-cane cogeneration in the low-carbon scenario is US$52 billion or US$35 billion more than in the reference scenario. This amount takes into consideration the high costs of interconnection, which may be prohibitive relative to overall generation investments, and installation equipment for approximately 300 new distilleries. The estimated cost per new plant is US$150 million on average, and the average distance to the grid is 35–40 km, for an overall 10,000–12,000 km of additional lines. US$13.7 million is required to refurbish power plants in existing mills, while new cogeneration units require an investment of nearly US$45.2 million. Installed capacity grows continuously over the 2010–30 period (from about 1,000 MW per year in the initial five-year period to nearly 5,000 MW per year in the final five-year period) due to growing distillery capacity (from 2 Mt per year in 2010 to 4.5 Mt per year by 2030).

Virtually all ethanol plants are self-sufficient with respect to electricity cogeneration. However, in many cases, entrepreneurs lack sufficient financial incentives to implement measures to increase electricity generation for sale to the grid. Furthermore, remuneration is higher for primary production investments (i.e., growing sugar-cane for ethanol). At least 6–10 years are needed to generate a return on invested capital in cogeneration projects.[129] As a result, larger-scale entrepreneurs with higher leverage capacities can more easily access lines of credit than can smaller-scale entrepreneurs. But the bulk of potential is not in the smaller mills. Private-sector investment and credit lines from such financial institutions as BNDES and FINAME-Agricola/FINEM exist. The most important barriers to scaling up sugar-cane cogeneration are the physical and economic restrictions with respect to grid interconnection (distance from the grid may make the investment prohibitive). In addition, there are regulatory issues related to setting tariffs on use of the distribution system. At the same time, technological improvements are being made with respect to biomass availability, hydrolysis for ethanol production, and gasification technology (which would benefit from more significant R&D efforts).

Cogenerators attempting to connect to the grid have encountered difficulties with distribution companies, which lack adequate incentives to recover their investment in transmission costs. This problem is caused mainly by a lack of information regarding the required investment, as the utility can impose technical solutions that investors cannot anticipate. This type of concern has already been dealt with for small hydropower (via discounts in transmission charges, which reduce total costs). If transmission lines are to be built by the cogeneration project developer without any financing assistance, many projects would not be viable. It should be noted that even larger cogeneration units have a smaller capacity than medium-sized thermal power plants, and are more dispersed, resulting in higher interconnection costs.

9.3.1.c Wind Energy

Cumulative costs for expansion of wind generation in the low-carbon scenario total US$12.9 billion, $8.6 billion more than in the reference scenario. Over the 20-year period, investment costs in the low-carbon scenario would amount to about $430 million per year.

The Brazilian government's main incentive program for wind energy is the renewable-energy program known as PROINFA. Created in 2002 and administered by Eletrobrás, PROINFA completed its first phase in 2005, with 3,300 MW of renewable energy sources (1,379 MW wind, 1,266 MW solar, and 655 MW biomass). The CDE provided funding for the first phase, and BNDES created

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129 Elimination of government subsidies for ethanol production began in the mid-1990s.

a program in 2004 to invest R$5.5 billion (US$2.5 billion) in PROINFA. According to Eletrobrás, targeted investments for PROINFA total about R$10.14 billion (US$4.6 billion), with financing of R$7 billion (US$3.18 billion). PAC investments in wind projects are estimated at R$59 billion (R$48 billion in PROINFA projects and R$11 billion in private-sector investments). The Fuel Consumption Account (CCC) finances PROINFA and other renewable-energy projects via a "subrogação" mechanism, whereby a portion of the subsidies to cover the deficit of isolated, diesel-based systems can be awarded to an alternative energy source, thereby reducing diesel consumption.

Overall, scaled-up implementation of wind-energy projects in Brazil would benefit not only from additional financing. More programs like PROINFA, which could guarantee Power Purchase Agreements or other revenue streams, are much needed.

9.3.1.d Energy-efficiency Measures

Cumulative investment costs for electricity-conservation options in the low-carbon scenario total US$60 billion, versus US$50 billion in the reference scenario, with additional annual costs of $458 million over the 2010–30 period. Although the marginal costs per tCO_2e for many of these mitigation options may be negative, implying significant economic savings, equipment and machinery will still entail investment costs.

While efforts to promote energy efficiency have helped to establish a legal framework and mobilize resources, a sustainable market for energy conservation has yet to mature. An energy efficiency law approved in 2001 (Law 10.295) stipulates minimum energy-efficiency standards for equipment and buildings. The sector already has dedicated funding sources and government programs (e.g., PROCEL, PROESCO, CTEnerg, and ANEEL Energy Efficiency Program). PROCEL, created in 1985, is a national program designed to combat electricity waste; 70 percent of its funding comes from the Global Reversion Reserve (RGR), which, since 1957, has assessed a 0.75–1 percent fee on the net profits of electric utilities.[130] PROESCO, a line of credit via BNDES, finances energy-economy projects for various areas and final uses. CTEnerg is a sectoral fund created in 2000 to invest in energy-efficiency R&D programs; funding sources come from the annual net revenues of electric utilities; in 2007, total collections amounted to R$200 million (US$90.9 million), of which only US$30 million was invested.

Energy-efficiency mitigation costs per Mt CO_2e are among the lowest. Given the level of investment required and Brazil's experience in financing energy-efficiency projects, heavy public-sector participation in financing such activities seems likely via such targeted programs as PROCEL, redirecting of fees collected by companies, and additional dedicated credit lines such as PROESCO.

9.3.2 Fossil-fuel Production

Cumulative investment costs for fossil-fuel production in the low-carbon scenario total US$133 billion, only $14 billion more than in the reference scenario. Low-carbon mitigation options are related to production and refining, conservation, and fuel switching.

With regard to gas-to-liquid (GTL), the main barriers to investment are its high costs and early stage of development. Financing requirements could be partially met via BNDES financing, gas-flaring fines, carbon financing through the CDM, and possibly elimination of royalties for GTL-destined gas.

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130 Collections are expected to terminate by the end of calendar year 2010; however, at the end of the 2008 fiscal year, the fund had collected more than R$7 billion (US$3.2 billion).

Another investment barrier is lack of incentives for oil-producing companies to reduce their own emissions. Typically, such companies account for their CO_2e emissions, and have the technical and financial capacity to act; but without any requirements, they would likely invest in exploration and production. Thus, it is important to create incentives to match the returns expected from their main business or obligate them, via regulations or standards, to eliminate part of their emissions.

Funding for additional technological research would also be beneficial. One such example is the research fund CT-Petro. Created in 1999, CT-Petro stimulates innovation in the oil-and-gas production chain and develops human capacity and projects in partnership with other companies, universities, and research centers in Brazil; 25 percent of its funding sources come from the value of royalties that exceed 5 percent of oil and natural gas production (FINEP 2008). In 2004, total funds were R$1.6 billion, but disbursed funds were only R$595 million or 37.5 percent of the total.

Flared-gas fines are another potential source of financing. Permissible limits for gas flaring are gradually lowered, and companies that breach those limits are fined. Brazil adopted such measures in the past (e.g., The Zero Burning Plan), which did not include fines for gas flaring (ANP 2001). The Zero Burning Plan led to a 2001 plan for gas optimization and use (Petrobras 2007).

Eliminating royalties could also generate funds. Currently, royalties are paid on the value of the natural gas burned, even if no economic benefit is derived from it. Eliminating this royalty would signify a change in existing law, which would involve other costs and measures beyond the scope of this study. Considering that royalties represent 10 percent of the gross value of production, at a natural gas price of R$0.70 per m^3 and a volume of 96.23 million m^3 per year, a benefit of R$6.7 million (US$0.3 million) per year would result, which could be invested in GTL.

With regard to mitigation options involving refining, it may be possible to cover part of the added financing costs via incentive programs for energy-efficient refineries. Already existing programs include the National Program for the Rationalization of the Use of Oil and Natural Gas Derivatives; known as CONPET, this program is coordinated by federal government entities and private initiatives. Petrobras is responsible for providing technical, administrative, and finance resources; but its annual budget is only R$5 million (US$2.3 million).[131] CT-Petro could be directed toward conducting research on such promising alternatives as carbon capture and storage (CCS).

9.3.3 Fossil-fuel Conservation

Total estimated investment costs to implement the fossil-fuel conservation mitigation options for the industrial sector reach about US$50 billion over the 2010–30 period; all are incremental from the reference scenario. The estimated investments are only envisioned for the low-carbon scenario, with the understanding that costs for the adaptation or substitution of new equipment are additional or complementary (energy-efficient investments are incremental by nature).

There are few sources of funds and programs for energy efficiency in the industrial sector, with the exception made by PROCEL for electric motors. With respect to fuels, which should be covered by CONPET, few substantive actions have been taken. Petrobras is to promote fuel-consumption reduction while, at the same time, maximize sales and profits. The same issue occurs with the rise in natural-gas supply, as the company's goal has been to grow the market,

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131 Since investments related to refining remain in the domain of Petrobras, additional financing requirements for these mitigation options are not discussed further with regard to private-sector involvement.

which is inconsistent with the goal of achieving lower demand and consumption.

The industry can access smaller lines through FINEP for projects related to development and innovation. In this case, resources come from sector funds administered by the Ministry of Science and Technology (MCT), such as the previously mentioned CT-Petro and CTEnerg. Companies have indirect access to these funds through partnership projects with universities or research centers or through direct access via subvention programs.

Fossil-fuel and energy-conservation mitigation options, particularly within the industry, would benefit from additional sources of funds or programs with targeted actions, such as incentives for solar thermal energy for fossil-fuel substitution.

9.3.4 Fossil-fuel Substitution: Renewable Charcoal

Although renewable charcoal to be used in the iron and steel industry also affects land use, for the purposes of this study section, it falls under the category of fossil-fuel energy substitution. For the 20-year period considered, cumulative investment costs for this mitigation activity total US$8.8 billion or US$42 million per year. The investment required is estimated at US$5 billion over the first 7 years, for the reduction of 567 Mt CO_2e or approximately US$2,000–2500 per ha. Although BNDES provides financing and specified lines of credit related to recovery and maintenance of legal reserves, as well as commercial planting, there is no differentiation made between planted forests for the steel industry and other industries (e.g., cellulose). Also, only recently has access to financing been made more viable through the ability to use planted forests as guarantees (similar to the financing provided for other crops). In addition, CDM projects involving planted Eucalyptus forests for the steel industry currently provide an additional source of financing. Steel industry companies may also be involved in financing of such projects, signifying the growing participation of the private sector in this mitigation activity; however, discussions have not been held with such companies to assess their potential level of involvement or interest. Were this mitigation activity to be implemented, it is likely that both the public and private sectors would have increased financing participation.

9.3.5 Conclusion

Despite the financing mechanisms available, the energy sector as a whole still has significant financing needs. These could perhaps be met by further dedicated allocation of resources (e.g., PROINFA renewable-energy programs, or additional incentives (e.g., enabling CDM financing, eliminating royalties on gas destined for GTL, or differentiating credit availability for industry-specific options). With regard to energy-efficiency mitigation options specific to fossil fuels in industry, existing financing available through specified programs may not be enough for implementing the low-carbon mitigation options. Added financial incentives, including industry-specific options (e.g., renewable charcoal for steel industry) may be needed.

9.4 Transport Financing Needs

Cumulative investments required for the transport sector in the low-carbon scenario total US$141 billion, $92 billion more than in the reference scenario or approximately US$5.1 billion more per year. Constructing the required infrastructure will require significant government intervention. At the same time, private-sector participation should grow through concessions and PPPs. In addition, macroeconomic strategic planning will be necessary to evaluate the

impact of the mitigation proposals.

The added investment for regional transport is US$48 billion (including $10 billion for increased domestic consumption of ethanol), while $44 billion more is needed for urban transport. To illustrate the size of the required investment, BNDES alone disbursed US$17.8 billion for highways, railways, and other transport-related activities over a one-year period ending in February 2009. The investment level needed varies significantly by mitigation type; for example, the construction of Metro lines and BRT systems cost US$49 billion, while bike lane investment requires only US$303 million.

Funding for the transport sector could be obtained through specific BNDES lines of credit, as well as the PAC (infrastructure participation) and existing dedicated funds. Other government transport programs include funds that use social security (FGTS) resources. The sector also counts on the Contribution on Intervention in the Economic Domain (CIDE), a dedicated tariff destined for government financing programs in infrastructure and transport.[132] In 2007, R$7.9 billion (US$4.7 billion) was collected through the tariff.

The transport sector is characterized by a high level of institutional complexity. Regional transport issues are linked to the Ministry of Transport (MT), Ministry of Defense (Air Transport), and Special Secretary of Ports; while urban transport is linked primarily to the Ministry of Cities. In addition, each of the country's more than 5,000 municipalities independently administers its own transit and transport systems. Such complexity increases the challenge of harmonizing coherent plans and policies, and makes it difficult to channel and mobilize resources where most needed in the most appropriate way.

Judging from current investment trends in the sector, a significant level of private-sector investment will be required, with financing intervention from BNDES. Foreign entities have expressed interest in investing in some of the country's infrastructure projects (e.g., bullet train).

BNDES also has a line of credit through its FINAME program dedicated to the purchase of trucks. However, it is oftentimes difficult to access this credit line because of the large number of independent truck operators. Large-cargo transport companies typically have an adequate management structure for replacing aged vehicle fleets. At the same time, they often use the services of independent operators. Differentiated credit terms, perhaps with longer payment periods and lower rates, could stimulate the renewal of the vehicle fleet. Assuming that 30 percent of the national truck fleet is older than 20 years (400k trucks), a subsidized line of credit to replace 25 percent of that fleet would require US$5 billion (at $50,000 per truck).

9.5 Waste Financing Needs

Cumulative investments required for the waste sector in the low-carbon scenario total US$84billion over the next 20 years ($4 billion per year) or about $34 billion more than in the reference scenario.

Brazil's waste sector has a history of underinvestment and, at times, neglect, with low private-sector involvement. This situation is attributable, in part, to a sector culture characterized by lack of long-term planning, which is detrimental to credit access, and possibly insufficient dedicated

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132 Created in 2001, CIDE is a tariff on imports and commercialization of oil and derivatives, natural gas and derivatives, and ethanol (fuel). Resources are destined for the government's financing programs in infrastructure and transport. CIDE was created to generate a constant flow of resources to finance the various sector investments needed.

funds combined with a lack of incentives. Waste management, which falls under sanitation, has a high level of institutional complexity. The main government entities responsible for planning, implementation, and strategy are the Ministry of Cities, Ministry of Environment, Ministry of Health, as well as the Ministry of Planning, Budgeting, and Management. There are policies for establishing the directives of basic sanitation, and at least 23 directed programs and plans, such as PLANSAB, whose goal is to achieve basic universal services. Currently, the waste sector is awaiting legislation that may dictate how waste management is handled (e.g., construction of sanitary landfills, disposal and treatment of solid waste, and recycling). Recent figures released by the Ministry of Cities (November 2009) indicate that in order to reach the universalization of basic sanitation services in urban areas, approximately R$250 billion would be required over twenty years, and that what is lacking are clear regulations for the sector, rather than funding.

It is envisioned that R$40 billion (USR18.2 billion) will be spent under the PAC for sanitation over the 2007-2010 period, or the equivalent of R$10 billion (US$4.5 billion) per year will be spent under the PAC for sanitation. Only a portion of this amount is designated for waste management, and spending distribution is to be made according to the needs of each region, with an estimated 52 percent to be applied in large urban centers or cities with more than 1 million residents.[133] It should be noted that financing for half of this amount, R$20 billion (US$9 billion), is expected to come from the private sector, as well as states and municipalities.

The national budget for 2007 allocated US$84.1 million (including US$31.4 million as credit from financial institutions) through the various sanitation programs. This amount is equivalent to 12 percent and 2 percent of the respective annual requirements for the reference and low-carbon scenarios. But only a portion of the funds dedicated to sanitation programs can be used for waste management. The urban cleaning tax charged to residents, highly correlated with the property tax, is not appropriately related to the amount of waste collected, representing only 20 percent of urban solid-waste collection. This is a significant issue that merits further debate and discussion.

CDM projects have provided a source of additional funds for waste management projects and the construction of sanitary landfills, either to speed up funding recovery or for debt abatement. CAIXA has presented a successful proposal that would allow for FGTS resources to be used for CDM projects.

With respect to public-sector financing of projects, municipalities' access to credit is at times jeopardized by restrictions imposed by the National Monetary Council (CMN). Municipalities have a window of time in which they are allowed to incur debt up to a certain amount stipulated by the CMN.[134] Unfortunately, many municipalities, which historically have lacked access to credit, are unaware of the credit-access rules. Typically, their projects are either not well-developed or, by the time they are, the window of time to incur credit has already ended. Specific lines, such as BNDES support lines for environmental projects,[135] target low- or lower-income municipalities of up to 100 percent participation.

Regarding private-sector financing of projects through concessions and PPPs, knowledge is still lacking in various areas. These include applicable regulations, the financing system, ability to utilize the CDM, and the higher cost of money.

Summing up, waste management depends on a variety of financing mechanisms, including dedicated taxes, government programs and funding, and CDM projects. The historical financing

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133 Currently, the main public-spending priority is regionally-integrated municipalities with over 100,000 inhabitants, although there are programs that target small- and medium-sized municipalities.
134 Through Resolution 2827.
135 These lines include solid waste management projects, ecoefficiency, recycling, and recovery of degraded areas.

and funding sources for waste projects, most of which has come from the public sector, indicates a lack of sufficient directed resources. Going forward, it appears that the private sector will need to take on a growing share of this sector's financing. To increase the deployment of financial resources, cohesive and more stable longer-term sectoral planning is needed. Resources need to be deployed consistently. In addition, both the public and private sector require greater knowledge of regulatory processes, including access to financing, as well as the differentiated structural mechanisms to integrate the financing of smaller projects.

9.6 Financial Incentive Mechanisms

The sale of the certified emission reductions (CERs) issued under the Clean Development Mechanism (CDM) is viewed as an important financing instrument to reach targets set by the Brazilian government under the proposed National Action Plan on Climate Change (NAPCC). The NAPCC includes targets for reducing deforestation rates in the Amazon and increasing energy efficiency, the renewable-energy mix in the national grid, ethanol concentration in the fuel mix for cars, and reforestation activities. Most of the key targets can benefit from carbon revenues; these include cogeneration and such other renewable-energy solutions as hydropower, reforestation and afforestation, energy efficiency, and fuel-switching programs.[136]

Most of the 163 CDM projects in Brazil are renewable-energy projects, most of which focus on sugar-cane bagasse cogeneration. Bagasse cogeneration represents 48 percent of total projects, followed by biogas (17 percent of all projects), and solid waste management (30 percent). CDM cogeneration projects account for a total of 1.126 MW installed capacity, while small hydropower plants account for 985 MW and wind energy 676 MW[137] Few reforestation projects are currently being developed as methodologies were developed slowly and market demand is reduced to the temporary nature of this asset. Most projects were developed in the states of São Paulo (22 percent), Minas Gerais (14 percent) and Rio Grande do Sul (10 percent).

Brazil has existing sources of funding for energy efficiency and renewable energy through government-mandated levies; these are directed toward such funds as the Fuel Consumption Account (CCC), Energy Development Account (CDE), and Global Reversion Reserve (RGR). According to the National Agency for Electric Energy (ANEEL), CDE collections for 2009 are estimated at R\$2.8 billion. Collections for the RGR fund, scheduled to terminate by the end of calendar-year 2010, had totaled R\$7.2 billion (US\$3.26 billion) at the end of fiscal-year 2008. Administered by Eletrobrás, RGR is a main source of funding for energy-efficiency programs under PROCEL. With regard to the CCC, collected levies totaled approximately R\$1.4 billion in 2008. Not all of the funds collected are used for renewable-energy or energy-efficiency projects, but they are significant in size.

Such funds, or a portion thereof, could be used to create the proposed Renewable Energy CDM Fund (RE CDM Fund), which, in turn, could invest in renewable-energy and energy-efficiency projects that generate certified emissions reductions (CERs) once approved by the CDM Executive Board. In a manner to be agreed on, all or a portion of the CERs generated would either remain with the project sponsor or be bought by the RE CDM Fund at agreed on prices that would allow for at least a minimum guaranteed level of project profitability. The CERs obtained by the RE CDM Fund could then be sold on the international market, growing Fund resources, which could then be used to further invest in the sector. If successful, this mechanism could be applied to

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136 Werner Kornexl, "Brazil Mitigation Strategy," World Bank, 2008.
137 Ibid.

other industrial projects or sectors that may also have mandated levies; or, if the fund permits, the income generated could be directed toward other types of projects. If successful, this mechanism would allow for government levies to either be reduced or redirected toward other sectors of the economy. If 1 percent of the CDE were dedicated to creating the fund, then approximately US$12 million—or 850,000 CERs, at an average price of US$15)—would be made available.

Other funds that receive similarly mandated levies but are not limited to energy-related activities include the Constitutional Financing Funds of the Northern, Northeastern, and Center-West Regions (FNO, FNE, and FCO, respectively). These funds receive 3 percent of overall tax collections, which are then used to finance activities in the respective regions; they are administered by such banks as the Banco da Amazonia, Banco do Nordeste, and Banco do Brasil. In 2009, their budgets were R$2.7 billion (FNO), R$7.5 billion (FNE), and R$2.9 billion (FCO). Financing programs include support for such activities as decreased deforestation and increased livestock productivity.

Currently, a proposal is circulating within the government to create the National Fund for Climate Change. This fund would provide the financial resources to implement the country's climate-change policies and the Climate Change Plan. The fund would use a portion of the resources generated through oil exploration and production to avoid or minimize the environmental damage caused by such activities. According to the National Plan on Climate Change (PNMC), this fund could be used as loans or grants for projects or studies. Based on rough estimates using the projected future production of Petrobras for 2010 and 0.05 percent of net revenues (2007 results), the fund could potentially have $50 million per year to spend on climate-change mitigation activities, excluding other potential funding sources, such as grants and/or loans from national and international financial institutions.

Another incentive mechanism is The Amazon Fund. Created in 2008 with a US$1 billion grant from the Norwegian government, The Amazon Fund will distribute this amount in grants over an eight-year period; the first parcel, in the amount of US$110 million, was received in the first quarter of 2009, with the remainder to be received by 2015. Funding sources are exclusively via donations (national and foreign), and the Fund is expected to grow to more than US$21 billion by 2021. Germany has committed EUR 18 million, and other countries are considering additional grants. BNDES, which administers and coordinates the Fund, provides donors non-transferable diplomas and will not generate carbon credits as compensation. Grants distribution will continue as Brazil reduces its emissions associated with deforestation. According to BNDES, the funds will finance non-reimbursable actions that help prevent, monitor, and combat deforestation and promote sustainable forest use and conservation in the Amazon biome. Up to 20 percent of funds may be directed to the development of deforestation monitoring and control systems for other biomes located in Brazil and other tropical countries. The Fund's technical committee comprises members of Brazil's federal government, including the Ministry of the Environment (MMA) and the Secretariat for Strategic Affairs (SAE); governments of Amazon states; and civil society representatives (nongovernmental organizations, companies, universities, and syndicates).

9.7 Capital Intensity

Another indicator, capital intensity, can be used to evaluate the costs of the proposed mitigation options. The capital intensity of a mitigation option is here defined as the incremental investment costs over the reference-scenario technology divided by the cumulative avoided emissions over the life of the study. In this study, the mitigation options with the lowest marginal abatement costs (MACs) are primarily energy conservation measures; however, these do not

necessarily represent the least capital-intensive options. For example, sugar-cane cogeneration has a negative MAC of US$105 per tCO_2e, but has a high capital intensity of $161.5 per tCO_2e. Conversely, existing refineries (incrustation control) has an MAC of US$73 per tCO_2e (resulting from operations and maintenance costs) but zero capital intensity (table 9.2).

Thus, a mitigation option that appears less capital intensive may not necessarily have the lowest MAC and vice versa. A possible implication of choosing a mitigation option based on lower capital intensity rather than a lower MAC is higher mitigation cost over the long run. Ideally, a mitigation option would have both a low MAC and low capital intensity. Scaled-up zero-tillage cropping is one such example, with a negative MAC and negative capital intensity (owing to fewer laborers and machine hours). Obviously, this is not possible for all mitigation options.

Table 9.2: Capital Intensity and Marginal Abatement Costs of Mitigation Options in the Low-carbon Scenario

Mitigation Option	Abatement cost (US$/ tCO_2)	Mitigation Option	Capital intensity (US$/ton CO_2)
Residential lighting	(119,7)	Transmission line Brazil-Venezuela	(43,8)
Sugarcane cogeneration	(104,7)	Scaling up no tillage cropping	(0,2)
Steam recovery systems	(97,0)	Refrigerators (MEPS)	(0,0)
Heat recovery systems	(91,7)	Existing refineries (incrustation control)	0,0
Industrial lighting	(65,0)	Recycling	3,3
Solar thermal energy	(54,7)	Landfill methane destruction	3,8
Commercial lighting	(52,3)	Reduction of deforestation + livestock	10,0
Electric motors	(49,8)	Ethanol displacing domestic gasoline	11,5
Combustion optimization	(44,1)	Wastewater treat. + methane destruction (res. & com.)	13,8
Refrigerators (MEPS)	(41,3)	Optimizing traffic	14,4
Recycling	(34,5)	Renewable charcoal displacing non renewable charcoal	15,5
Transmission line Brazil-Venezuela	(30,5)	Heat recovery systems	17,0
Furnace heat recovery system	(25,6)	Combustion optimization	21,1
Natural gas displacing other fuels	(20,2)	Steam recovery systems	21,9
Other energy efficiency measures	(13,5)	Furnace heat recovery system	28,5
Ethanol displacing domestic gasoline	(7,9)	Investing in bike lanes	31,2
Wind	(7,6)	Ethanol exports displacing gasoline abroad	33,9
Optimizing traffic	(1,9)	Gas to liquid (GTL)	36,5
Gas to liquid (GTL)	(1,5)	Other energy efficiency measures	45,1
Reduction of deforestation + livestock	(0,5)	Reforestation	49,9
Scaling up no tillage cropping	(0,3)	Solar thermal energy	57,5
Investing in bike lanes	1,2	Existing refineries (energy integration)	77,1
Ethanol exports displacing gasoline abroad	2,1	New refineries	80,2
New industrial processes	2,1	Natural gas displacing other fuels	93,4

Landfill methane destruction	2,9	Residential lighting	95,9
Solar heater - residential	4,4	Wastewater treat. + methane destruction (ind.)	122,7
Existing refineries (energy integration)	6,6	Sugarcane cogeneration	161,5
Wastewater treat. + methane destruction (res. & com.)	10,4	Investing in railroad and waterways vs. roads	175,0
New refineries	19,1	Existing refineries (advanced controls)	214,1
Renewable charcoal displacing non renewable charcoal	20,5	New industrial processes	280,6
Investing in railroad and waterways vs. roads	29,0	Industrial lighting	281,7
Reforestation	39,3	Commercial lighting	326,9
Existing refineries (incrustation control)	72,9	Investing in metro	391,2
Existing refineries (advanced controls)	95,1	Solar heater - residential	391,4
Wastewater treat. + methane destruction (ind.)	103,3	Wind	407,5
Investing in metro	106,5	Electric motors	775,9
Bullet train: SP and RJ	400,3	Bullet train: Sao Paulo and Rio de Janeiro	4.468,4

By plotting the capital intensity of each mitigation option, one can illustrate the investment intensity of a GHG mitigation measure against its potential to reduce emissions (figure 9.1).

Figure 9.1: Investment-intensity Carbon Abatement Curve
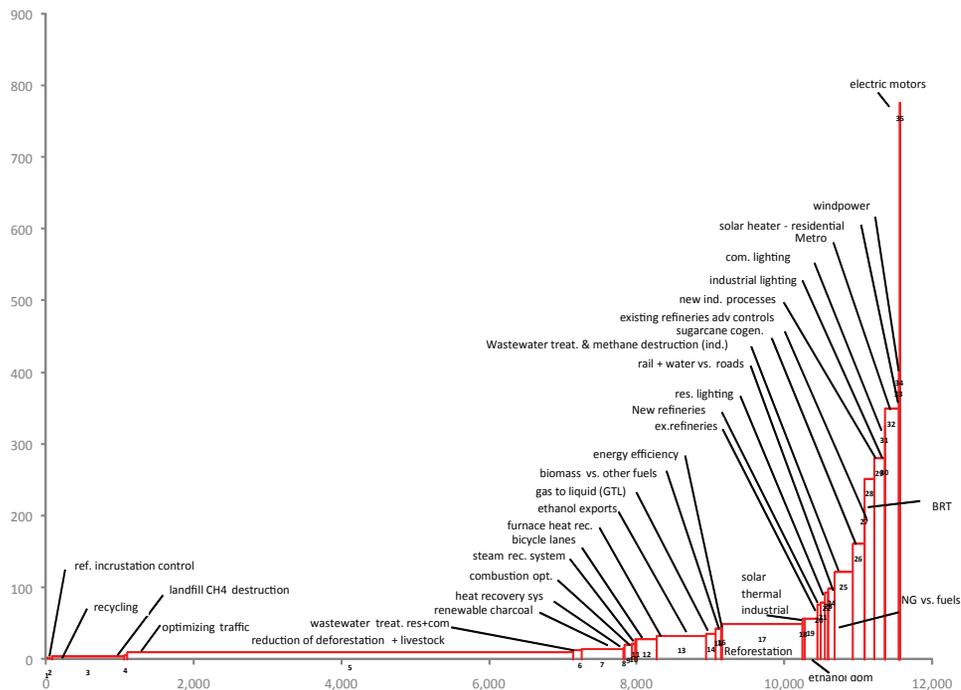
One may compare the capital intensity and abatement costs from the social perspective of the mitigation options by sector. As expected, Brazil's LULUCF sector has the highest potential for emissions reduction at a low MAC cost and low capital intensity, followed by the energy sector. The transport sector is the most capital intensive, as well as the most costly, while the waste sector is costly (considering the universalization of sanitation services by 2030), but not necessarily as capital intensive (figure 9.2).

Figure 9.2: Evaluating Marginal Abatement Costs,
Capital Intensity and Potential for Emissions Reduction, by Sector
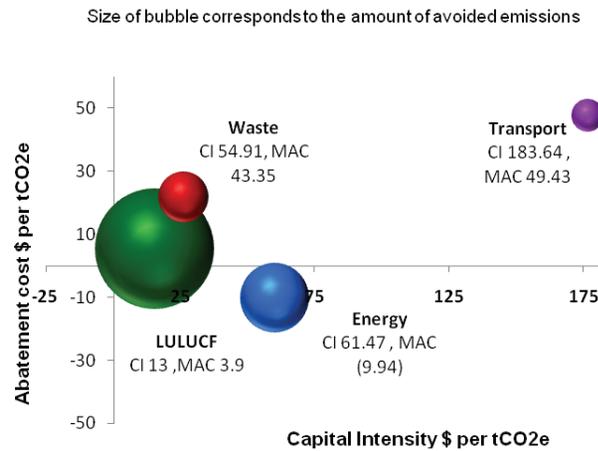
Mitigation options that conserve fossil fuels, such as steam-recovery and heat-recovery systems, are not only low in capital intensity; they also have some of the lowest abatement costs, similar to such fossil-fuel substitution options as solar thermal energy, renewable charcoal, and ethanol displacement of gasoline. Mitigation options related to fossil-fuel production are capital intensive, and the emissions avoidance is not as significant as that of options that substitute for fossil fuels. Urban-transport mitigation options are less capital intensive at lower abatement costs than regional-transport options. However, energy-conservation options appear more capital intensive, with a less significant amount of avoided emissions.

One may also compare the abatement costs from the private perspective (i.e., break-even carbon price, detailed in table 7.2), capital intensity, and total volume of financing needed, either for financing the investment cost or the incentive required to make the mitigation and carbon uptake options attractive to economic decision makers. Some less capital-intensive sectors may require similar amounts of financial incentives as more capital-intensive ones (waste, energy substitution, and LULUCF versus urban and regional transport (figure 9.3).

Figure 9.3: Evaluating Required Incentives and Capital Intensity, by Subsector
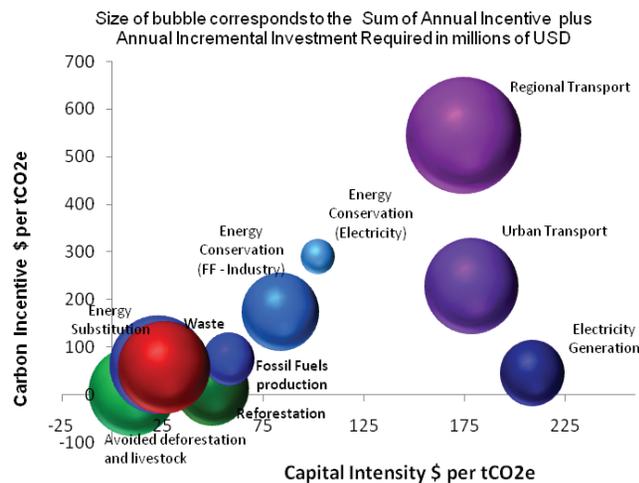
Chapter 10
Meeting the Low-carbon Scenario Challenge

This study has demonstrated that Brazil can contribute significantly to mitigating future GHG emissions, principally through reducing national emissions from deforestation, but also by reducing emissions beyond its borders via carbon uptake and the export of ethanol as a gasoline substitute. This chapter synthesizes the proposed strategies for moving toward a low-carbon scenario for each of the four sectors considered in this study and identifies the main challenges policymakers face in fully harvesting these opportunities.

10.1 Drastic Reduction in Deforestation

In moving toward a national low-carbon scenario, Brazil's main challenge is no doubt the reduction of deforestation. Despite the Brazilian government's recent success in implementing aggressive forest protection policies, deforestation is expected to continue as the country's largest source of GHG emissions well into the future. Moreover, several recent studies, including a World Bank assessment of Amazonian forest dieback,[138] have shown than deforestation means far more than releasing GHGs: There is a clear interplay between deforestation and expected damage to the forest from global climate change, the most severe progression of it following the same spatial pattern as deforestation. For the sake of reducing GHG emissions, as well as avoiding accelerated dieback of the Amazon forest, fires should be eliminated from the Amazon region.

Brazil has gained considerable experience in forest-protection policies and projects and finding ways to generate economic activities compatible with the sustainability of native forests. Forest-protection projects and policies are used as dikes to counter the progression of pioneer fronts. However, a more drastic reduction in forest destruction would require more than protection. Shifting to a low-carbon scenario would require acting on the primary cause of deforestation, demand for more land for agriculture and livestock. Therefore, this study proposes a strategy that acts on two complementary fronts: (i) eliminate the structural causes of deforestation and (ii) protect the forest against remaining attempts to cut. Implementing the first part would involve working with stakeholders who use already deforested land, while the second would include those that have a vested interest in new forest cuts.

With regard to the first front, eliminating the demand for more land would require accommodating the expansion of agriculture and the meat industry—both of which are important to the Brazilian economy—on already deforested land. That would mean a drastic increase in productivity per hectare. Technically, one available option is to increase livestock productivity, thereby freeing up large quantities of pasture. This option is technically possible since current average livestock productivity is low and would entail the scaling up of already existing productive systems in Brazil (i.e., feedlots and crop-livestock systems).

The potential for releasing and recovering degraded pasture is considerable and is enough to accommodate the most ambitious growth scenario. Moreover, moving from lower- to higher-productivity production systems can trigger a net gain for the sector economy since more intensive processes converge with higher economic returns (chapter 7). But this option also presupposes four challenging issues.

First, productive livestock systems are far more capital-intensive, both at the investment stage and in terms of working capital. Having farmers shift to these systems would require offering them a large volume of attractive financing far beyond current lending levels. Commercial

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138 See "Assessing the Risk of Amazonian Forest Dieback: An Assessment from the World Bank," by Jose A. Marengo, Carlos A. Nobre, Walter Vergara, Sebastien Scholtz, Alejandro Deeb, Peter Cox, Wolfgang Lucht, Hiroki Kondo, Lincoln Alves, and Jose Pesquero.

interest rates are usually too high to make such investments attractive. Moreover, banks are often unwilling to lend to farmers, whom they perceive as insufficiently creditworthy. Thus, a large volume of financial incentives, along with more flexible lending criteria, would be needed to make such financing viable for both farmers and the banking system. Over the past five years, the Brazilian government has developed programs to stimulate the adoption of more productive systems (e.g., PROLAPEC and PRODUSA) in order to reduce business risks, increase income in the field, and renovate degraded pasture areas. A first attempt to estimate the volume of incentives required indicates an order of magnitude of US$21.5 billion per year.

Second, these systems require higher qualifications than traditional extensive farming, which is used to move on to new areas as soon as pasture productivity has degraded, eventually converting more native vegetation into pasture. Therefore, the financing effort should be accompanied by intensive development of extension services. Public policies that promote rural extension and training of cattle ranchers would be important in overcoming this barrier.

Third, a rebound effect should be prevented. That is, the higher profitability of needing less land to produce the same volume of meat might trigger an incentive to convert more native forest into pasture. Such a risk is especially high in areas where new roads have been opened or paved. Therefore, the incentive provided should be geographically selective: It should be given only when it is clearly established, on the basis of valid and geo-referenced land ownership title, that the project will include neither conversion of native vegetation nor areas converted in recent years (e.g., less than 5 years), whether legally or not. This study verified that such a stipulation would be technically possible, since it verified that enough pasture can be freed up nationally even without increasing productivity of livestock in the Amazon region. Therefore, any subsidized financing for livestock production in the Amazon region should be made on a extremely selective and stringent basis, and the area in question should be closely monitored.

Fourth, several attractive options considered in the low-carbon scenario to mitigate emissions or increase carbon uptake amplify the requirement of freeing-up pasture considerably. For example, full compliance with the Legal Reserve Law would result in the replanting of more than 44 million ha currently allocated to other activities. While replanting the forest would remove a large amount of carbon dioxide (CO_2) from the atmosphere, this area—more than twice the expected expansion of agricultural and pasture land under the reference scenario—would no longer be available for such activities. Avoiding a "deforestation leakage" would thus require that the equivalent additional amount of pasture be freed up; otherwise, a portion of production would have to be reduced to prevent the conversion of more native vegetation elsewhere. The same rationale applies to the expansion of any other activity that requires land (e.g., bioenergy activities involving ethanol or renewable charcoal), though on a far smaller scale. Under the low-carbon scenario, further expansion of these activities, taken together, would require less than one-fourth of the additional land required for legal forest reserves. Thus, there is a difficult trade-off between (i) more efforts to increase livestock productivity to release more land and (ii) full enforcement of the recovery of legal reserves and crop expansion. Less compliance with the current legal obligation regarding forest reserves would make the goal of accommodating all activities without deforestation less difficult, but it would mean less carbon uptake; the converse is also true.

To protect the forest against the remaining causes of deforestation, it is proposed that forested areas where deforestation is illegal be protected against fraudulent interests to cut. It should be noted that there may be a significant lag between the time that demand for land is reduced and the time that the behavioral change of deforestation agents at the frontier, whether legal or illegal, could be effectively observed.

Protecting forested areas where deforestation is illegal could be achieved via an array of activities, ranging from repressive police action to sustainable-use projects. In recent years, the Brazilian government has made considerable efforts in this area, particularly under the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM). Protection measures may include activities similar to those already put into practice under the PPCDAM, such as (i) expansion and consolidation of protected areas, (ii) development of integrated projects, and (iii) promotion of the sustainable use of forest resources. Such efforts will need to be maintained and probably increased.

If the proposed strategy is fully implemented—that is, the demand for additional land is phased out and the forest is protected against the remaining causes of deforestation—then the contribution of Brazil's LULUCF-sector activities could be inverted from high-net GHG emissions to a net GHG uptake of about 195 Mt CO_2 per year by 2030.

10.2 Better Transport-sector Policies and Institutional Coordination

The main potential for reducing Brazil's transport-sector emissions is improving the transport services offered. The impact of transport infrastructure projects in terms of emissions is a side-effect, which is generally positive but not significant enough to drive the decision-making process. At the same time, two important caveats apply. First, Brazil can further reduce emissions significantly by substituting ethanol for gasoline; fuel substitution also applies to petro-diesel, which can be substituted by bio-diesel, although the experience is far more limited. Second, the development of transport infrastructure, such as the opening of new roads in the Amazon forests, can lead to increased deforestation and thus emissions. This impact, albeit complex, has been established by geo-statistical analysis and taken into account in the evolution of deforestation in the reference scenario (chapter 2).

10.2.1 Urban Transport

About 42 percent of direct sector emissions result from the urban transport subsector, particularly congestion in large urban areas (chapter 5). Vehicles in traffic jams—buses, trucks, and cars—all emit GHGs while the timely service they are expected to deliver is delayed, resulting in large opportunity costs for the users. Unlike the energy sector, where emissions usually increase or decrease according to supply, the converse is true for urban transport; that is, insufficient supply results in increased emissions in the form of traffic congestion.

The key issues faced by the urban-transport sector are not technological, although some efficiency gains can still result from technology innovations. Mass-transport technologies, non-motorized transport options, and demand management measures are all available and road-tested. Rather, the main challenge centers on financing and institutional coordination, which delay the implementation of transport projects. For example, Brazil's more than 5,000 municipalities independently administer their transit and transport systems, making it difficult to harmonize nationwide plans and policies. Such complexity makes it difficult to mobilize the most appropriate resources where needed. In addition, mass transport systems in urban areas are capital-intensive, which prevents many municipalities from implementing them. One way to overcome the limited investment capacity of the public sector is to promote public-private partnerships (PPPs).

10.2.2 Regional Transport

For regional transport, the main challenge to reduce emissions involves the design and implementation of appropriate modal-shift policies and investments. Any intervention aimed at modifying the transport matrix should be guided by national, regional, and international market needs and demands. If not, the result may be underuse of high-cost investments. For example, the potential for establishing new waterways and railways in Brazil's north, northeast, and central-west regions is more limited than generally thought (chapter 5). To meet the freight transport targets under the low-carbon scenario, it is important to promote better integration and partnerships among rail concessionaires and between the concessionaires and the various spheres of government, including regulatory authorities. For instance, because of inadequate facilities for efficient inter-modal transfer, road transport is usually preferred over coastal shipping. The various transport modes are generally operated privately; thus, their efficient integration requires new infrastructure and terminals, calling for better coordination and support from public authorities. For policies involving intermodal-transfer projects to succeed, there must be appropriate allocation of resources, as well as measures to facilitate the financing of the large investments required to build and adapt the needed infrastructure. The Ministry of Transport (MT) could coordinate such efforts.

10.2.3 Further Substitution of Gasoline by Ethanol

Bio-ethanol as a fuel substitute for gasoline already contributes to the low-carbon intensity of the transport sector. Without ethanol, GHG emissions would be 50 percent higher in 2030 than currently projected under the reference scenario. At the same time, a significant opportunity remains to reduce transport emissions through the increased participation of bio-ethanol as a substitute for gasoline. This would represent one-third of the emissions reductions targeted for the transport sector under the low-carbon scenario.

The key challenge, which the Brazilian government has dealt with for several decades, is how to ensure that market price signals are aligned with this objective. On the demand side, most new cars produced in Brazil are flex-fuel vehicles, which, by definition, can switch continuously from gasoline to ethanol and vice-versa. On the one hand, these vehicles present an opportunity for high levels of substitution. Yet, GHG benefits could quickly be lost if gasoline proves less expensive for the consumer. Market price signals are key determinants of ethanol's high market share. Because of the high volatility of oil prices, a financial mechanism would need to be designed and implemented to absorb price shocks and maintain the attractiveness of ethanol for vehicle owners. On the supply side, it is necessary to provide sufficient incentives for sugar-cane and ethanol producers to invest in new ethanol capacity, in the face of fluctuations in international petroleum and sugar prices. Removing trade barriers to ethanol imports from other countries would help to promote low-cost Brazilian ethanol production.

10.3 Exploration of Existing Energy-sector Potential

The main challenges to emissions mitigation in the energy sector are not only related to the potential for energy conservation and fuel switching in the industrial sector. Certain assumptions that underpin the reference scenario also require significant efforts.

10.3.1 Secure the Low-carbon Options in the Reference Scenario

Unlike the other sectors considered in this study, the energy sector would not be able to maintain emissions at or below the 2010 level under the proposed low-carbon scenario. Even achieving a 20-percent emissions reduction compared to the reference scenario would result in a 40-percent rise in emissions between 2020 and 2030.

According to the PNE 2030, on which the reference scenario is based, most of Brazil's remaining large hydropower potential will have been fully exploited by 2030. For this reason, the energy sector has little opportunity left to further reduce emissions. Even so, per-capita energy-sector emissions—even under the reference scenario—will continue at or below today's global per-capita average and at less than half the current OECD average (chapter 4).

Such favorable comparisons result, in part, from Brazil's past efforts to develop local renewable energy. They also reflect assumptions in the reference scenario for continued growth of hydropower capacity and the significant development of biomass, wind, and nuclear energy. These assumptions reflect the Brazilian government's strategic goals for energy-sector development, including energy independence and diversification, over the coming decades.

The PNE 2030 projects that hydroelectricity will represent more than 70 percent of power generation, which implies increasing hydropower generation capacity at a pace that has not yet been observed. Indeed, the participation of hydro-energy at new energy auctions has been limited by the environmental licensing process. As a result, the participation of fuel oil, diesel, and even coal-based power plants, which often face less difficulty in obtaining environmental licenses, has increased.

More recently, bids on the two large Rio Madeira power plants were successfully completed, and the government has adopted a new regulation requiring fossil fuel–based thermal power plants to offset their emissions through tree plantings, renewable energy, or energy conservation,[139] suggesting that adjustments are already under way. Measures to improve the efficiency of the environmental licensing process for hydropower generation could include (i) ensuring that the design of electricity-sector plans, programs, and policies take social and environmental factors into account, along with economic, financial, and technical factors; (ii) promoting and establishing mechanisms to resolve disputes among players in the licensing process; (iii) preparing an operations guide, which defines the approaches used during the process; and (iv) building technical capacity and upgrading and diversifying the professional skills of environmental agencies.[140]

For nuclear energy, the PNE 2030 has set an ambitious goal of building 5.3 GW of additional nuclear-generation capacity until 2030, which is triple the current capacity. Wind generation and bagasse-based cogeneration would each increase more than tenfold. Thus, the already low-carbon intensity of the reference scenario leaves little room for further GHG abatement with these technologies under the low-carbon scenario.

10.3.2 Fully Explore the Existing Framework for Energy Conservation

Harnessing the mitigation potential of energy efficiency under the low-carbon scenario requires fully exploring the options offered by the existing legal framework. Progress, albeit slow,

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139 IBAMa, Normative Instruction, no. 7.
140 "Environmental Licensing for Hydroelectric Projects in Brazil: A Contribution to the Debate," Summary Report. World Bank Country Management Unit, March 28, 2008.

has been made in implementing the energy efficiency law, and several available mechanisms promoting energy efficiency address the needs of all consumer groups (e.g., PROCEL, CONPET, and EPE planned auctions). These initiatives offer the possibility of creating a sustainable energy-efficiency market. Barriers to this end include an overemphasis on procedures and weak coordination between power and oil-and-gas programs. Key problems to address are: (i) price distortions that introduce disincentives for energy conservation and (ii) separation of the energy-efficiency efforts of power and oil-and-gas institutions. Better institutional coordination might be achieved via a committee responsible for development of both programs.

10.3.3 Resolve the Smart-grid Financing Issue

The main barrier to implementing bagasse cogeneration and wind energy is the cost of interconnecting with the sometimes distant or capacity-constrained sub-transmission grid. This reduces the feasibility of cogeneration vis-à-vis alternatives, the localization of which can be optimized with regard to the grid. If the cost continues to be fully borne by the respective sugar mills and wind-farm developers, the contribution of cogeneration and wind energy will likely remain low, resulting in the entry of more fossil fuel–based alternatives. The key question is how to finance the required grid. An ambitious smart-grid development program would help to optimize the exploration of this promising but distributed low-carbon generation potential.

10.3.4 Increase Energy-sector Mitigation via Ethanol Exports

Brazil's considerable experience with bio-ethanol presents an opportunity for the country to reduce global GHG emissions by increasing ethanol exports for gasoline substitution. The additional reduction in emissions would total 786 Mt CO_2 over the 2010–30 period, equal to about one-third of the energy-sector emissions reduction achieved. Implementing this option would require overcoming barriers to ethanol exports. It would also require demonstrating that the incremental area planted with sugar cane would not contribute to carbon leakage (i.e., deforestation associated with the expansion of agricultural land for sugar-cane cultivation). Under the low-carbon scenario, the land area allocated to sugar cane in 2030 would be 6.3 million ha more than under the reference scenario (19.1 versus 12.7 million ha), representing a tripling of the current area, which is still less than the area planted to soybean in 2006 (22.7 million ha) and one-tenth current pasture area (estimated at 210 million ha). This study demonstrates that this option would become technically feasible if the proposed measures to reduce deforestation drastically. However, it would be essential to coordinate the pace of implementation to effectively establish the global benefit of ethanol exports.

10.4 Institutional Framework and Incentives for the Waste Sector

Brazil's waste sector has a history of underinvestment with low private-sector participation. This situation can be attributed, in part, to a sector culture characterized by overall lack of long-term planning, which is detrimental to credit access; insufficient allocated funds; and lack of incentives. Both solid and liquid waste management face a high level of institutional complexity and decentralization, making it more difficult to leverage the large amount of required financial resources. There is, however, a legal and institutional framework enabling the voluntary partnership of federal entities alongside municipalities for waste-management consortiums, as well as intermunicipal consortiums (Law of Basic Sanitation). Meanwhile, the Law of PPPs

(n. 11.079/2004) encompasses the legal framework for the establishment of public-private partnerships, which serves to promote the required private sector participation. It must be noted, however, that since waste-management is under the jurisdiction of the municipalities, the appropriate capacitation must be expanded in order to improve their long-term planning as well as project development capabilities. It is also imperative that both the municipalities responsible for granting concessions, as well as the interested private sector players expand their capacities with respect to the working knowledge of the existing legal structure, regulations, and procedures necessary in order to access the available financing resources (i.e. within the appropriate stipulated timeframes, etc.)

In modern landfills, unlike open dumps, fermentation is anaerobic and therefore generates methane (CH_4). Emissions increase along with the expansion of waste collection and disposal. Compared to emissions from other sectors, waste-management emissions increase and decrease the most in the respective reference and low-carbon scenarios. Under the reference scenario, the CH_4 generated is a powerful end-of-pipe GHG, which is not necessarily destroyed. The emissions are quickly boosted as ever greater numbers of people begin to benefit from solid and liquid waste-collection services. But given that CH_4 can easily be destroyed, incentives created by the carbon market under the low-carbon scenario could encourage participation in projects designed to destroy landfill gases. To meet sectoral challenges, this study proposed (i) establishing a legal and institutional framework to facilitate the establishment of inter-municipal and regional consortia to handle waste treatment and (ii) providing incentives for institutional involvement in shared management of systems involving concessions or public-private partnerships (PPPs) under long-term contracts.

10.5 Final Remarks

Brazil harbors large opportunities for mitigation and carbon uptake of GHG emissions at relatively low costs. This positions the country as one of the key players to tackle the challenge posed by global climate change. This study has demonstrated that a series of mitigation and carbon uptake measures are technically feasible and that promising efforts are already under way. Yet implementing these proposed measures would require large volumes of investment and incentives, which may exceed a strictly national response and require international financial support. Moreover, for Brazil to harvest the full range of opportunities to mitigate GHG emissions, market mechanisms would not be sufficient. Public policies and planning would be pivotal, with management of land competition and forest protection at the center.

Annex A
Set of Common Assumptions

Table A.1: Macroeconomic and Sector Model Parameters and Sources

Variable	Source
Macroeconomic Parameters	
Discount rates	PNE 2030 Scenarios (8%)
Economic growth projections (projected GDP growth)	PNE 2030 Scenarios (table A.2); Scenario B1 is the BAU
Interest rates, exchange rate	National banks
Input-Output (I-O) tables and social accounting matrix	IBGE
Population growth	IBGE 1980–2050 (PNE is disaggregated by region (table A.3, table A.4)
Labor supply and wage rates	PME (monthly employment survey), IBGE
Commodity prices, price index, w tax rates, and import duties	National Statistics Office
Other variables to be included	
Land Use and Agriculture Model	
Land use by annual crops	Municipal agricultural research, IBGE
Pasture	2006 agricultural census (IBGE)
Urban area	EMBRAPA (*Mapeamento e Estimativa da Área Urbanizada do Brasil*) (www.urbanizacao.cnpm.embrapa.br/)
Planted forest area (economic exploitation)	ICONE team
Natural landscape	PRODES/INPE (www.obt.inpe.br/prodes/), PROBIO, SOS Mata Atlântica, and others
Conservation units	IBAMA and regional environmental agencies
GHG coefficients by land-use type	IPCC or national sources
Hydrography and permanent preservation area	UFMG team, based on GIS estimation
Indigenous reservation	FUNAI
Weather restriction	CONAB (www.agritempo.gov.br)
Agricultural costs	ICONE team
Agricultural return and risks	ICONE team
Location of sugar-cane mills (actual and projected)	ICONE team
Projected agricultural yields and technology	ICONE and working groups C, D, and F
Industrial sugar-cane technology (projected)	ICONE and working groups F and K
Energy Sector Model	
Energy commodity prices	PNE 2030 (figure A.1, figure A.2)
Oil prices (international)	PNE 2030 (figure A.1)
Base-year data on energy production, trade, and consumption (by sector, fuel)	National Energy Balance (BEN) 2006, base year 2005
Local commodity prices (actual and projected)	ICONE team

Cost of energy-producing and utilizing technologies	PNE 2030, thematic reports
Efficiencies of energy-producing technologies and consumer devices and processes	
GHG emission coefficients by fuel and technology types	National emission inventory/IPCC
Other variables to be included	
GHG emission coefficients	National emission inventory/IPCC
Technology costs (demand and supply side in both energy and forestry/agricultural sector)	IEA/EIA

Table A.2: PNE 2030 Macroeconomic Scenarios

Scenario	Percent annual growth rate of value added, 2005–30				
	Agriculture	Industry	Service	Brazil	World
A1	5.3	4.2	5.4	5.0	3.8
B1	4.2	3.7	4.2	4.1	3.0
B2	3.5	3.0	3.2	3.2	3.0
C	2.6	2.2	2.2	2.2	2.2

Table A.3: Population (millions of inhabitants), 2005–30

Region	2005	2010	2015	2020	2025	2030
North	14.86	16.43	17.87	19.18	20.40	21.49
Northeast	51.31	54.18	56.81	59.21	61.43	63.43
Southeast	79.02	84.31	89.16	93.59	97.68	101.36
South	27.14	28.77	30.26	31.63	32.89	34.02
Center-West	13.14	14.35	15.46	16.47	17.41	18.25
Brazil	185.47	198.04	209.56	220.09	229.80	238.56

Table A.4: Urban Population Rate in 2030

Region	%
North	76.4
Northeast	78.6
Southeast	95.0
South	89.7
Center-West	93.3
Brazil	88.0

Source: PNE 2030
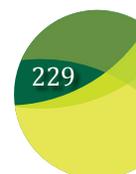
Figure A.1: Evolution of International Oil Prices (Brent type)

Figura 1.13: Evolução dos Preços Internacionais do Petróleo (tipo Brent)

US$/bbl

Preços constantes US$ [2006]
Preços nominais

Elaboração: EPE
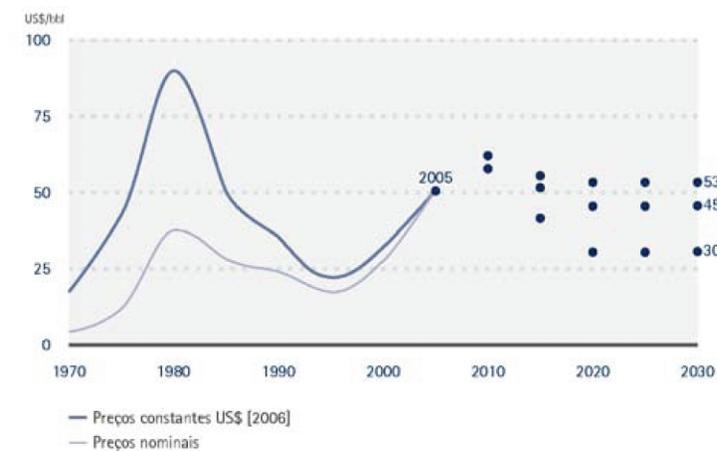
Figure A.2: International Natural-gas Prices

Figura 1.14: Preços Internacionais do Gás Natural
(US$ de 2006)
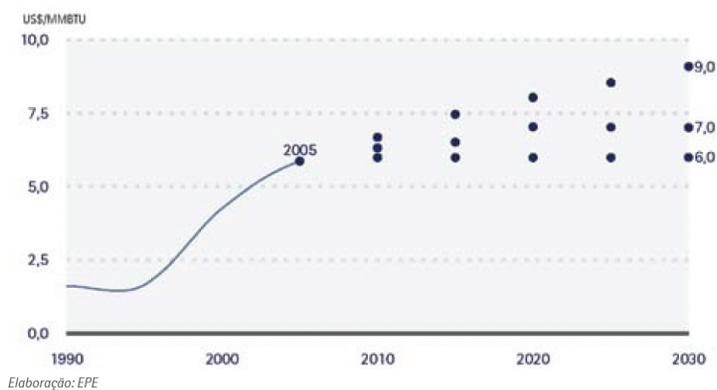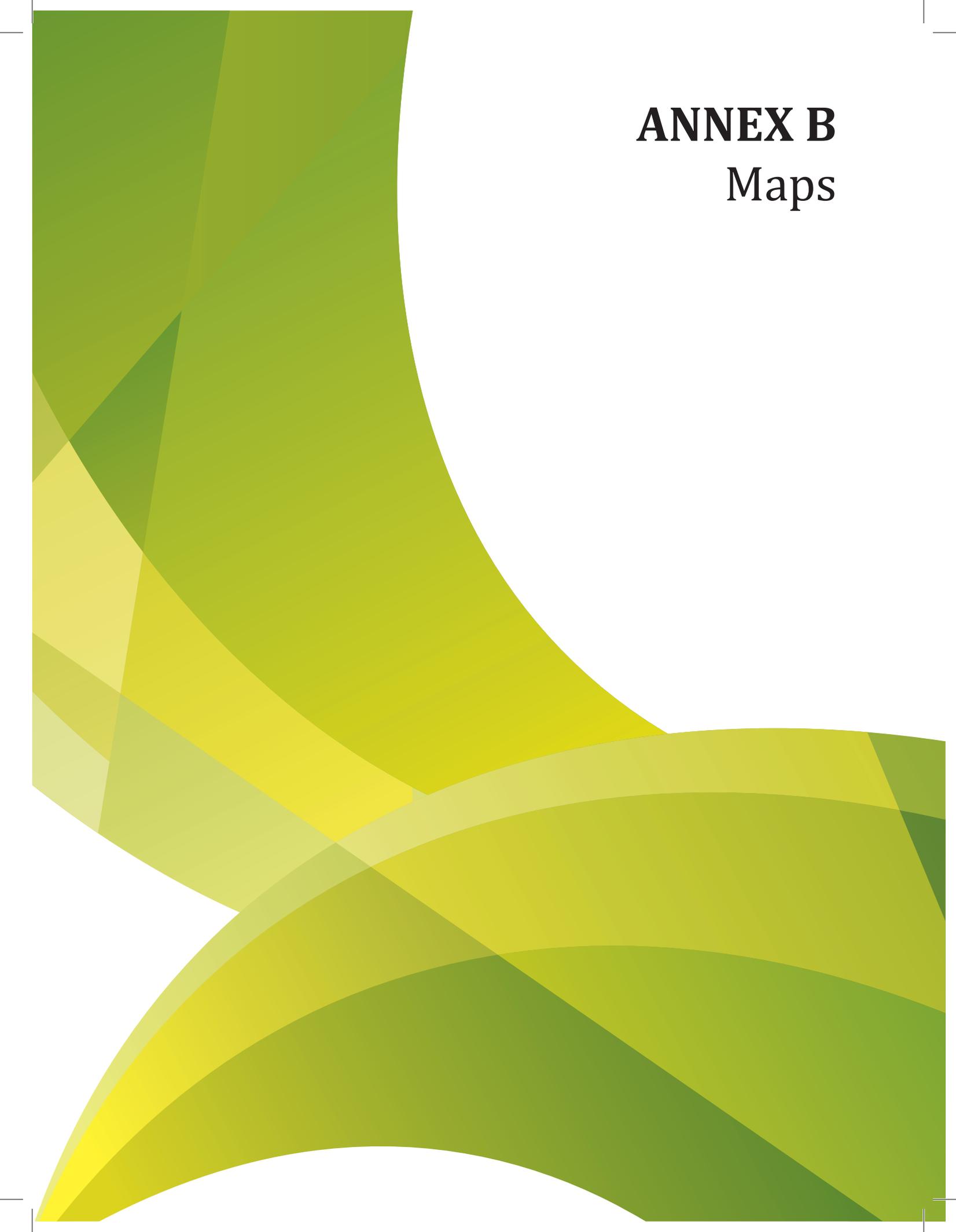
US$/MMBTU

Elaboração: EPE

ANNEX B
Maps

AGRICULTURE

Map 1: Change in Area Cultivated by Crop, 2010-2030

2010
Area Cultivated (ha x 1000)

15 525   South
12 841   Central West Cerrado
9 489   Southeast
5 870   MAPITO and Bahia
3 984   Northeast Coast

2030
Reference Scenario
Area Cultivated (ha x 1000)

20 029   South
16 532   Central West Cerrado
12 276   Southeast
8 482   MAPITO and Bahia
4 111   Northeast Coast

2030
Low Carbon Scenario
Area Cultivated (ha x 1000)

20 316   South
17 462   Central West Cerrado
16 368   Southeast
9 197   MAPITO and Bahia
4 331   Northeast Coast

- Cotton
- Rice
- Beans
- Corn
- Soy
- Sugar Cane

Source: ICONE, World Bank Brazil Low Carbon Case Study

Map 2: Total Cumulative Emissions from Agriculture, 2010-2030

Emissions (Mt CO2e)

1.693   Brasil
2.048

469   RS
199   PR
54   TO
22   PI
1   RR

Source: EMBRAPA, ICONE, World Bank Brazil Low Carbon Case Study
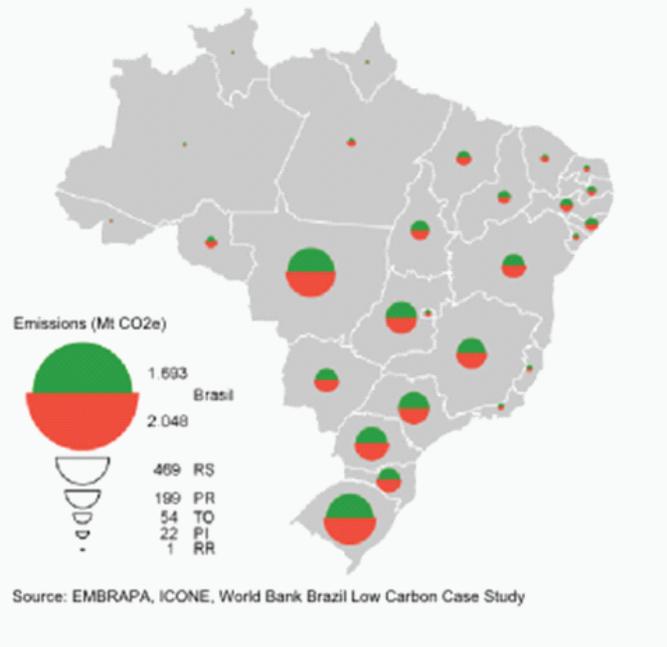
LIVESTOCK

Map 3: Number of Heads of Cattle
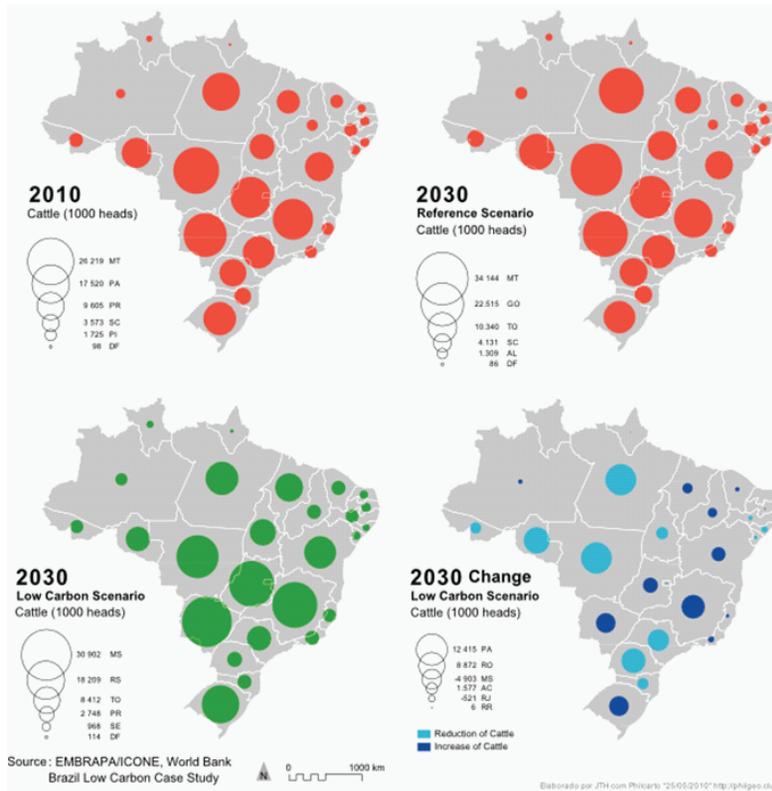
Map 4: Total Cumulative Emissions from Livestock, 2010-2030
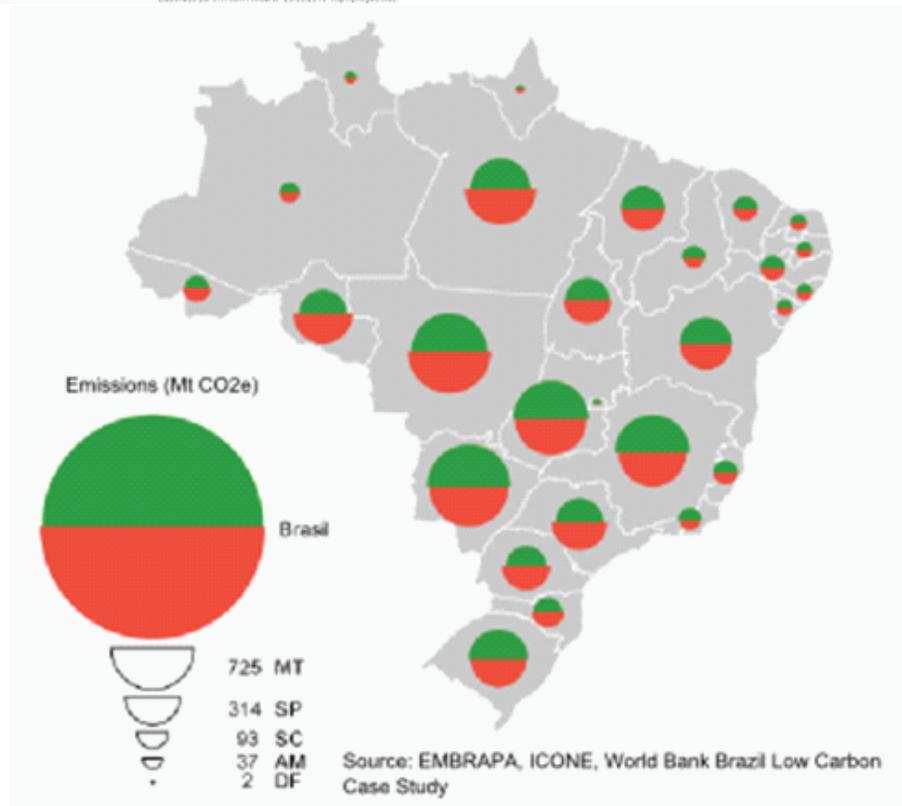
DEFORESTATION

Map 5: Total Area Deforested, 2010-2030

Deforestation (Km2)

61 836	PA	
41 572	MT	
12 756	MA	
5 609	BA	
1 536	SC	
169	PB	

Low Carbon Scenario
Reference Scenario

Source: EMBRAPA/ICONE, World Bank Brazil
Low Carbon Case Study

0 km   500
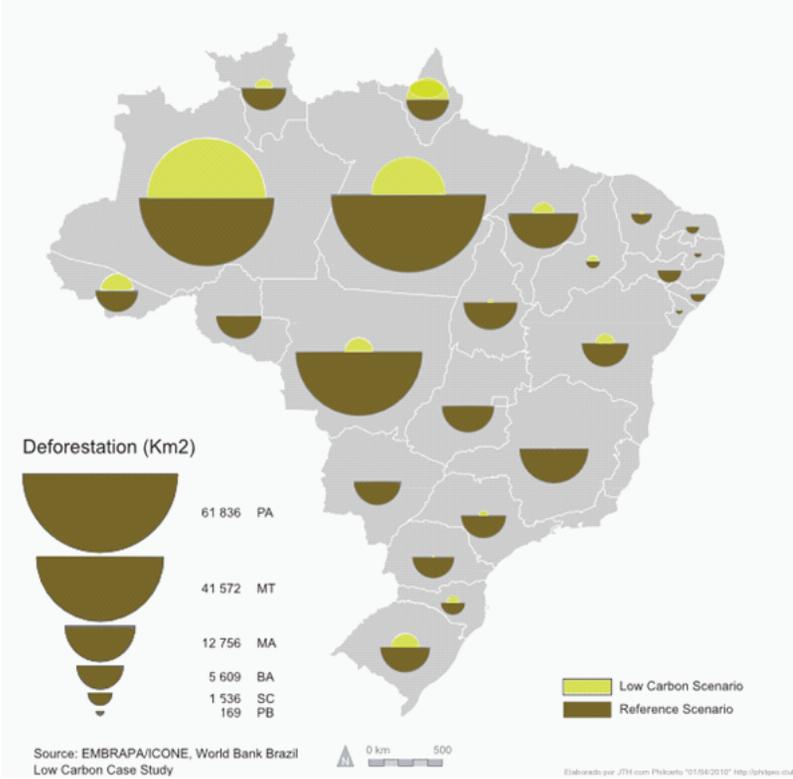
Map 6: Total Cumulative Emissions from Deforestation, 2010-030

Emissions (Mt CO2e)

3 314	Brazil
9 497	
2 508	PA
817	RO
222	AP
31	GO
1	SE

Source: EMBRAPA/ICONE, World Bank
Brazil Low Carbon Case Study
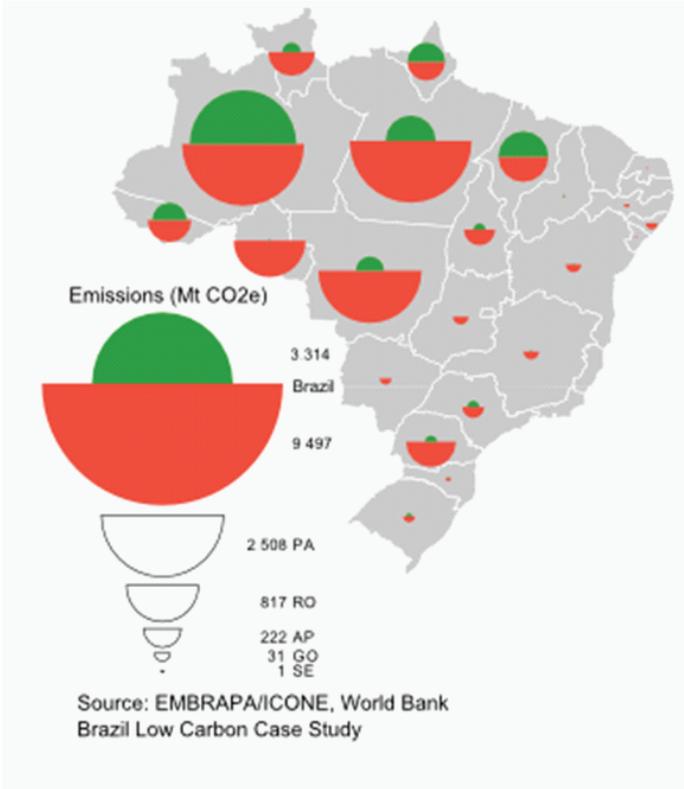
LAND USE – TOTAL

Map 7: Area used for Agriculture, Pasture, and reforestation by Region
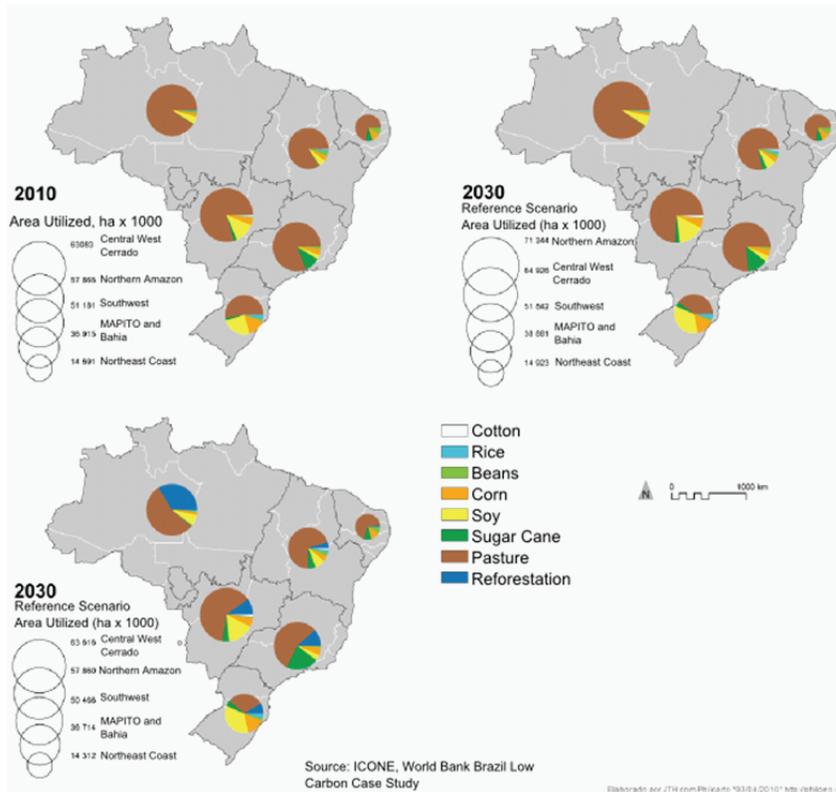
Map 8: Total Cumulative Emissions from Land Use (Agriculture, Livestock, Deforestation, Reforestation), 2010-2030
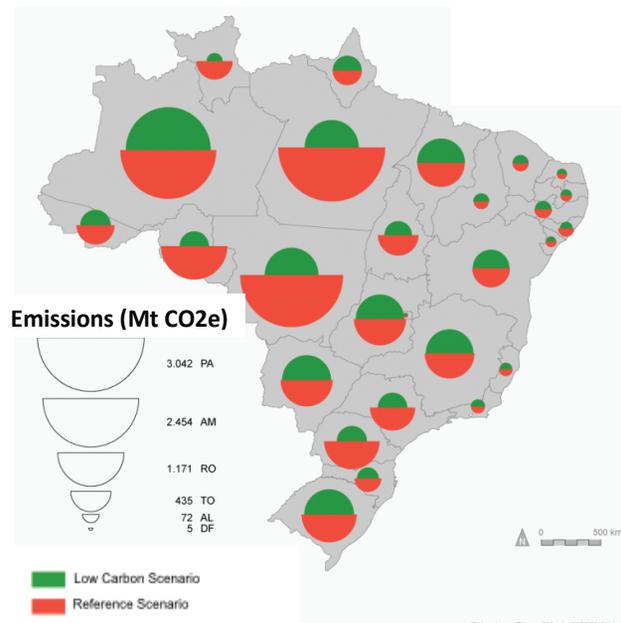
Map 9: Land Area Used by Pasture

2010
Reference Scenario
Pasture (1000 hectares)

29 334	MG
16 801	GO
8 904	SP
3 320	SC
802	RR
134	DF

2030
Reference Scenario
Pasture (1000 hectares)

27 817	MG
15 854	GO
8 366	SP
3 669	AM
1 171	RN
104	DF

2030
Low Carbon Scenario
Pasture (1000 hectares)

21 715	MG
13 580	MT
7 322	TO
3 436	RO
1 100	RN
92	DF

2030 Change
Low Carbon Scenario
Pasture (1000 hectares)

17 219	PA
6 698	RO
3 343	PR
-631	PI
-408	RS
4	CE

Reduction of Pasture
Increase of Pasture

Source: EMBRAPA/ICONE, World Bank
Brazil Low Carbon Case Study

0   1000 km

Elaborado por JTH com Philcarto *25/05/2010* http://philgeo.club

ELECTRICITY

Map 10: Annual Electricity Consumption
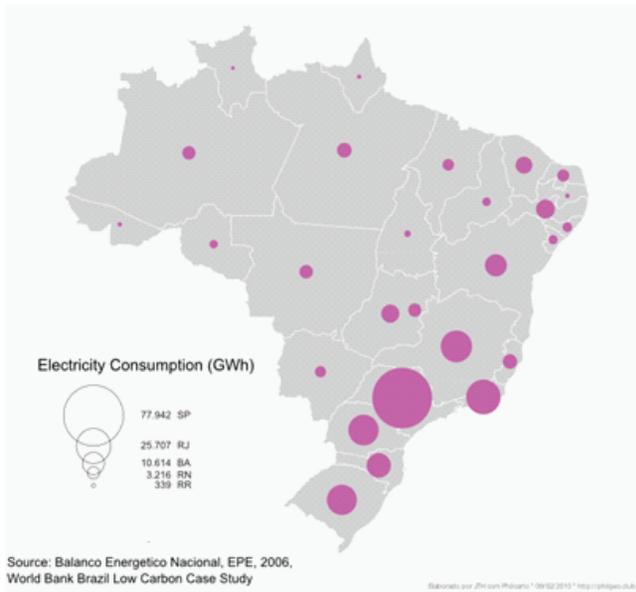
Map 11: Annual Electricity Generation

Electricity Consumption (GWh)

77.942 SP
25.707 RJ
10.614 BA
3.216 RN
339 RR

Source: Balanco Energetico Nacional, EPE, 2006,
World Bank Brazil Low Carbon Case Study

Electricity Generation, (GWh)

73691 PR
31747 PA
10931 SE
3014 RO
75 RR

Source: Balanco Energetico Nacional, EPE, 2007
World Bank Brazil Low Carbon Case Study

Mitigation 2010-2030
(MT CO2e)

6,82 SP
2,25 RJ
1,13 SC
0,54 CE
0,24 MS
0,03 RR
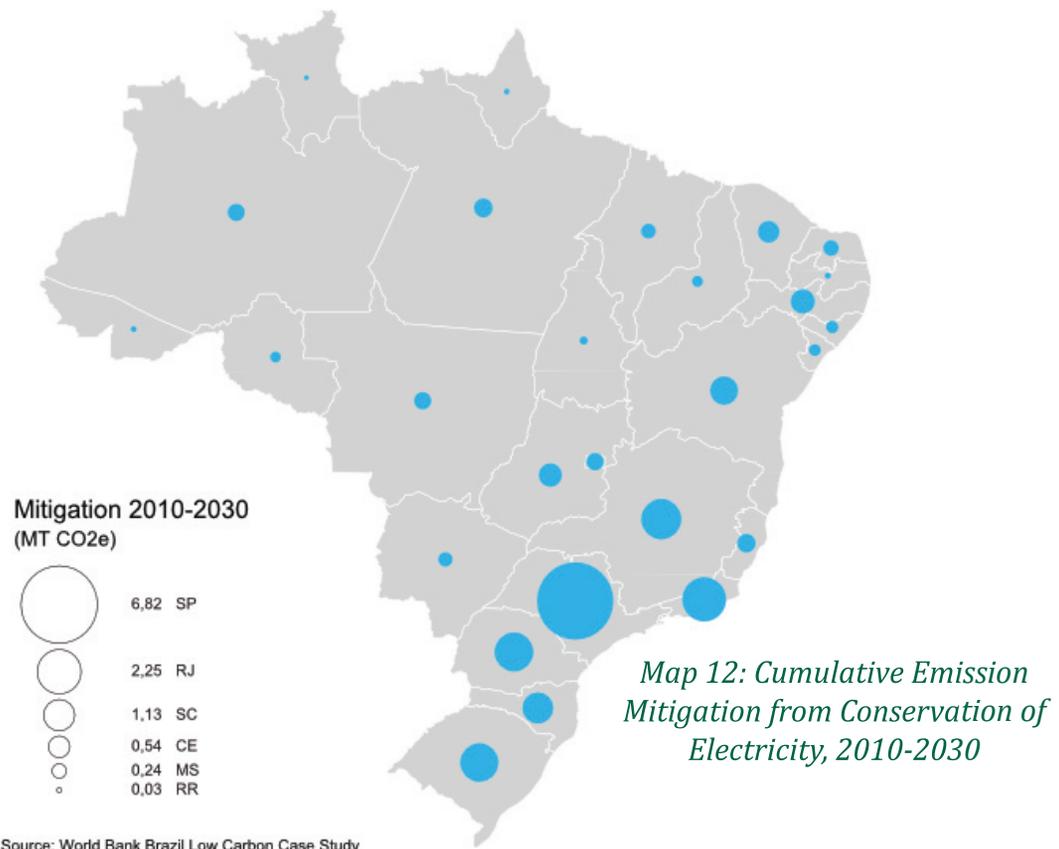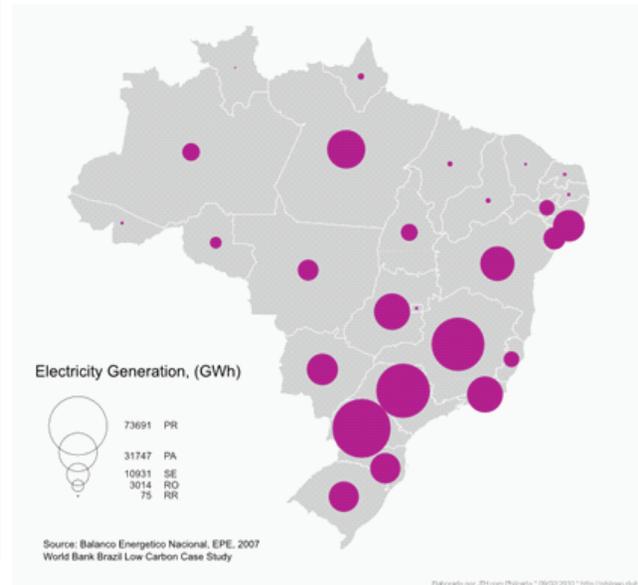
Map 12: Cumulative Emission Mitigation from Conservation of Electricity, 2010-2030

Source: World Bank Brazil Low Carbon Case Study

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Brazil Low-carbon Country Case Study

Map 13: Installed Cogeneration Capacity, 2010 and 2010, and Resulting Emission Mitigation, 2030

2010
Reference Scenario
Installed Capacity (MW)

2.918	SP
373	MG
328	MS
240	PE
55	PB
9	PI

Source: ANEEL, World Bank Brazil Low Carbon Case Study

2030
Low Carbon Scenario
Installed Capacity (MW)

16.353	SP
7.877	MG
3.113	MS
1.143	TO
301	ES
52	SE

Source: World Bank Brazil Low Carbon Case Study

2030
Emission Mitigation
(MtCO2e)

5.021	PR
2.180	PB
691	SP
360	MG
165	PI
18	MS

Source: World Bank Brazil Low Carbon Case Study

0   1000 km

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EXISTING REFINERIES

Map 14: Annual Emissions and Mitigation from Existing Refineries for the period 2015-2030

Source: PEE/COPPE/UFRJ, World Bank Brazil Low Carbon Case Study
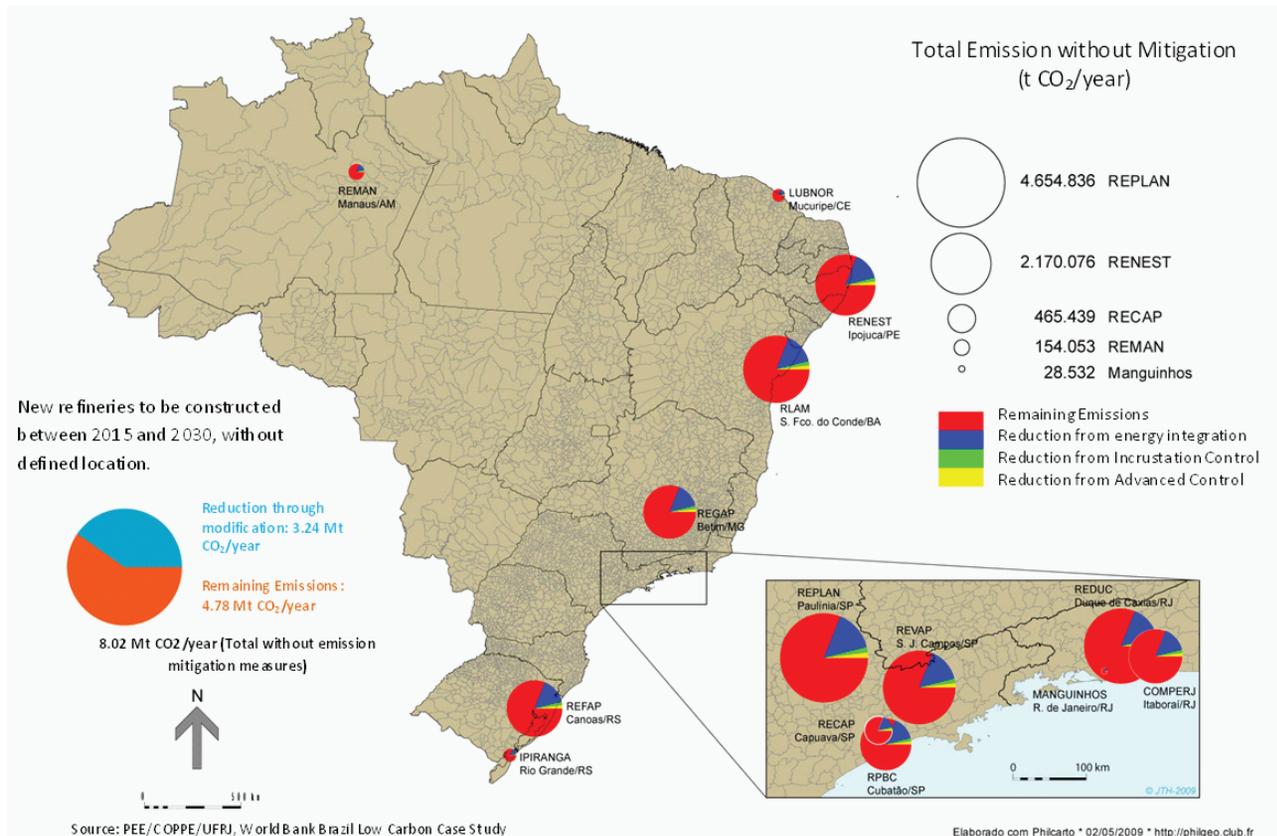
INDUSTRY – USE OF FOSSIL FUELS

Map 15: Total Energy from Fossil Fuels used in Industry
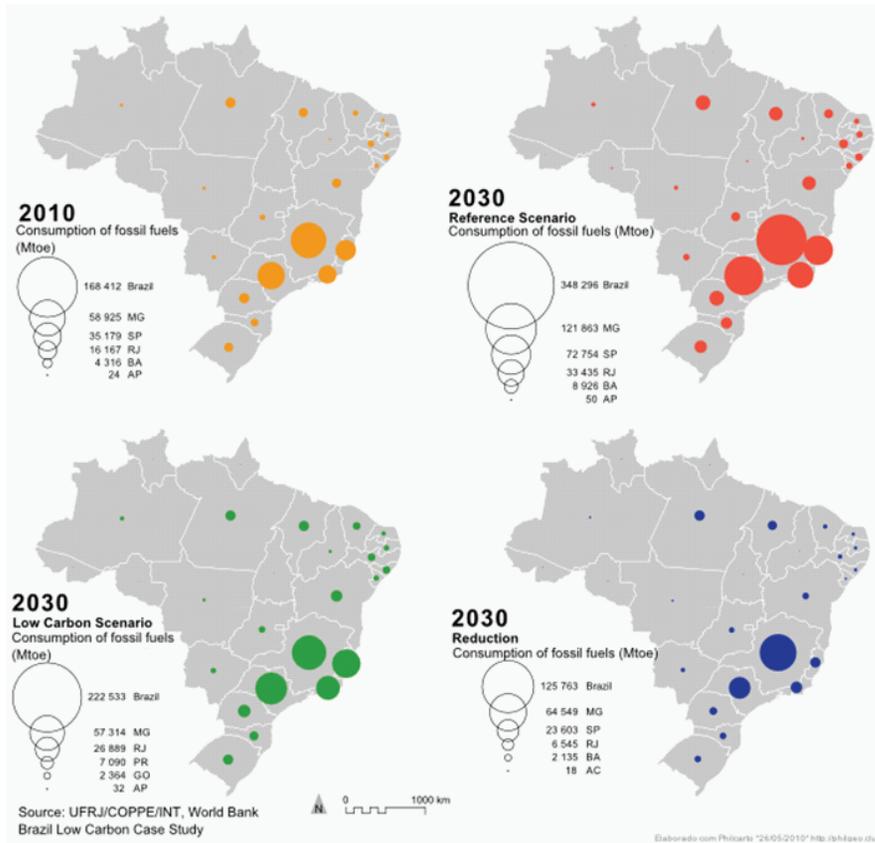
Map 16: Cumulative Emissions from Industry, 2010-2030
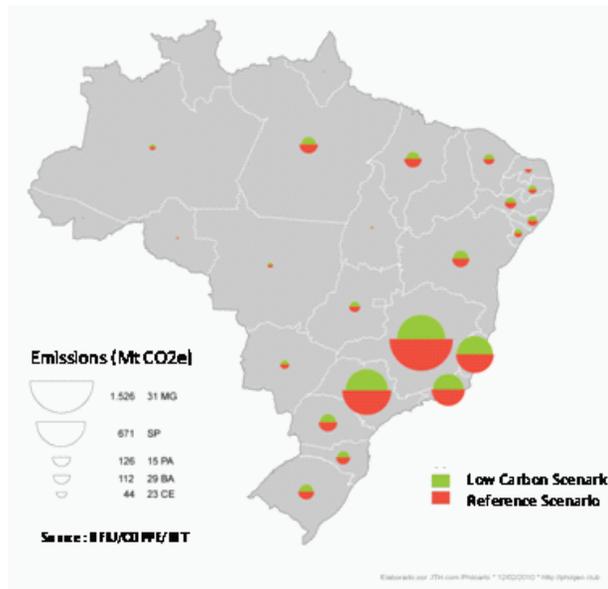
Map 17: Cumulative Mitigation by Activity, 2010-2030
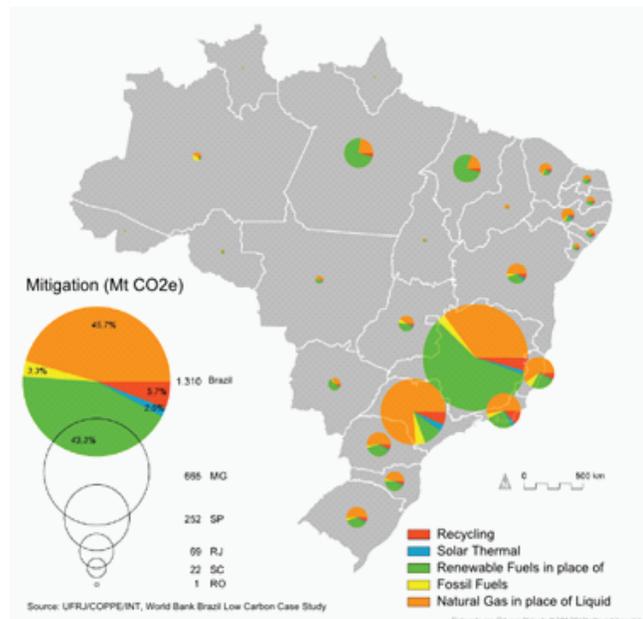
ENERGY - TOTAL

Map 18: Total Cumulative Emissions from the Energy Sector, 2010-2030

Emissions (Mt CO2e)

1.750 MG
788 RJ
401 PR
135 GO
39 AM
1 DF

Cenário de baixo carbono
Cenário de referência

Fonte: EMBRAPA, CETESB, UFMG, UFRJ, LOGIT, ICONE.

Elaborado por JTH com Philcarto "05/05/2010" http://philgeo.clut

Map 19: Cumulative Mitigation by Activity, 2010-2030

Mitigation (Mt CO2e)

85,83%
8,40%
1,43%
4,34%

1.526 Brasil
672 MG
283 SP
58 ES
9 MS
1 DF

Source: World Bank Team, Brazil Low Carbon Case Study

Energy Efficiency (Electricity)
Existing Refineries
Industry (Fossil Fuels)
Gas to Liquids

Elaborado por JTH com Philcarto "17/05/2010" http://philgeo.clut

TRANSPORT

Map 20: Growth in Transport Fleet, 2007 to 2030
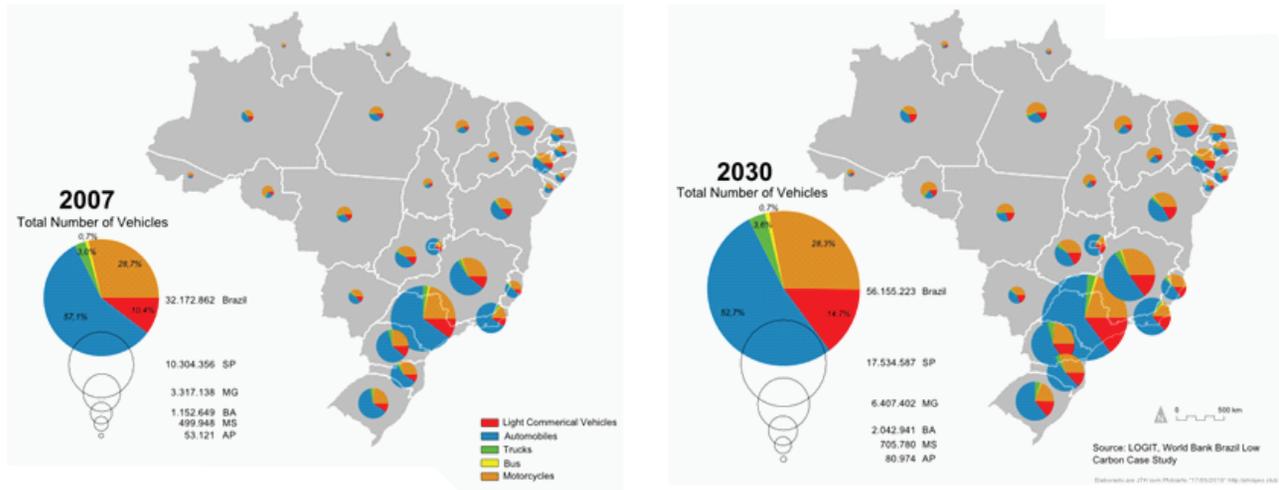
Map 21: Changes in Passenger Load
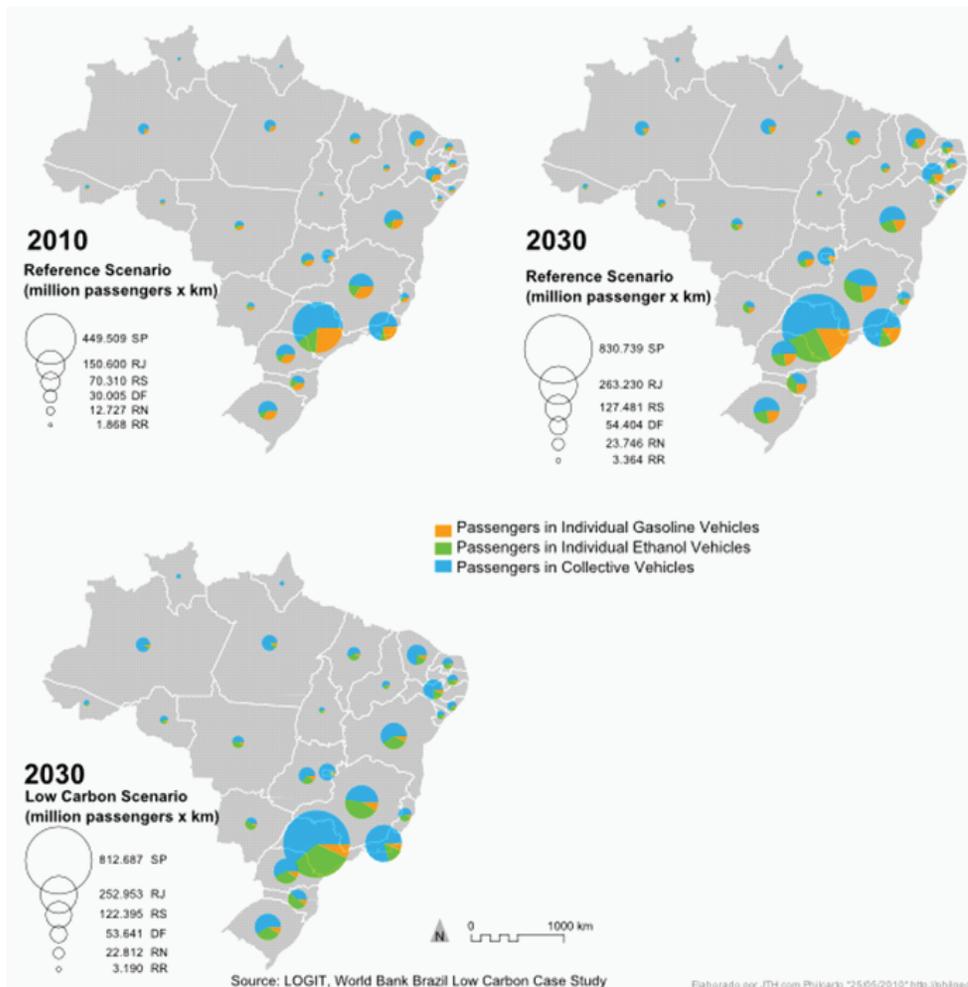
Map 22: Cumulative Emissions and Mitigation from Urban and Regional Transport, 2010-2030

Emissions, Reference Scenario (Mt CO2e)

735	SP
281	RJ
78	PE
27	AM
2	RR

- Urban
- Regional

Emission, Low Carbon Scenario (Mt CO2e)

603	SP
232	RJ
63	PE
22	AM
2	RR

- Urban
- Regional

Mitigation (Mt CO2e)

132	SP
49	RJ
15	PE
11	GO
5	AM
	RR

- Urban
- Regional

Source: LOGIT, World Bank Brazil Low Carbon Case Study

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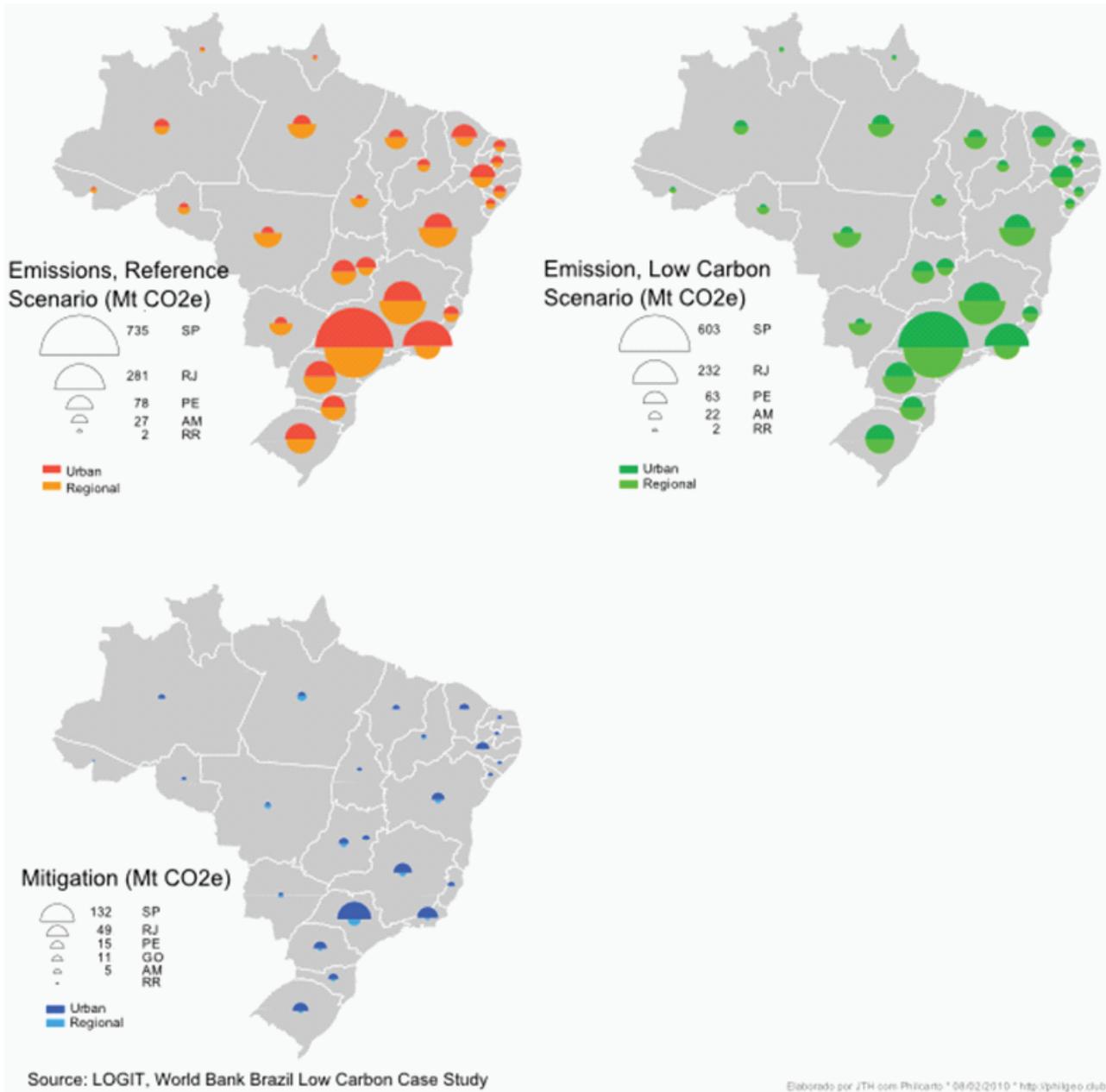
WASTE

Map 24: Waste Produced by State, 2010 and 2030

Quantity of Trash (Mt)

19 450   SP
8 357   MG
3 493   PE
2 540   PA
1 305   RN
152   RR

2030
2010

Source: CETESB, World Bank Brazil Low Carbon Case Study
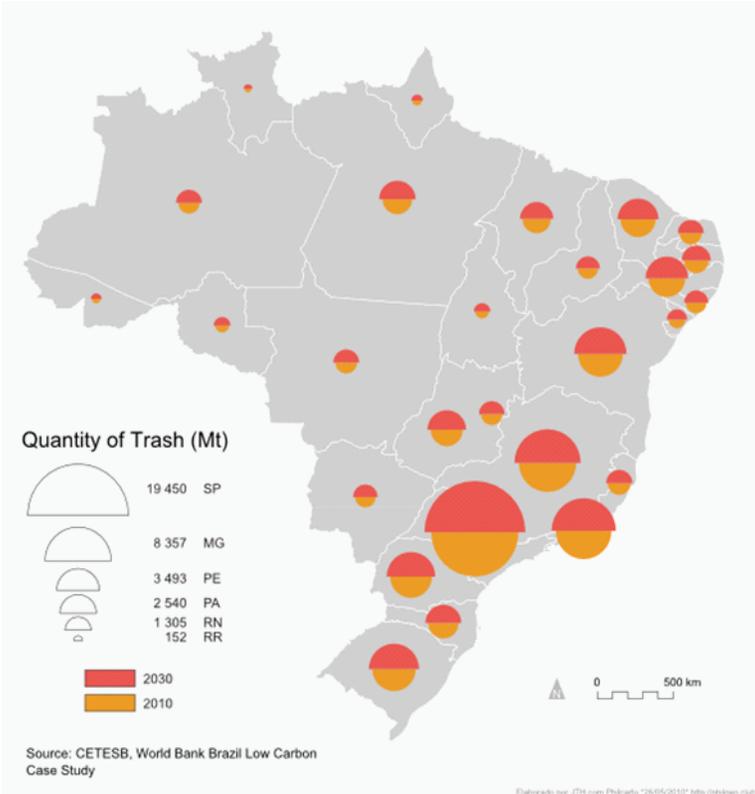
Map 25: Total Cumulative Emissions from Waste, 2010-2030

Emission (Mt CO2e)

1692   Brazil

651   SP
267   RJ
50   RS
27   AL
1   RR

Low Carbon Scenario
Reference Scenario

Source: CETESB, World Bank Brazil Low Carbon Case Study
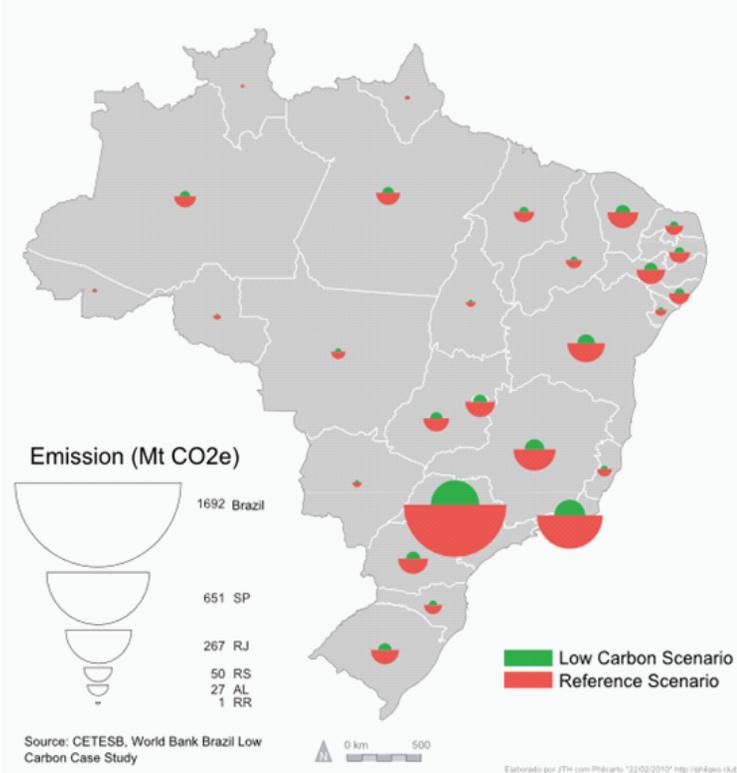
ALL SECTORS

Map 26: Cumulative Emissions and Mitigation by Sector, 2010-2030
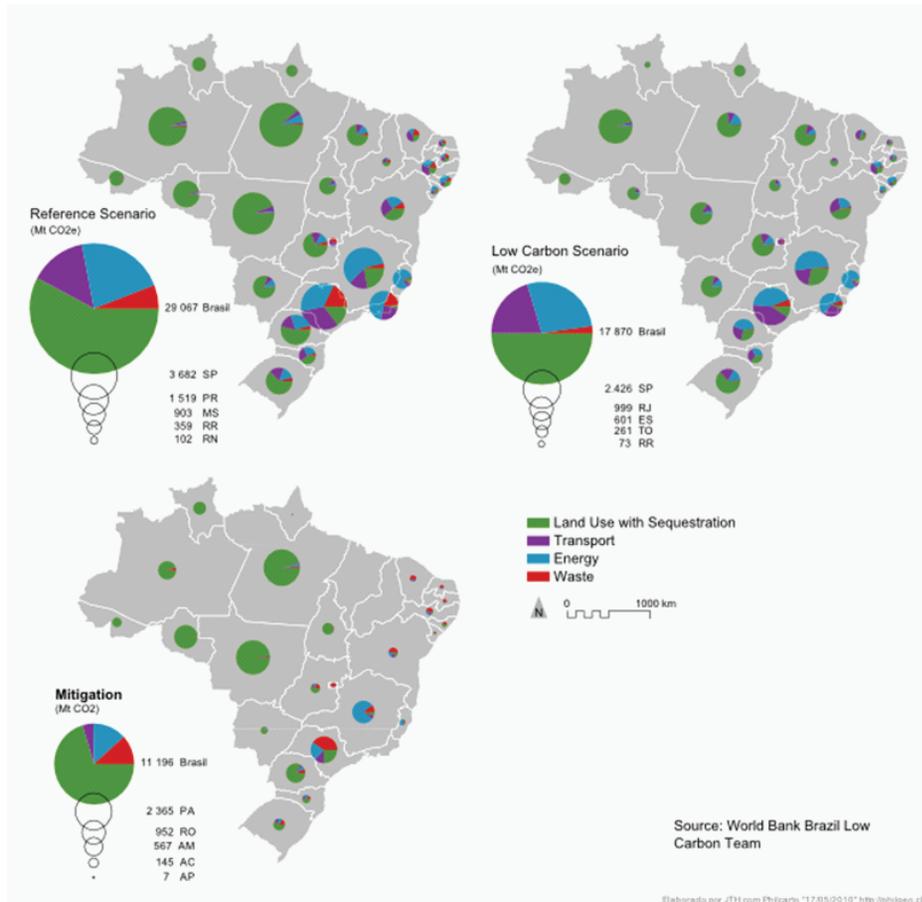
Map 27: Total Cumulative Emissions, 2010-2030
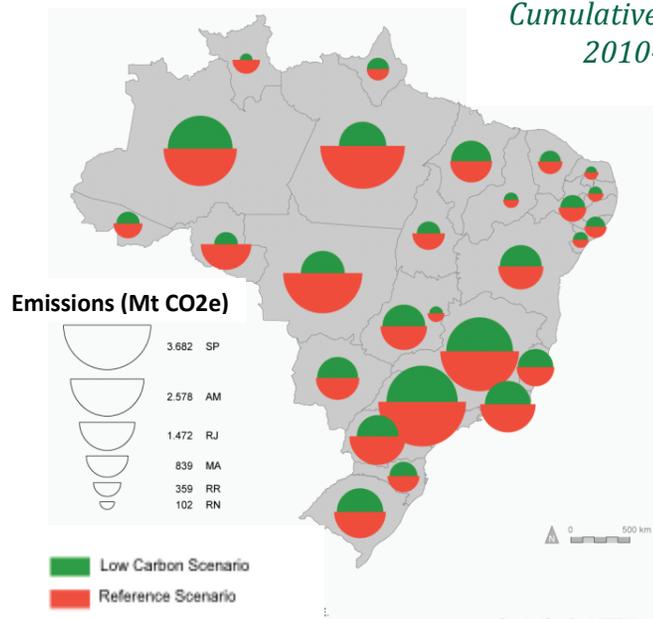
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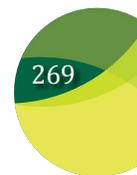
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ESMAP

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