LOW-CARBON DEVELOPMENT FOR COLOMBIA

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REPÚBLICA DE COLOMBIA
DNP Departamento Nacional de Planeación

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CONTENTS

TABLES

FIGURES

BOXES

ABBREVIATIONS

(All references to $ are US$)

ABP	Agricultural best practices
ACD	Above-Ground Carbon Density
AFOLU	Agriculture, forestry, and other land uses
AGRONET	Red de Información y Comunicación Estratégica del Sector Agropecuario
ANDI	Asociación Nacional de Industriales (National Industry Association)
BHP	Boiler horsepower
BRT	Bus rapid transit
CAF	Development Bank of Latin America (Corporación Andina de Fomento)
CBA	Cost Benefit Analysis
CDM	Clean Development Mechanism (Mechanismo de Desarrollo Limpio, MDL)
CENICAFE	National Center for Coffee Research (Centro Nacional de Investigaciones de Café)
CES	Constant elasticity of substitution
CET	Constant elasticity of transformation
CFL	Compact fluorescent lamps
CGE	Computable general equilibrium
CH_4	Methane
CIAT	Centro Internacional de Agricultura Tropical
CIF	Centificate Forest Initiative (Certificado de Incentivo Forestal)
CIPAV	Centro para la Investigacion en Sistemas Sostenibles de Produccion Agropecuaria
CO_2	Carbon dioxide
CONPES	Consejo Nacional de Poltica Económica y Fiscal
CREG	Comisión Reguladora de Energía y Gas
DANE	National Department of Statistics (Departamento Nacional de Estadísticas)
DDRS-DNP	Dirección de Desarrollo Rural Sostenible-DNP
DIAN	National Department of Taxes and Customs (Departamento Nacional de Impuestos y Aduanas)
DNP	Departamento Nacional de Planeación
DOE US	Department of Energy
EE	Energy efficiency
EIECC	Study of Economic Impact of Climate Change in Colombia (Estudio de Impactos Económicos del Cambio Climático en Colombia
EPM	Empresas Públicas de Medellin
EIA	Energy Information Administration
ENA	Encuesta Nacional Agropecuaria
ESMAP	World Bank's Energy Sector Management Assistance Program
FAO	Food and Agricultural Organization (UN)
FARC	Revolutionary Armed Forces of Colombia (Fuerzar Armas Revolucionarias de Colombia)
FEDEGAN	Colombian Cattlemen's Association
FINAGRO	Fund for Financing the Agricultural Sector (Fondo para el Financiamiento del Sector Agropecuario)
FTA	Free trade agreement
GDP	Gross domestic product
GEF	Global Environmental Facility
GHG	Greenhouse gas

H_2S	Hydrogen sulfide
ICR	Rural Capitalization Incentive (Incentivo de Capitalizacion Rural)
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies
IDP	Internally Displaced Person
IPCC	Intergovernmental Panel on Climate Change (UN)
ISS	Intensive silvopastoral systems
KFW	Kreditanstalt Für Wiederaufbau (German Development Bank)
LCD	Low-carbon development
LPG	Liquid petroleum gas
LSU	Livestock unit *(Unidad de Gran Ganado)*
MAC	Marginal abatement curve
MADR	Ministry of Agriculture and Rural Development
MBD	Million Barrels per Day
MCFD	Million Cubic Feet per Day
MEG4C	DNP's CGE model for climate change
MME	Ministry of Mines and Energy
MPC	Million cubic feet
MW	Megawatt
NGOs	Non-Governmental Organizations
NH_3	Ammonia
NMT	Non-Motorized Transport
NOX	Nitrogen oxide
NPV	Net Present Value
O&M	Operation and maintenance
ODS	Ozone depleting substances
OECD	Organization for Economic Cooperation and Development
PEGA	Strategic Plan for Colombian Livestock
PES	Payments for Environmental Services
PM	Particulate matter
PND	Plan Nacional de Desarrollo
PROURE	Rational Use of Energy Program (Programa de Uso Racional de Energía)
PSS	Power system simulator
R&D	Research and development
RE	Renewable energy
REDD	Reducing Emissions from Deforestation and Forest Degradation
SAM	Social Accounting Matrix
SIN	Interconnected (electricity) system
SETP	Sistemas Estratégicos de Transporte Público
SITP	Sistema Integrado de Transporte Público
SOX	Sulfur oxide
TA	Technical Assistance
TLC	Tratado de Libre Comercio entre Colombia y Estados Unidos, (the United States-Colombia Trade Promotion Agreement (CTPA))
TSR	Technically specified rubber
TTE	Total Transport Emissions
UNDP	United Nations Developnment Program
UNFCCC	United Nations Framework Convention on Climate Change
UPME	Unidad de Planeación Minero Energetica
VOC	Volatile organic compound
ZNI	Non-Interconnected Zones

PREFACE

The evidence is mounting that the impacts of climate change are likely to be severe for both industrial and developing countries. New studies are published each month linking climate change to more severe droughts and tropical storms, the death of coral reefs and the fish species they sustain, negative impacts on livestock and crop production, and the risks of sea level rise and coastal flooding. While some level of warming appears to be inevitable, one of the ways to insure against the most extreme climate change scenarios is to reduce emissions of greenhouse gases (GHGs). While many countries recognize the urgency of curtailing GHG emissions, there are questions about what measures can be taken in the near and medium term, how much they will cost, and whether there are major trade-offs in terms of economic and social development.

This report is intended to contribute to Colombia's climate change strategy and action plan. It represents a two-year effort by a team of Colombian and international experts to identify and evaluate policies and actions to reduce greenhouse gas emissions. The study used two important tools for undertaking low-carbon assessments: an economic methodology for estimating the costs of low-carbon measures across sectors. This methodology allows, for example, the comparison of very different types of measures, such as introducing more efficient street lights and afforestation programs. The second tool is a macroeconomic model developed by DNP to assess the integrated impacts of specific low-carbon measures on the rest of the economy, including economic growth and employment.

The typical focus of low-carbon development studies is on the emissions associated with energy production and consumption, which for the world as a whole, dominate GHG emissions. While not unimportant in Colombia, the largest sources of emissions and potential for reducing emissions are from land-use (agriculture, forestry, and land-use change, referred to collectively in this study as AFOLU). The study has identified a number of ways to reduce AFOLU emissions through high-priority development activities in agriculture and forestry that are part of Colombia's development strategy. Not surprisingly, to realize these measures it is necessary to address pressing policy actions related to infrastructure, land rights, and to maintain stability in rural areas.

Colombia has been a pioneer in sustainable transport, and many of the measures and programs evaluated in this study provide lessons for transport planners domestically and internationally. While the study has focused on discreet interventions that can be undertaken now – such as investing in BRT, modernizing and integrating public transport systems, and expanding non-motorized transport—other efforts to improve the efficiency of cities and lower GHG emissions by changing the spatial organization of cities will take time.

The study takes an economic approach by subjecting promising low-carbon measures to detailed cost-benefit analysis. While many measures are found to have good financial and economic returns, a fundamental question is why they are not already being undertaken. What this and other studies have found is that the availability of commercial technology and good financial returns is often not enough to overcome information and knowledge gaps, institutional and legal constraints, or social customs. The inability to overcome these barriers is typically the reason that low-cost actions are not undertaken. To partially overcome this problem, the study focused on low-carbon measures that had already proven successful in Colombia or in a similar economy elsewhere. In order to mainstream low-carbon development, it will be necessary to raise public awareness and educate consumers, provide public demonstrations and training, establish new standards and regulations, and provide new financial incentives.

The next few years are critical for taking serious climate mitigation actions. A number of studies have focused on the longer term, and the promise of new technologies. While new low-carbon technologies will play a critical role in reducing future emissions, an explicit objective of this study was to identify measures that could contribute significantly to emissions reductions that could begin immediately, and to evaluate the contribution of those measures to economic growth and employment.

Many of the measures identified and evaluated in this study –energy efficiency, renewable energy, and sustainable transport—are likely to be applicable in other countries. Given the large share of current emissions and future emissions reductions in agriculture, forestry, and land-use, the report is likely to be especially important for countries in South America, Africa, and Southeast Asia as they seek to define and implement low-carbon policies.

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This report was prepared by a large multi-disciplinary team comprised of Colombian experts and World Bank staff. The study was managed in the World Bank by Todd Johnson and Erick C.M. Fernandes. Todd Johnson was the overall editor of the final report.

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OVERVIEW

Colombia is well-positioned to pursue a low-carbon development path given the country's already large hydropower production, a model urban transport program, and significant potential to reduce emissions from agriculture, forestry, and other land-use (AFOLU). While reducing carbon emissions through these and other activities can demonstrate Colombia's commitment to addressing global climate change, the primary driver of such activities should be that they are part of the country's economic and sustainable development agenda. Policymakers need to ensure that public policies for climate mitigation support projects that are economic and achieve macroeconomic goals such as generating income and employment.

Given the importance of hydropower and Colombia's huge potential for expanding agriculture and forestry, another consideration is that mitigation measures should not increase the country's vulnerability to climate change impacts—some could actually do that—but should also increase the country's resilience to natural and manmade disasters. These findings are based on an analysis of Colombia's climate mitigation options made jointly by the World Bank and the Department of National Planning (DNP).

1. Country Context

Colombia is in the process of preparing a national climate change strategy to evaluate the country's vulnerability and options for mitigating greenhouse gas (GHG) emissions. This report is one of several inputs to Colombia's evolving climate mitigation strategy – *Estrategia Colombiana de Desarrollo Bajo en Carbono* – ECDBC. The principal objectives are: (a) to identify and evaluate mitigation measures in key sectors, including an assessment of the costs and benefits of different options, (b) assess the macroeconomic impacts of low-carbon development (LCD), and (c) provide a summary of the costs and mitigation potential of LCD options and the implications of pursuing such a strategy.

As with other developing countries, Colombia is vulnerable to the impacts of climate change from a number of dimensions. Changes in precipitation and run-off pose significant problems given to the importance of hydropower and potential impacts on agricultural production. Based on its own vulnerability and an understanding of the need for global action, Colombia has actively participated in international climate agreements and taken actions domestically to address the causes and consequences of climate change.

In terms of emissions, Colombia is not a major contributor internationally of GHG emissions (ranked 41st among all countries). Indeed, the large share of hydropower (70 percent of installed capacity), makes the power sector one of the least carbon-intensive in the world.

The country also has a relatively low per capita level of emissions: Of these, as much as 38 percent of its GHG emissions come from agriculture, 14 percent from land-use change (deforestation), 37 percent from energy production and consumption (of which the largest share is from transport), and the remaining 11 percent from wastes and industrial process emissions (such as cement).

In devising the country's climate mitigation strategy, the government's focus has been on identifying low-carbon measures that are aligned with domestic economic and social development objectives. This principle has been key in selecting the low-carbon interventions that were evaluated for this report.

2. Mitigation Options, by Sector

Using a common economic cost-benefit methodology, experts in energy, transport, and AFOLU (agriculture, forestry, and land-use) evaluated various promising low-carbon measures. Although an attempt was made to evaluate the largest and most promising ones, not all mitigation options were assessed due to time, resource, and data constraints.[1] Three principal criteria were used to select them: (a) a large potential for reducing GHG emissions, (b) good economic returns, and (c) a high likelihood of being implemented (related to technical, political, and social feasibility).

A. Energy

The financial and economic returns of many energy efficiency (EE) projects are high and can provide other benefits such as improving industrial competitiveness and reducing peak loads. However, the low carbon footprint of Colombia's power sector means there is much less potential for reducing emissions compared to countries where hydro is not so abundant. Indeed, its dependence on hydro, and the vulnerability this entails relative to climate risks, provides a compelling case for expanding non-hydro energy sources. Falling technology and development costs of some renewable energy sources are becoming increasingly attractive, and can help diversify Colombia's hydro-dominant power sector.

(1) Energy efficiency

All the efficiency interventions assessed – residential and commercial lighting, refrigeration, industrial motors, and public lighting – were found to be "no regrets" options for reducing GHG, meaning they generate positive economic benefits regardless of their climate change benefits. As in other countries, replacing incandescent lights with efficient bulbs yielded the highest financial and economic returns. Also, improving the efficiency of motors in the industrial sector has good potential, echoing an UPME study that estimates that the replacement of old or oversized motors can yield savings from 5 to 25 percent in electricity consumption, among other benefits. Measures the government can take to improve existing energy efficiency programs include better labeling, information campaigns, and improved standards. With respect to efficient motors and street lights, the study recommends learning from several pilot projects in concentrated areas or industries before scaling-up the programs on a national basis.

1 Measures for which sufficient information was unavailable were excluded from the analysis, including those in oil and gas production, storage and transmission, refining, and petrochemicals.

(2) Fuel substitution

Substituting natural gas for coal in small and medium industrial boilers has a large potential. The CO_2, PM, NOx and SOx emissions from coal boilers have deteriorated air quality substantially, while maintenance costs and fuel storage space for coal boilers are considerably higher than for gas. Replacing coal with natural gas could reduce up to 52 percent of the GHG emissions from boilers, and reduce 96 percent of particulate emissions. A 2008 DNP study estimated there are some 6,000 excess deaths in Colombia as a result of poor air quality.

The report recommends a pilot in the Valle del Aburrá area, a region with a high density of boilers that currently use coal and are close to natural gas distributors. To promote a boiler substitution program, a more complete audit of the quantity and size of boilers with nearby natural gas distributors is needed. Further, incentives such as low-interest loans for small and medium enterprises (SMEs) to help with the transition to natural gas could spur a boiler conversion program.

(3) Low-carbon technologies to generate electricity

Colombia's wind regime has been rated among the best in South America, while the country's geothermal resources are being explored for commercial development. Renewable energy (RE) interventions such as wind and solar PV are attractive, given falling technology and development costs. More important, low-carbon energy technologies such as geothermal, wind, and solar, can diversify the country's hydro-dominant electric power sector using domestic resources. In this context, the study examined two RE investments: (a) an 893 MW wind park in La Guajira, and (b) a set of geothermal plants with a power capacity of 379 MW.

The analysis found that wind and geothermal are already close to being economic, especially compared to coal plants. However, from a financial perspective it is very difficult for wind projects (and perhaps for geothermal when such projects get closer to implementation) to compete with conventional technologies in Colombia. Although current regulations allow "firm energy" payments to wind power plants (see definition below), such payments may be undervalued, perhaps significantly, compared to the contribution that wind plants provide to the system's reliability.

To promote wind and geothermal energy, the government can provide developers with better data on resource potential, support and improve access to research and technology development, and facilitate grid access of new generating plants. Also, it can play a more active role by promoting access to financial instruments aimed at reducing GHG emissions. Aside from international financing, it could provide wind developers with financial incentives through government fiscal mechanisms, including tax credits for investment, or through contributions to the Fund for the Electrification of Off-Grid Regions (FAZNI). For geothermal, the government could help overcome critical exploration risks, if not by directly financing drilling tests, then by providing other fiscal incentives to companies such as tax deferral or advances against future income.

B. Transport

As in many parts of the world, transport is the fastest growing source of GHG emissions and in Colombia, transport consumes the most fossil fuels. The study estimated that as a result of projected fuel consumption, CO_2 emissions from transport would increase from

24.2 million tons in 2012 to 46 million tons in 2040. The growth is driven mainly by diesel, whose consumption and emissions would increase by 127 percent. Thus, the study evaluated low-carbon measures in three principal transport subsectors: public transport, freight, and private vehicles.

(1) Public transport

With a share of 65-85 percent of motorized trips, public transport is still the most important mode of transport in the cities. However, its low quality has caused a shift towards private cars and motorcycles, illegal buses, and motorcycle taxis: In 2011, 327,000 new vehicles were sold—the largest number in a single year, and a 33 percent increase over 2010. The analysis of low-carbon interventions in public transport is complicated, since there are many ancillary benefits, including those in health (from improved air quality), fewer accidents, and greater access to transport by low-income groups.

Bogotá Integrated Public Transport System (SITP)

The Integrated System of Public Transport (SITP) goal is to improve the efficiency of urban transport by reducing the high number of buses and frequency on a given route. Under this measure, Bogotá's bus fleet would be reduced from around 20,000 to 12,000 units, without reducing overall service; this would be accomplished by eliminating redundancy and improving the fleet's efficiency. The measure reduces the kilometers each vehicle travels, as well as diesel consumption and GHG emissions. If the SITP were introduced, CO_2 emissions from public transport could be reduced by 44 percent in 2040. Also, by replacing 60 percent of the diesel fleet with electric buses, emissions could be reduced by 66 percent in 2040 compared to the baseline (ie. with diesel buses only).

Bus Rapid Transit (BRT)

Bus Rapid Transit (BRT) systems, which are an efficient and affordable alternative to urban rail systems, have grown in Colombia and worldwide in recent years. BRT systems replace traditional ones with high-capacity articulated buses that reduce per passenger fuel consumption and emissions. The system mimics a modern rail system by having dedicated bus routes, a feeder system, automated ticketing, and boarding at platforms. Compared to rail, the bus system maintains considerable flexibility to change routes and expand. The BRT was introduced in Bogotá, and is now being expanded to five district capitals: Medellin, Cali, Barranquilla, Cartagena and Pereira. The full BRT program in these five cities will involve constructing 447 km of dedicated bus lanes, of which 282 km were built in 2012.

Strategic Public Transportation Systems (SETP)

The SETP program is intended to improve the public transport systems in medium-sized cities (250,000 to 600,000 inhabitants) by optimizing the supply of vehicles and related transport systems. Typical measures include installing a unified fare-collection system, transfer terminals, bus stops, traffic and transport information controls, and road construction and maintenance. The SETP was estimated to reduce CO_2 emissions from public transport by 63 percent for the six cities[2] by 2040.

2 Six cities—Armenia, Pasto, Popayan, Sincelejo, Santa Marta, and Monteria—have already developed SETP plans and are the ones where the action was evaluated.

(2) Freight

Road transport accounts for 64 percent of total freight transport in Colombia, followed by rail, which is mainly for coal (33 percent), and by water (3 percent). The average age of the country's truck fleet in 2010 was 19 years, compared with 13 years in Mexico and 16 years in Brazil.

Improvements in freight-vehicle driving techniques

By adopting better driving techniques, freight operators could significantly reduce their fuel consumption and CO_2 emissions. Drivers can be trained in good driving habits, such as avoiding rapid acceleration and unnecessary braking, maintaining a constant speed when possible, and not continually operating engines at high revolutions per minute (RPMs). By launching a driving scheme similar to the SmartWay program in the US, and assuming that half of all freight drivers in Colombia participated, it is estimated the program could reduce fuel consumption (by participating companies) up to 7 percent, and CO_2 emissions by 6.2 million tons from 2012-2040. The program's benefits, largely through lower fuel consumption, greatly outweigh the costs, making the activity attractive both financially and environmentally.

(3) Private transport

Battery Electric Vehicles and Congestion Charging in Bogotá

The advantage of promoting Battery Electric Vehicles (BEVs) for the private automotive fleet is that nearly 70 percent of the country's electricity is produced from domestic hydropower plants. Further, electric vehicles powered by hydro-electricity would not only reduce local and global pollutants, but, given the high costs of petroleum, consumers could enjoy large fuel cost savings by switching from internal combustion technology to BEVs.

Bogotá currently has some traffic restrictions for private vehicles –such as the *pico y placa* program–but the city's rate of motorization has continued to rise. One solution could be congestion-charging. Under such a program, private vehicle users pay a fee to drive in certain areas during certain days and hours, usually with a higher fee during rush hours. Where congestion charging already exists, results have been impressive: CO_2 emissions were reduced by 19.5 percent in London and 18 percent in Stockholm. Congestion charges, along with increased use of BEVs, would reduce cumulative emissions by 41 million tons of CO_2 from 2012-2040. Although implementation costs of the BEV technology are high, the savings in the fleet's operating costs are greater.

While falling rapidly, high upfront costs for batteries and the cost and complexity of installing public charging facilities—which now make the electric car program uneconomic—may slow the introduction of electric vehicles in Colombia. Other problems involve trade barriers on imported BEVs, such as high customs duties, that could inhibit or halt the import of electric or hybrid vehicles.

C. Agriculture, forestry and land use (AFOLU)

The AFOLU sectors currently account for over half of Colombia's GHG emissions, including those from deforestation, livestock, and fertilizer. The potential to develop agriculture and forestry programs is large, which has implications for regional and national economic development as well as GHG emissions: Already, agriculture and other land-use activities have benefitted from reduced rural violence over the past decade. Further, deforestation is expected to decline as forests come under dedicated management plans and as the local economy in these areas develops. Thus, properly managed, agriculture could reduce emissions in the livestock sector, where productivity has historically been extremely low. Moreover, large tracts of land, especially in Orinoco, are being developed for commercial timber and other plantation crops (palm, fruit trees, and coffee). Through their contribution to carbon sequestration in soil and woody biomass, commercial plantations could significantly reduce net carbon emissions. From an emissions perspective, the most important AFOLU interventions evaluated were those related to preventing deforestation, along with commercial plantations, and livestock.

(1) Avoided deforestation

If natural forests were managed in a sustainable manner, they could have significant mitigation potential since they cover 55 percent of country's territory. Currently, few sustainable management programs exist. Projects that reduce deforestation and forest degradation (REDD+[3]) have been proposed to address the problem of poorly managed, selective logging. A conservative estimate is that REDD+ projects could be adopted on 2.5 million hectares (ha) in the Amazon and Pacific coast regions. Among the benefits are that they can provide monetary incentives to local communities to manage and protect forests. Such income is intended to compensate communities for income they would no longer earn from the sale of timber or from transforming forests into crop areas. REDD+ is also attractive to investors in carbon markets, since the program would prevent deforestation of some 27,500 ha on the Pacific Coast and 12,500 ha in the Amazon region each year. However, an important constraint to REDD+ activities is that the framework for international support is still being negotiated; this has delayed the signing of REDD+ agreements and the transfer of financial resources to forest communities. Nearly 50 percent of the country's forests have been titled to Afro-descendant and indigenous communities, making forestry programs important both socially and economically.

(2) Commercial plantations

Large forest plantations cover only around 20,000 ha, but offer a promising long-term mitigation strategy given the government and private sector proposed expansion plans. A high scenario of 4 million ha of forest plantations from 2012-2040 was evaluated, of which 6 percent was in the Andean region, 19 percent in the Caribbean region, and 75 percent in the Orinoco region. If the plan were introduced, it would sequester about 44 million tons of CO_2e/year, or approximately half of Colombia's current AFOLU emissions. About US$450 million a year of private investments would be needed for the 4 million ha, which is assumed would come from investors and commercial banks given the profitability of commercial timber plantations. Other plantations that were evaluated included rubber (260,000 ha) and fruit trees (395,000 ha).

3 Reducing emissions from deforestation and degradation (REDD). According to the U.N., "REDD+" goes beyond deforestation and forest degradation, and includes conservation, sustainable management of forests, and enhancement of forest carbon stocks.

Aside from rural security issues, major barriers to commercial plantations are the relatively undeveloped infrastructure in promising areas, labor shortages, a lack of technical know-how, and continuing constraints and sensitivities related to land reform. The government is currently working on a new land policy that intends to protect small land-owners while at the same time allow the cultivation of larger and more economically viable farms.

(3) Livestock

Livestock is a major contributor to Colombia's current and future GHG emissions. There are around 39 million ha of pasture nationwide, out of a total land area of 113 million ha—accounting for over a third of the country. From 2010-2011 alone, the number of cattle grew from 24 to 27 million. Several programs—intensive silvopastoral systems and improved pastures—are being promoted to improve the productivity and sustainability of livestock production. Intensive silvopastoral systems **(**ISS**)** are an integrated form of agro-forestry that combines pasture for livestock with the production of fodder, timber, or fruit. ISS is a way to convert low productivity, extensive ranching into more efficient production models with higher animal carrying capacity and the production of cash crops. The planting and management of trees and shrubs contributes to improved pasture quality through nitrogen-fixation, shade for the livestock to reduce heat stress, improved quality of forage through high-protein leguminous species, and enhanced carbon sequestration relative to traditional pastures. According to Colombia's livestock federation (FEDEGAN), ISS could increase the average carrying capacity of pastures from 0.71 to 3.3 livestock units per hectare. Colombia now has about 20 million ha of low productivity pastures, and while only 5,000 ha now apply ISS, the practice could conservatively be expanded to 3.8 million ha throughout the country. The main barrier to rapidly expanding it is ranchers' limited understanding about how to implement the program, its costs and benefits, and the lack of extension services. The Ministry of Agriculture MOA) has embraced the program, which will help overcome some of the barriers.

3. Macroeconomic Assessment

It is important for policymakers to understand how a LCD program might affect the macroeconomy, including national income and employment. Specifically, it is important to know how actions taken in one sector could have positive or negative impacts on others. To explore these macroeconomic impacts, the study utilized an applied computable general equilibrium (CGE) model. The model is based on an earlier CGE model developed by DNP that was modified and linked with the cost-benefit analysis in order to assess various climate mitigation measures. By assessing several representative types of low-carbon measures in the energy, transport, and AFOLU sectors—which account for nearly 60 percent of the emissions reduction of the study—it is possible to determine the expected direction and magnitude of the macroeconomic effects of specific climate mitigation measures.

The analysis suggests that improvements in energy efficiency, such as lights and refrigerators, will have positive macroeconomic impacts on GDP and employment: The impacts that investments in forest plantations and similar projects that sequester carbon could have are particularly encouraging. Unlike the typical case where GHG emissions are positively correlated with energy consumption, an increase in the Forestry sector output lowers GHG emissions. The use of green taxes was also explored as part of the macroeconomic analysis, and showed that what happens to the revenue generated from green taxes has a big impact on economic growth as well as GHG emissions.

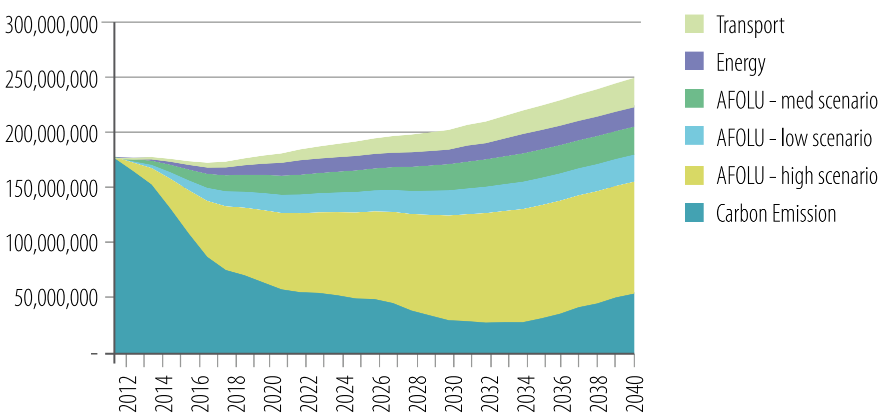
The macroeconomic analysis demonstrates the importance of considering not only the direct impacts of low-carbon interventions on macroeconomic variables such as GDP and employment, but of the broader effects on the rest of the economy such as through backward linkages to markets for capital and labor.

4. Integrated Analysis: A Low-Carbon Scenario

A. Potential to reduce emissions

By adopting the low-carbon measures in the energy, transport, and AFOLU sectors, Colombia could maintain and actually lower its GHG emissions over the next three decades. The estimates are based mainly on aggregating the low-carbon measures by sector, plus making some adjustments to account for gaps in the sectoral analysis. Under a baseline emissions trajectory to 2040, emissions would increase about 1.3 percent a year, reaching around 250 $mtCO_2$ in 2040. If the measures were adopted, Colombia could reduce emissions by as much as 200 $mtCO_2$ in 2040, and thus reduce overall emissions to less than one-third their 2012 level. The lowering of overall emissions would depend to a large degree on how fast or extensively the AFOLU activities are developed. In light of these large uncertainties, several AFOLU scenarios are presented in Figure 1, representing low, medium and high reduction potential. Transport sector measures could provide about 50 $mtCO_2$ reduction potential by the year 2040. The energy sector potential includes the EE and RE measures described in Chapter 2, plus recent estimates of CDM potential for efficiency and renewables in the energy and industrial sectors.

Figure 1 | Colombia GHG emissions by sector, 2012-2030



B. A framework for low-carbon development

An important principle of Colombia's climate change strategy has been the alignment of low-carbon development with the country's broader economic development goals. Table 1 shows in a qualitative way how low-carbon measures can contribute to the economic development goals of national income growth, competitiveness, sustainability and resilience, and social inclusion.

Table 1 | Low-carbon measures

Objectives	Energy	Transport	AFOLU
Economic growth	Renewable energy	Bus rapid transit (BRT); battery electric vehicles (BEVs)	Commercial plantations, fruit and vegetable production
Competitiveness	Energy efficiency	BRT; SETP; SITP; freight efficiency	Improved pastures; productivity gains in livestock
Sustainability/ resilience	Renewable energy	BRT, SETP, SITP, non-motorized transport (NMT); BEVs	REDD, silvopastoral systems;
Inclusion	Renewable energy for access	SITP, BRT, SETP, NMT	Fruit and vegetable production

C. Carbon development trends and low-carbon policies

Several key development trends are expected to greatly impact Colombia's GHG emissions over the coming decades. Some are common in other developing countries, however, others are region- and country-specific.

Hydropower. As noted, the dominance of hydropower is a major reason for the low carbon-intensity of Colombia's energy sector. Despite substantial untapped potential, uncertainties exist as to how rapidly remaining hydropower resources can be developed, and the vulnerability to droughts and floods that could be created by building new hydro production without major water storage capacity. Climate change is expected to exacerbate the variability in rainfall and runoff patterns.

- **Overcome barriers.** Improved management of the social/environmental aspects of developing hydropower can help reduce licensing and construction delays. Size can also matter: Developing smaller plants often has the advantage of lower environmental/social impacts, shorter licensing times, greater ease of financing, and shorter construction periods. However, small run-of-river hydro plants are also more at risk to climate variability.

- **Multi-purpose water control projects.** One of the limitations of the current hydropower system in Colombia is the lack of storage capacity to regulate flows during wet and dry seasons. Increasing this capacity through multi-purpose water control projects could help reduce the impacts of drought and floods and reduce the affects on power production, when compared to run-of-river plants.

Fossil fuels. Oil, gas, and coal production in Colombia has been expanding. While there are growing financial and development pressures to increase domestic consumption of coal for power generation and industrial use, this would raise GHG emissions. Over the coming years, international carbon taxes could affect Colombia's coal industry and exports, as well as other hydrocarbons (petroleum and natural gas).

- **Energy diversification.** Fossil fuels, especially natural gas, have been important in diversifying away from hydro in the power sector. The country could diversify further with a range of renewable and low-carbon energy technologies (wind, geothermal, biomass, and solar), which are increasingly competitive as technology costs fall and the costs of conventional energy sources rise.

- **Domestic coal and natural gas.** If coal was more widely used domestically, this could diversify the energy portfolio; but, it would also increase carbon emissions. When both operating and social/environmental costs are included, natural gas is usually the preferred fuel for residential and commercial consumers, industries such as electronics, food and beverages, and power generation.

Urbanization. Urbanization in Colombia over the past 40 years – over three-quarters of the population live in cities – has led to the increased demand for many energy-intensive activities such as light and air conditioning for buildings, heat and power for industry, water supply and sanitation, and mobility. Urbanization has led to a rapid rise of car ownership, contributing to greater congestion, the consumption of petroleum products, and higher GHG emissions. However, the demand for transport has also spurred the development of more efficient public transport systems, such as Transmilenio. In addition to policies and programs the country is implementing to improve public transport, several other cross-cutting themes are the following:

- **Managing private vehicle growth.** By limiting the use of private vehicles, overall urban transport systems can operate more efficiently. Colombia could limit motorization rates by increasing fuel and vehicle taxes (which are low by international standards), which, in turn, could generate revenue for urban transport programs. As noted above, congestion charging, which is now easier to implement given advances in electronic toll technology, could dramatically reduce traffic and congestion and also be a source of revenue.

- **Cleaner fuels and vehicles.** Public and private vehicle fleets could become less carbon intensive through vehicle inspection and maintenance programs that keep highly polluting, inefficient vehicles off the road. There are a number of relatively new technology and fuel options that can reduce both global and local pollutants, including battery electric and hybrid vehicles, natural gas vehicles, and clean diesel. Removing high customs duties for low-carbon transport technology and establishing research and development programs could facilitate the adoption of low-carbon urban transport technologies.

Land. The future of land use in Colombia is a major wildcard for GHG emissions. Government plans to expand agricultural and forestry activities could reduce emissions and sequester large amounts of carbon. Among policies to encourage agricultural development are:

- **Maintaining security.** To attract investment into agriculture and forestry, the government needs to guarantee rural security.

- **Pro-agrarian programs.** Displaced farmers could be encouraged to return to agriculture through land restitution and land titling programs, the provision of TA and extension services, connections with markets to commercialize production, incentives for infrastructure investment, and agricultural R&D.

- **Access to credit.** Linking credit programs for small farmers to sustainable land management practices (as in Brazil) can benefits farmers and reduce deforestation rates.

- **Efficient land markets.** Large-scale development requires a more efficient land market, which could involve increasing the farm tax and returning land that was seized by armed groups. Other schemes could provide concessions on vacant lands or to smallholders and cooperatives.

Climate change impacts. DNP and others have demonstrated the risks to Colombia from climate change, including impacts on water availability and economic production in climate-sensitive sectors such as agriculture and forestry. Low-carbon policies should therefore be designed in a way that considers the risks of climate change, and where possible, contribute to sustainability and resilience. Climate-sensitive policies and actions that Colombia can take while pursuing low-carbon development are:

- **Assess climate vulnerability.** The vulnerability of agriculture, forestry, and hydropower to climate change must be assessed, not only for low-carbon development scenarios but for Colombia's baseline program (eg. hydropower and forestry plantations).

- **Build in resilience.** For climate sensitive sectors, measures can be taken to reduce climate risks. As noted above, multi-purpose water control projects could improve hydro flows, reduce flooding, and facilitate irrigation that could greatly expand the productivity of rice and other crops. Updated risk assessments (eg. planning infrastructure for a 100-year flood) should be conducted and used for planning purposes. When implementing "firm energy," planners should be aware of and include climate impacts.

5. Summary and Conclusions

One of the study's main contributions is the tools introduced to evaluate climate mitigation actions and programs: A microeconomic tool (cost-benefit analysis) evaluated specific low-carbon projects, while a macroeconomic tool (CGE Model) evaluated the impact of low-carbon measures and programs on the broader economy.

The cost-benefit analysis allows cross-sectoral comparisons of low-carbon actions in terms of mitigation potential and costs, which is important for policymakers in deciding the optimal use of climate mitigation funds from either international or domestic sources. The macroeconomic analysis demonstrated the importance of considering not only the direct impacts of low-carbon measures on macroeconomic variables (such as GDP and employment), but also the broader economic impacts such as backward linkages to factor markets that have been found to be particularly significant in terms of agricultural and rural development.

The findings from the study can feed into the growing pool of knowledge in Colombia on low-carbon development. While many studies have been conducted on the country's energy and transport, those on agriculture and forestry have been limited. The work on AFOLU confirms the significant potential for mitigation, but also explores the many barriers to rural development such as security, land restitution, infrastructure development, and financing. At a minimum, the sectoral analyses demonstrate that many low-carbon measures are already being adopted and expanded in Colombia, and that many of these are consistent with national development goals.

CHAPTER 1
Climate Mitigation in Colombia: Growth, Competitiveness, and Sustainability

1. Objectives of the Study

The objective of this study is to assess the costs and benefits to Colombia of pursuing a LCD path. Already, there are low-carbon activities for the short and medium term to lower GHG emissions. An important question is how much do they cost, not only from a financial perspective, but in terms of their broader development impact on economic growth, employment, and environmental and social sustainability? Since the 1992 Earth Summit in Rio De Janeiro, countries around the world have been seeking answers to these questions and trying to find practical and cost-effective ways to limit GHG emissions within the context of economic development. Much has been learned over the past 20 years, but there is considerable uncertainty about the type of measures available within different sectors and their real or "net" cost given the many benefits associated with changes in fuels, technologies, production practices, or consumption habits.

The Colombia Low-Carbon Study *(Colombia: Estudio para la Disminución de Emisiones de Carbono – CEDEC)* sought to introduce tools and methodologies to evaluate potential climate change mitigation options across key economic sectors—energy, transport, and land-use. By analyzing low-carbon options using a common methodology (Box 1), the study provides insight into some of the areas that are key to (a) mitigating climate change, (b) identifying barriers to implementation and (c) discussing sector-specific and economy-wide policies to promote LCD.

The study focused on benefit-cost analysis, assuming that all low-carbon projects should be evaluated—not only for their contribution to reducing GHG, but their overall economic viability. The guiding principle was to identify projects/programs that have many benefits for the country's financial, economic, social, and environmental development and that priority should be given to those that are "no-regrets"— meaning they should have not only global environmental benefits but be domestic economic priorities as well. However, projects were also prioritized by the extent to which they could reduce global emissions and their cost was expressed in terms of the net discounted cost per ton of CO_2e. Climate change mitigation options were prioritized based on their potential to reduce GHG emissions, net benefits, political and social feasibility, institutional, legal, and other conditions.

The analyses focused on strategic sectors and themes identified by the government and World Bank after consultations with government agencies, academic institutions, and public and private stakeholders. One of the study's main contributions is the analysis of land-use measures.

Aware that most of Colombia's GHG emissions are from land-use activities, livestock, fertilizer, and deforestation, the study goes beyond previous analyses that focused mainly on emissions related to energy consumption. In fact, one of the initial hypotheses was that not only do most of Colombia's emissions come from land-use, but that a large share of the potential to reduce them is also in this area.

A second contribution is its analysis of macroeconomic aspects of LCD. Finance ministries are often concerned that LCD will entail higher costs to the economy and reduce national income, and create unemployment or other negative impacts. Rather than finding a cost to LCD, this study found that certain actions can actually benefit national economic development. Although it is difficult to make a macroeconomic assessment of LCD for the next decades, the study attempted to evaluate the implications of projects for their capacity to reduce emissions. By assessing key types of low-carbon projects, such as Energy Efficiency (EE), alternative transport technologies, and forestry plantations, the analysis provides a framework for evaluating the general equilibrium macroeconomic impacts of mitigation projects on such variables as GDP and employment.

2. The Logic of Low-Carbon Development

Why should Colombia pursue low-carbon development? Clearly the climate risks the country faces cannot be reduced merely by mitigation actions it adopts on its own—which is the problem when taking action on global public goods. Recognizing the difficulty for countries to reduce their emissions based on a simple calculus of costs and benefits, policymakers often look for other project benefits to justify them. In other low-carbon studies, a principle incentive has been the prospect of obtaining international financial support, such as from the Clean Investment Fund or the Global Environment Facility, for specific measures. However, although the study does not diminish the importance of international support, it looked for measures that are in Colombia's national interest to adopt, regardless of international financial transfers. Among the benefits that low-carbon activities can have are improving competitiveness, contributing to economic growth, promoting sustainable development, increasing resilience, and advancing social development goals.

One important class of projects for reducing GHG emissions is EE, where new technologies or management practices lower energy consumption while providing the same level of energy services, whether for electricity, heat, or transport. Such measures not only reduce energy consumption but often make production more efficient, leading to lower operating costs and potential improvements in the competitive position of industrial or commercial enterprises. While end-use improvements in electricity consumption can improve economic efficiency and competitiveness, the dominance of hydropower in Colombia means that reductions in GHG emissions will be lower than in countries with a larger share of fossil-based electricity. The study evaluated some measures that fall into the category of EE, including well-known examples such as efficient lights and appliances; but, they also include those such as Bus Rapid Transit (BRT) that can reduce energy consumption per trip, or low-till farming. Other measures can increase the efficiency of resources in general, such as productivity improvements in livestock.

Measures that reduce emissions as production increases—such as forestry projects where carbon is stored in woody biomass and soils—are an example of low-carbon actions that can directly benefit economic growth. But there are a broader set of projects that can contribute to growth, as will be seen in the macroeconomic analysis: Projects that have good financial and economic rates of return will also generate income and jobs. In the microeconomic analysis of low-carbon measures, projects with positive economic rates of return would meet the criteria of contributing to economic growth. The macroeconomic analysis tests this assumption by looking at the broader inter-sectoral impacts of measures taken in one sector on the rest of the economy. In general, looking for measures with positive economic rates of return will be a good indicator that the project is in the no-regrets category.

3. Climate Change Concerns

Climate change impacts pose a growing threat for Colombia. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report predicted that under business as usual scenarios, temperature increases in the LAC region (compared to 1961-1990) could be from 0.4ºC to 1.8ºC by 2020 and from 1ºC to 4ºC by 2050 (Magrin and Nobre, 2006). These projections, derived from global circulation models, also forecast changing precipitation patterns across the region (Christensen et al. 2007).

Water impacts will be particularly acute. The same report predicted that runoff levels will rise in coastal regions, in the eastern flatlands, and in areas that already have had floods and landslides in the last decade. In contrast, the northern and Andean regions will have decreased runoff, which may affect water distribution projects and affect dams and hydroelectric production.

The economy depends particularly on agriculture which, for the most part, is projected to be severely affected by potential climate changes (with problems caused both by temperature and precipitation changes). A large part of agro-ecosystems are vulnerable to increased aridity, soil erosion, desertification and changes in the hydrological system—which increase the risk of crops being flooded. Also, increased wind and hails storms will be serious problems.

Further, health impacts are likely to be severe. Due to flooding in some areas and changes in temperatures that extend breeding seasons, there could be an increased incidence of vector-borne diseases (malaria and dengue fever): Andean regions are already vulnerable to these epidemics in addition to depleted water resources.

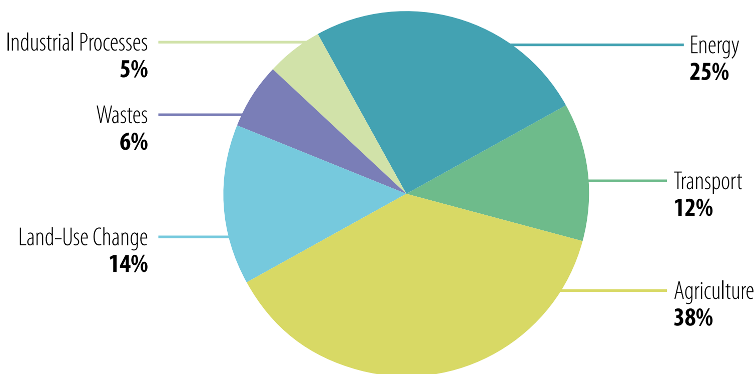
Colombia ecosystems will also be strained through the reduction of glaciers and moorlands. An increase in median sea temperature may further affect corals and dependent marine life, negatively affecting biodiversity and fishing resources. In addition, there are likely to be considerable impacts to forests—but specific effects are still less known.

4. GHG Emissions

Colombia's main GHG is carbon dioxide (50 percent), followed by methane (30 percent) and nitrogen oxide (19 percent). The remaining one percent includes GHGs not covered in the Montreal protocol, such as HFCs, CFCs, halocarbons, and sulfur hexafluoride (Ideam, 2008c). As much as 38 percent of Colombia's emissions are from agriculture, 14 percent from land-use change (deforestation), and 37 percent from energy production and consumption. Together, agriculture and land-use change contribute over half of the country's emissions. (Figure 2)

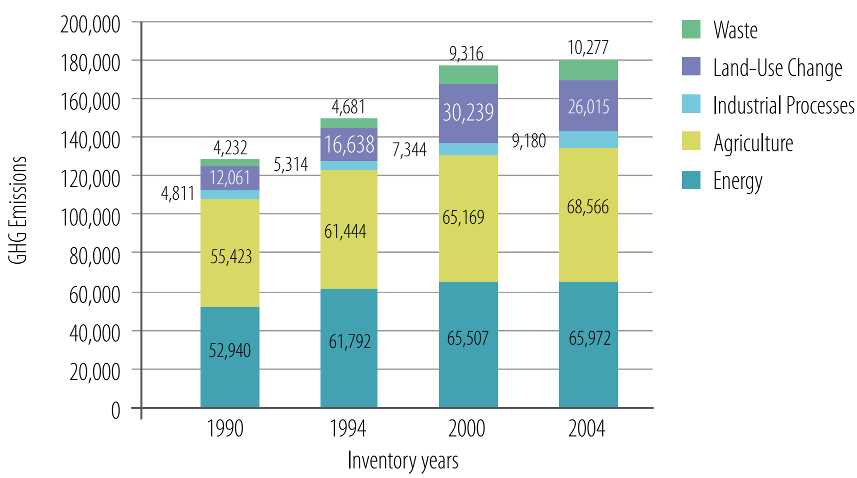
Among other developing countries, Colombia's CO_2 emissions are 41st, higher than Peru (44th), but lower than Bolivia (38th). Colombia contributes 0.37 percent (180,010 Gg) of world total emissions (49 Gt), and its individual emissions per capita are below the world average, and far below those in Europe, Western Asia and North America.

Figure 2 | GHG emissions by sector, 2004



The total share of emissions from 1990-2004 increased by about 50,000Gg CO2e, or by 40 percent. As illustrated in Figure 3, in the period from 2002-2004, energy (-4.3 percent) and agriculture (-4.5 percent) decreased their share of emissions, while the figures for industry (+1.0 percent), waste (+1.9 percent) and land-use change (including forestry at 5.6 percent) increased.

Figure 3 | GHG emissions inventory, 1990 to 2004



Source: IDEAM 2nd National Communication to the UNFCCC

Land use, including emissions from agriculture, forestry, and deforestation, is the most important contributor to Colombia's GHG emissions. These sectors produce a large amount of methane and nitrous oxide emissions, which are 21 and 310 times as potent as carbon dioxide emissions on a hundred-year basis. According to total GHG emissions in 2004, enteric fermentation and nitrogen fertilizer application contributed 33,258 and 32,593 Gg CO_2e, respectively. Agriculture accounted for about 12 percent of 2006 GDP, but employed nearly one-quarter of the country's population.

5. Climate Change Actions

Recognizing the threat of climate change to its development, Colombia has been very active in international negotiations. As a non-Annex I country, it is not mandated to limit or reduce its GHG emissions under the Kyoto Protocol, but it has firmly adopted the United Nations Framework Convention on Climate Change (UNFCCC) principle of "common but differentiated responsibilities," and has pledged to reduce its GHG emissions accordingly on a voluntary basis.

Colombia submitted its 1st National Communication to the UNFCCC in 2001 and its 2nd in 2010. The latter included an update of the National GHG Inventory for 2000 and 2004, along with vulnerability and adaptation studies for various sectors, including water resources, and a chapter on mitigation measures. It also included a national strategy on education, information, awareness, and raising issues about climate change and the various scenarios defined by the IPCC.

The Ministry of Environment and Sustainable Development is the national authority on the environment. It oversees Colombia's commitments to the UNFCCC and other climate change related actions and is the Designated National Authority on climate change in general and, in particular, on the Clean Development Mechanism (CDM). The Ministry has a Climate Change Mitigation Group in charge of structuring and marketing the Colombian portfolio in the GHG emission reduction market.

The Ministry also has a Technical Inter-Sectoral Committee on Mitigation of Climate Change (CTIMCC, Spanish acronym)—which describes proposals related to mitigation in the National Climate Change Policy, proposing recommendations of projects for the Clean Development Mechanism for National Approval and following up on their implementation. It consists of permanent as well as ad hoc members.

Colombia has several groups that support adaptation. (a) The Integrated National Adaptation Project (INAP) supports prevention and adaptation measures to climate change, focusing mainly on highland ecosystems, the island areas and human health. (b) The Interagency Group on Climate Change (IGCC) was formed in 2009 to coordinate adaptation efforts, where 12 Colombian government agencies are involved. Some regions and local communities have also begun their own programs, such as in the Zona Cafetera (The Coffee Region) and the Capital Region. These programs have begun to include surveillance and early warning systems for dengue fever and malaria.

Colombia's Climate Change Agenda has been integrated at the national economic planning level to address the challenges and exploit the opportunities in this area. One priority is to create and implement a National Climate Change Policy, as stipulated in the 2006-2010 National Development Plan (PND). This highlights the importance of: (a) implementing a national plan of action, complemented by plans at the regional, local, and sector levels; (b) developing an integrated framework that supports adequate inter-agency coordination with a clear identification of the roles and responsibilities of the various entities; (c) strengthening institutional capacity for gathering/managing information and monitoring; and (d) promoting greater participation in the carbon market.

6. Introduction to the Sectoral Analysis

The following three chapters assess the GHG reduction potential by sector, as evaluated under the CEDEC study. For this analysis, the economy was divided into three primary sectors: energy, transport, and AFOLU. The sectoral work draws on the efforts of the sectoral teams, which are composed of experts from Colombia, with inputs from international specialists.

The study is not intended to be comprehensive, meaning that it has not evaluated every potential low-carbon measure. Instead, given its limitations, it took a strategic approach: The main goal was to demonstrate a consistent, rigorous approach for evaluating possible low-carbon measures. A second goal was to apply the methodology to a set of measures that have good prospects for reducing emissions overall during the study period (up to 2040). The sectoral actions were selected based on their relevance to economic and social development and the feasibility of launching them in the short to medium term. While some promising measures were excluded due to inadequate data, efforts were made in each sector to select a range of actions that cover: (a) those that could reduce the most emissions, and (b) those that are representative (eg. in terms of net cost and economic feasibility)—so the analysis could be extended to similar measures.

The microeconomic work used cost-benefit analysis adapted for low-carbon measures (Box 1). The methodology is similar to that used for World Bank project appraisals and focuses on ensuring that projects are "economic" in the sense that the social benefits are greater than the costs. Before the cost-benefit analyses, sectoral teams were instructed in the use of the common methodology, and then applied it to the most promising measures in their areas.

Box 1 | Cost-Benefit Analysis Methodology

The CEDEC economic analysis used a standardized cost-effectiveness (C/E) framework for all sectoral actions. The methodology is not technically a cost-benefit analysis since it does not measure the benefits of climate change mitigation in terms of reduced impacts, but it instead compares the costs of different actions to reduce GHG emissions. The analysis calculates the net present value of the direct economic costs and benefits of each action from 2012-2040 to arrive at the net benefits of reducing emissions.

The cost-effectiveness of reducing GHG emissions was thus the present value of the net cost of reducing (avoiding) one ton of CO_2-equivalent emissions (US$/t CO_2e). For each action over the study period, reductions in annual emissions added up to the cumulative emissions reduction, and the stream of annual net cost was discounted at 10 percent each year to arrive at the present value of the net cost in 2008. In the economic analysis, CO_2 emission reductions were not assigned a value, but instead all costs were expressed relative to CO_2e, which implied that at a net cost per ton of CO_2e of zero, the project had a rate of return equal to the discount rate, or 10 percent.

The net benefit of the mitigation action was calculated by subtracting the direct costs from direct financial benefits of implementing it. The financial costs reflect economic opportunity costs to the extent that corrections were made for taxes and subsidies and that traded goods were at their import and export parity values. Examples of direct benefits included energy cost savings or travel time and travel cost savings. Environmental externalities were considered as indirect benefits and were included in the analysis where estimates of pollutants and impacts could be calculated. Interventions where environmental externalities were particularly important, such as urban transport, were calculated and included in the results (Chapter 3).

The major shortcoming of the cost-benefit analysis and the resulting MAC curve was where major costs or benefits were not quantified. With respect to energy efficiency, the absence of "transaction costs" was often cited as the reason why economic projects do not get implemented. Transaction costs are often hidden costs that are not calculated when appraising a project, and can include ex-ante and ex-post costs (information, contracting, monitoring and verification) as well as those related to implementation. Non-quantified benefits were particularly lacking in many forestry or land-use projects, such as those associated with soil or water conservation and biodiversity protection. It was also difficult to quantify the social benefits of various types of projects including those in energy, land-use, and transport, which involved increased access to services (energy, mobility), reductions in poverty and income inequality, or general improvements in the quality of life (personal security).

The sectoral analyses are structured as follows: (a) background information on the sector in terms of historical development and emissions, (b) the sector's baseline growth including GHG emissions, (c) the evaluated CEDEC interventions, (d) the barriers to implementing the low-carbon interventions, and (e) conclusions.

7. Macroeconomic Analysis

One DNP role with respect to climate change policy is to assess the possible economic impacts of a changing climate as well as of policies to ameliorate them (adaptation) and of those to reduce emissions (mitigation). DNP previously evaluated some potential impacts in a 2011 study.[4] As mentioned above, one goal of the CEDEC study is to introduce a tool to evaluate the macroeconomic effects of low-carbon interventions. While an assessment of the overall effects is beyond the scope of this report, a methodology for assessing the general equilibrium effects of specific low-carbon investments is introduced. By evaluating key types of low-carbon measures – which account for a large share of Colombia's emission reduction potential – it is possible to indicate the expected general equilibrium effects of climate mitigation.

4 SDAS-DNP, (2010). Análisis de los Impactos Económicos del Cambio Climático utilizando un Modelo de Equilibrio General Computable.

8. Structure of the Report

Chapters 2-4 summarize the detailed sectoral work undertaken as part of CEDEC and the main results. Chapter 5 presents the macroeconomic analysis of low-carbon interventions and their impact on the broader economy. Chapter 6 discusses the integrated analysis as well as the conclusions for Colombia's overall climate mitigation program. The conclusions also identify actions for the near to medium term that would have added economic and environmental benefits.

CHAPTER 2
GHG Mitigation in the Energy Sector

The energy sector – both energy production and consumption – accounts for about a third of Colombia's GHG emissions. While they are low, given the dominance of hydropower, fossil fuel consumption has been growing—not just for power, but also for industry, and transport (Chapter 3). Chapter 2 explores past and future energy supply and demand and evaluates various promising low-carbon interventions.

1. Background

Colombia is in an enviable position in terms of energy resources: It has significant hydropower resources and domestic hydrocarbon reserves (oil, gas, coal). Also, it has large but not fully quantified stocks of non-conventional energy resources (wind, biomass, solar, and geothermal).

More than two-thirds of its installed power capacity is hydro, but as the economy has grown over the past 15 years, the use of fossil fuels has expanded, especially for transport, industry, and power generation. For example, an additional 27 percent of power capacity is from natural gas—and the percent is growing—while the percentage of hydro has declined somewhat since the mid-1990s, due to government policies intended to reduce the country's vulnerability to climatic events (Box 2) (REEP 2012). Moreover, there are plans to increase the production of fossil fuels in the future (Box 3).

Ecopetrol, the national oil company, has become one of the largest oil companies in Latin America and internationally, and Colombia was the world's fifth largest coal exporter in 2012. While oil and coal have been targeted for export, natural gas is largely for domestic use where its share of energy supply has been growing in the power, industrial, commercial, and residential sectors (REEP 2012).

Relative to most countries, the carbon intensity of Colombia's economy is low, and only about 36 percent of its GHG emissions are from the production and consumption of energy (IDEAM, 2008), which compares to the world average of nearly two-thirds, including both CO_2 and methane emissions (IPCC 2007). Thus, it is important to identify ways to reduce carbon emissions through measures that also contribute to the country's economic and social development.

In the energy sector, promising areas include efficiency improvements in lighting, residential appliances, and industrial equipment. At present, its program of expanding the use of natural gas can both lower the carbon intensity of the economy and provide benefits to commerce and specific high-tech industries, besides having positive environmental and health impacts. For Colombia, which already gets most of its electricity from large hydropower, the challenge has been to find competitive non-hydro, renewable energy alternatives. While there are many competitive options for renewables in off-grid areas (including small hydro, solar, wind, and biomass), the challenge is to develop grid-connected renewables such as wind and geothermal that can compete with hydro and natural gas.

A. Sector development

Since the 1990s, numerous changes have occurred in the structure and efficiency of Colombia's energy sector. The most important was the creation of a wholesale energy market where public and private economic agents participate: Wholesale agents and large-scale consumers purchase energy and power in large blocks by signing contracts with generators or on the spot market. Generators that participate are connected to the National Interconnected System (SIN).[5] The price of energy is established according to transactions made through the spot market and contractual agreements among agents (Maurer et al. 2011).

Also, various reforms were introduced to spur economic development and promote greater private sector involvement in the electric power sector, including the unbundling of electricity generation, transmission, and distribution (Maurer et al. 2011). These changed the energy sector from a highly regulated system to a more market-oriented one.

Further, given Colombia's high dependence on hydro, the El Niño-Southern Oscillation in 1992 prompted a significant change in the power sector: After a series of droughts and power shortages, the government enacted policies to reduce reliance on hydro (World Bank 2010), which caused installed capacity to drop from 79 percent in the early 1990s to 68 percent today (UPME 2011).

The Planning Unit for Mining and Energy Planning (UPME) evaluates different expansion alternatives to meet national energy requirements and fulfill reliability indexes. UPME has estimated future installed capacity, with adjustments due to replacing power plants (both coal and natural gas) and the new auction for the reliability charge. In UPME's recent plans, there are no non-hydro renewable energy plants or cogeneration projects.

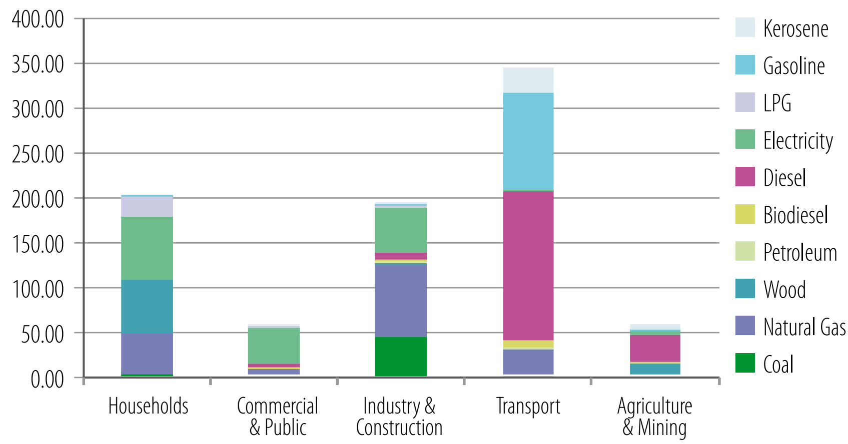
B. Growing energy demand

According to information from the last National Energy Plan (UPME, 2006), end-use energy consumption increased by 11.5 percent from 1990-2005, while the population grew by 25 percent and gross domestic product (GDP) increased by 54 percent. In recent years, primary energy production increased by 3.5 percent—with a larger contribution from coal (+6.9), natural gas (+3.9), and petroleum (+1.22). Since 2004, Colombia added 1,090 MW of new capacity equally distributed between hydro and thermal sources. On the other hand, fuelwood consumption gradually decreased, due to growing urbanization and a successful LPG program in rural areas

5 Electricity in Colombia is supplied mainly through the National Interconnected System (*Sistema Interconectado Nacional*, SIN), which serves 96 percent of the population. Isolated local systems that provide service to remote regions not connected to the SIN are called the Non-Interconnected Zones (*Zonas No Interconectadas*, ZNI).

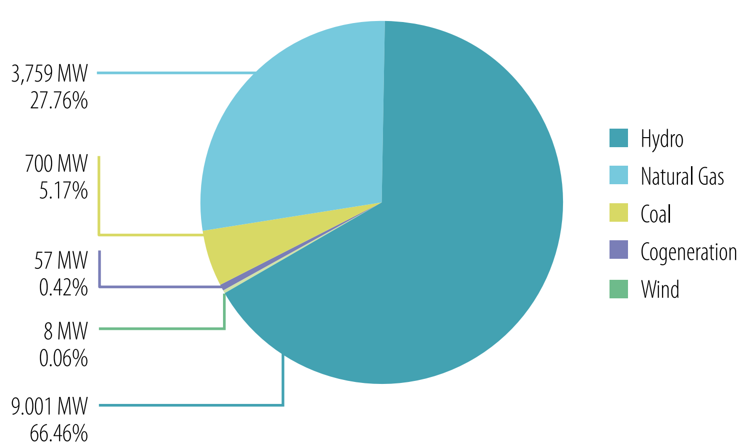
By sector, transport is responsible for a third of energy demand. Diesel consumption recently surpassed that of gasoline, reflecting the strong growth in commercial vehicles, freight, and buses. Manufacturing and construction account for slightly more than one quarter of demand, with coal being the dominant fuel and natural gas showing an increasing penetration for steam and heat production for industrial processing. The residential sector represents just over 20 percent of the country's energy consumption; however, this share has been decreasing due to the replacement of fuelwood with natural gas, LPG, and electricity. Figure 4 illustrates the composition of internal demand and the share of each type of energy by sector (UPME, 2009).

Figure 4 | Final consumption by sector [PJ] 2009



Regarding electricity, the net effective installed capacity in 2009 was 13,543MW (UPME 2009). As Figure 5 shows, 66.5 percent was from hydro, followed by fossil fuels (33 percent), which are composed of natural gas (28 percent), coal (5 percent), and fuel oil cogeneration (0.2 percent). Colombia currently has one 19.5MW wind power project.

Figure 5 | Installed capacity for electricity generation [MW], 2009



Source: (UPME, 2010)

Since 2004, electricity capacity increased by 7.2 percent (UPME 2011). The results of the first electricity auctions (in May and June 2008), indicated that the share of hydropower would increase over the coming decade, to about 72 percent of generation capacity in 2018. The second auction, in December 2011, added 498MW of thermal generation and 518MW of hydropower. Considering the added capacity and plant retirements, total installed capacity will increase by 27 percent by 2020—with 3,050 MW from hydro plants and 850 MW from thermal.

Box 2 | Hydropower and "firm" energy

As in Brazil, Colombia's primary source of electricity is hydro. However, unlike Brazil, only 6 percent of Colombia's hydro plants have reservoirs with multi-year storage capacity. In fact, 15 percent of its plants have run-of-river reservoirs that can be depleted in a single day, and 55 percent have reservoirs that are subject to monthly regulations (Mauer et al 2010). This modest storage capacity makes the system vulnerable to hydrological risks: In just one season, hydropower production can range from 45 percent to 95 percent. During periodic droughts, the lack of regulatory capacity poses a major problem for the energy sector.

To increase stability, the government introduced the concept of "firm" energy in its energy auctions. Thus, energy producers with the technical capacity and ability to provide on-demand energy when it is needed most (ie., when water isn't flowing) were paid a premium through a firm energy payment.

The firm energy market pays generators a reliability fee for their firm energy obligations (OEF – in Spanish – *Obligaciones de Energia Firme*) in exchange for a commitment to provide energy at a fixed price whenever spot prices exceed a pre-defined scarcity price (World Bank, 2011). Firm energy auctions provide incentives to invest in new generation projects, and producers are legally obligated to provide firm energy. Over the long-run, this makes the system more reliable while promoting competitive prices (by auctioning the credits).

Unfortunately, in response to short-term problems (such as unexpected droughts), the government has had to directly intervene in energy markets, which can undermine the firm energy market. Also, because the energy sector is dominated by few agents, the "scarcity price" can be manipulated, making it more expensive for consumers and potentially disadvantaging smaller producers.

Last, firm energy payments negatively affect most sources of renewable energy and the payments are extremely low compared to similar capacity payments in other countries (Oxford Institute for Energy Studies, 2012).

Per capita consumption of energy and electricity is relatively low compared with other Latin American countries (World Bank 2012). Also, the industrial sector's share in electricity and energy demand is low compared to Venezuela, Argentina, Brazil and Uruguay, whose consumption is two to three times higher. However, it is expected that energy consumption in all sectors will continue to grow.

Box 3 | Fossil fuel production

Colombia is a major regional producer of fossil fuels. In 2010, proven oil reserves (R) were a little over 2 billion barrels (bbl) with an annual production (P) of 785,000 bbl per day, giving a R/P ratio of seven—meaning there are roughly seven years left of production at the current rate of extraction. Proven natural gas reserves amount to 7,058 trillion cubic feet (tcf), with a daily production rate of 1 billion cubic feet (bcf) and approximately 17 years of reserves (ANH 2011). Until recently, Colombia had not reached maximum production due to security concerns in rural production areas and a lack of foreign investment. However, high oil prices, changes in the regulatory framework, and improved security conditions have significantly increased oil production activity. The recovery factor has improved through secondary recovery wells and is expected to increase further with the introduction of new tertiary recovery technologies. The increase in foreign direct investment and offering of new exploration and production contracts are expected to significantly increase crude stocks in the coming years: The goal of the central government to produce one million bbl of oil equivalent was met in the first half of 2013, and the goal proposed in the National Development Plan (DNP, 2011) is to produce 1.42 million bbl of oil equivalent in 2014. A significant proportion of this production will be exported. For example, in 2010, 56 percent of oil production was for export—with the percentage expected to increase.

Natural gas production is intended mostly for domestic consumption with some surplus taken by Venezuela. In 2008, the government officially authorized the export of natural gas, a move expected to further increase production. To facilitate export, Colombia plans to install gasification and/or liquefaction facilities on the Atlantic Coast.

Proven coal reserves in 2010 were 6.593 billion tons (UPME, 2011), mostly thermal coal, which is produced almost exclusively (90 percent) in the departments of Guajira and Cesar. In 2013, domestic coal production was 86 million tons. Of this amount, about 90 percent was exported—making Colombia the fifth largest coal exporter in the world. The production target for coal for 2014 in the National Development Plan (DNP, 2011) is 124 million tons. Domestic consumption of coal, mostly for the industrial and commercial sector, is less than 6 million tons. However, an increase in industrial activity or power generation could lead to higher domestic demand. In power generation, coal-fired generation is expected to grow, in order to make the hydro-dominated system more reliable.

C. Energy efficiency and alternative energy

(1) Energy efficiency (EE)

The legal framework for energy efficiency (EE) in Colombia was established over the last decade, mainly with Law 697 in 2000. It created EE guidelines, incentives, and specific programs, and in 2010, the government adopted an action plan called PROURE (Program of Rational and Efficient Use of Energy and Non-Conventional Sources of Energy): The goal was to reduce electricity demand by 8.66 percent in the residential sector, 2.66 percent in the commercial sector, and 3.43 percent in the industrial sector from 2010-2015.

Several EE initiatives were introduced. (a) A program was created in the Ministry of Mines and Energy (MME) to promote more efficient lights, which began replacing all incandescent bulbs in public buildings. (b) Authorities also considered banning the sale of incandescent lamps after 2010, as occurred in other countries, but the measure has not yet been adopted. (c) A refrigerator replacement program is being established under PROURE, administered by MME. (d) Since 1995, the government launched a policy to replace mercury vapor bulbs with sodium vapor for street lights (Afanador, 2009), (UPME, 2007). This process has been underway in municipalities around the country, although no details on achievements have been published.

Currently, no programs promote EE industrial motors, despite the large share of industrial energy consumption that such equipment consumes. However, several ongoing programs facilitate boiler replacement. And, in Bogotá, there is a proposed pilot boiler program upon which the analysis in this study was based. In addition, a program known as OPEN (*Oportunidades de Mercado para Energías Límpias y Eficiencia Energética*) offers opportunities for improvements in EE in Bogotá, especially in fuel consumption for the production of steam or direct heat. The program's early recommendations are to improve current operations by installing equipment such as meters, while not completely replacing the boilers, presumably due to considerations of cost and the availability of gas. EPM (*Empresas Públicas de Medellin*) is promoting the replacement of coal boilers with natural gas for medium and large boilers in the Valle del Aburrá region.

(2) Alternative energy (AE)

Colombia's renewable and alternative energy resources to generate power are extensive and include wind, solar, geothermal, and biomass. However, the relative abundance of hydro and conventional fossil fuel resources has limited the development of the country's renewable and other AE resources. A 2001 law to promote AE lacks key provisions to achieve its objective, such as feed-in tariffs, and has so far had little impact on expanding production. Currently, aside from a number of small hydro plants, Colombia's first flagship AE project is a 19.5MW wind farm in Jepirachi owned by EPM, that initially struggled due to the inexperience of the project operators and a series of misfortunes (Box 4). Although UPME's recent expansion plans have not considered renewables, companies such as EPM and ISAGEN have conducted studies in La Guajira to build wind farms of between 150MW - 300MW.

Colombia currently does not have any installed geothermal capacity. Its first test geothermal well was drilled by Geoenergia Andina S.A. in 1997. After a lapse of more than a decade, the Inter-American Development Bank provided a US$2.8 million grant in 2011 to the Colombian utility Isagen to investigate the geothermal potential in the del Ruiz Volcanic system, which contains the Chiles, Cerro Negro, and Azufral geothermal reservoirs. If the test drilling results are positive, more funds will be needed for the second stage of deep drilling. After this, if the area shows potential, Isagen plans to build a 50MW power plant in the area. Also, in February 2012, Ecuador and Colombia declared their intention to jointly explore the del Ruiz system on their shared border.

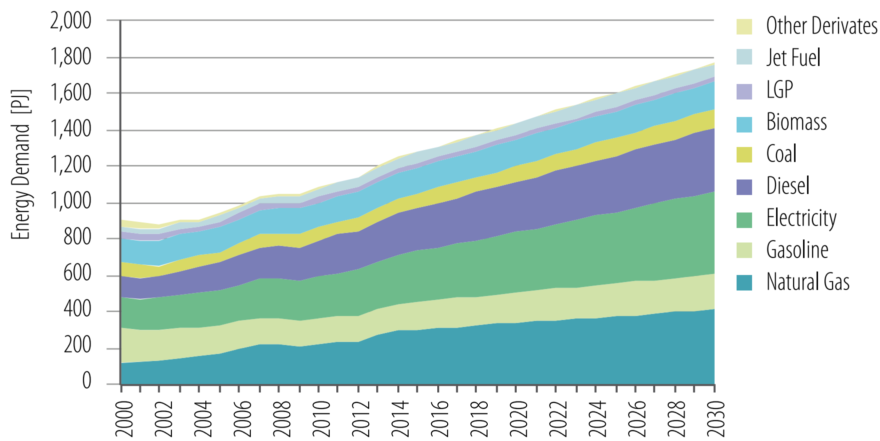
Box 4 | Initial experiences from the Jepirachi Wind Plant

The 19.5MW wind farm at Jepirachi in the Guajira region was installed by the Colombian company, EPM, with the support of CDM funding. When EPM built the plant, it expected the wind industry would grow, supported by government policies. Instead, it faced financial difficulties due to operational and technical factors. The operating and maintenance (O&M) costs of the 15 turbines were considerably higher than expected due to several lightning strikes that damaged the blades. Also, the automatic controllers were unable to adjust to the very strong wind conditions, creating excessive torque, which damaged the machines. The developer then switched to manual controllers, which led to added expenses and lower efficiency. Further, there were unseasonably low winds due to a La Nina event that coincided with the opening of the wind plant, causing lower than average wind speeds, which reduced power production.

2. Baseline Analysis

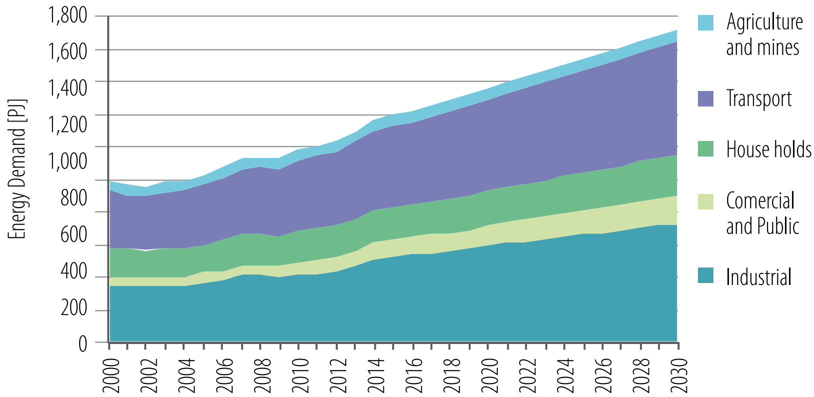
Electricity (hydro), natural gas, and diesel are expected to represent the largest share of the national energy mix in 2030 (when demand is expected to double), followed by biomass, gasoline, and coal (UPME, 2010) (Figure 6). The average annual growth rate for the period is 2.55 percent (2010–2030). Transport and industry will continue as the largest consumers (Figure 7).

Figure 6 | Total energy demand by fuel type, 2000-2030 [Petajoules]



Source: UPME

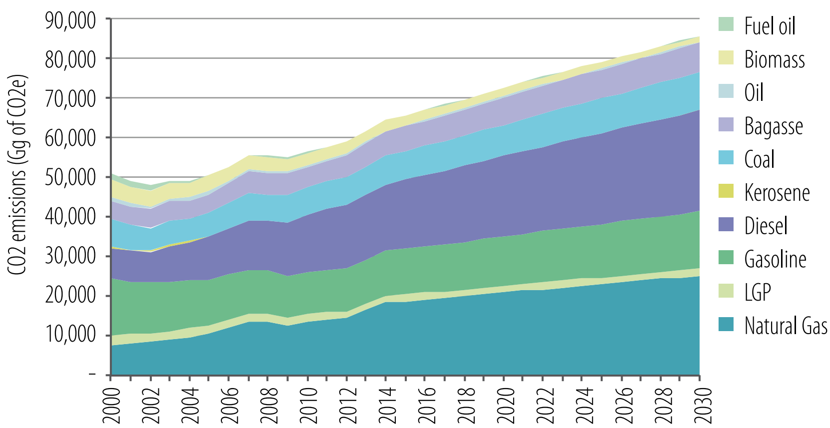
Figure 7 | Total energy demand by sector 2000–2030 [Petajoules]



Source: (Uniandes, 2010), based on (UPME, 2010) data

Based on these demand estimates, the study calculated the corresponding GHG emissions (Figure 8).

Figure 8 | CO_2 emissions from final energy demand (Gg of CO_2e)



Source: Uniandes (2010) prepared with UPME (2010) data. Natural Gas (GN), Crude Oil (PT), Coal (CM), Biomass (Biomasa), Bagasse (BZ), LPG (GLP), Gasoline (GM), Kerosene (KS), Diesel (DO), Fuel Oil (FO).

Forecasts of electricity generation and emissions

Each year, the Mining and Energy Planning Unit (*Unidad de Planeación Minero Energética,* UPME) prepares the Electric Energy Generation and Transmission Reference Plan. It quantifies the need for expanded generation for the National Interconnected System (*Sistema Interconectado Nacional,* SIN), as well as new requirements for transmission and distribution networks to meet the electricity demand.

According to UPME projections, 8,394MW will be added to the electricity system from 2011-2025 to meet future demand. Over the next 14 years, new capacity is expected to come from hydro (6,070 MW), natural gas (760 MW), coal (1,362 MW), and liquid fuels (202 MW).

MME established targets for EE and non-conventional energy resources. Under the URE (*Uso Racional de Energia*) program, expected reductions due to efficiency gains for 2015 are 14.8 percent for electricity consumption and 2.1 percent for other energy sources. The expected reduction in total energy demand is 4 percent in 2015 (2.3 percent in electricity and 1.8 percent in other energy fuels). If the URE measures are implemented in a steady manner, UPME expects the average annual growth rate of energy demand will be reduced by over one percent from 2010-2030, compared to the reference case (from 2.55 to 1.45 percent).

While UPME has not included any new renewable energy (RE) options in its expansion plans, the government has set targets: For the national interconnected system (SIN), Colombia aims to have 3.5 percent of new renewables (small hydro, wind, geothermal, and biomass) in 2015 and 6.5 percent by 2020. For the non-interconnected areas (ZNI), the target penetration rate for new renewables (small hydro, wind, solar PV, and biomass) is 20 percent in 2015 and 30 percent by 2030.

3. Low-Carbon Measures

Given Colombia's large existing hydro contribution and government programs such as PROURE, it is important to examine what additional low-carbon measures could be adopted that would be financially and economically attractive. While Colombia's clean energy matrix has limited the opportunities for obtaining carbon financing for energy-related low-carbon interventions, there are other reasons for undertaking EE, fuel switching, and AE projects, including competitiveness and energy diversification, as well as reducing peak demand and local pollutants.

Applying the cost-benefit methodology described earlier, Chapter 2 evaluates potential low-carbon measures in the production and use of energy (not including transport). The discounted costs and benefits of each are assessed, including externalities such as air pollution, where possible. For comparison purposes, the final costs are expressed in terms of US$ per ton of CO_2 reduced. Measures that are economic will have a negative net cost per ton of CO_2, while those that are not will have a positive net cost of CO_2.

Two types of measures were selected: (a) those currently promoted under government programs that could be expanded or improved, and (b) new opportunities developed in other countries that appear to have good economic and GHG reduction potential, and would contribute towards sustainable development. The low-carbon measures in the energy sector are divided into three categories: energy efficiency, fuel substitution, and new technologies for power generation.

A. Energy efficiency (EE)

EE measures are an important way to reduce energy use and GHG emissions because the potential is large and investments are usually quite attractive financially. While the returns to EE projects are usually high, there is sometimes uncertainty over the cost of implementation and a debate over how to allocate the costs. So-called "transaction" costs can include adopting policies and regulations, disseminating information to buyers and sellers, bundling many small projects together, arranging financing, and monitoring savings. The measures described below have been implemented in Colombia and elsewhere with varying degrees of success, but almost always with high economic returns and good potential for saving energy and reducing emissions.

(1) Residential lighting

Internationally, replacing incandescent light bulbs with more efficient compact fluorescent lamps (CFLs) or light-emitting diodes (LEDs) are popular programs due to their generally high rates of financial and economic returns. CFL technology provides an efficient lighting service with a fraction of the electricity needed for traditional tungsten filament light bulbs used in standard incandescent lamps. Production has expanded globally and bulbs now come in various shapes and sizes for use in all types of fixtures, and are particularly suited for residential and commercial lighting. Efficient bulbs provide a number of benefits: financial savings for the household, reduced loads for the utilities (often during peak hours), and reduced GHG emissions. The residential lighting measure proposes exchanging traditional bulbs for CFLs, assuming several technology and market penetration scenarios.

Methodology and results

The cost-benefit analysis of efficient residential lighting was conducted in three stages. First, a model assessed different penetration scenarios by different groups of consumers. Second, the economic evaluation was conducted, considering purchase costs, lifetime use, energy savings, and GHG reductions. Two different electricity tariffs were considered, reflecting the full tariff (equivalent to US$0.175/kWh), and one that only included transmission and distribution charges (US$0.111/kWh). Third, a CFL replacement program was evaluated assuming market penetration in three population groups.

Depending on the rate of penetration (full penetration by 2030 in the first case, and 2020 in the second), the replacement of 50.6 million incandescent bulbs would reduce 0.17- 0.23 million tons of CO_2 per year, with an overall benefit of US$145 - US$160/tCO_2.

A program that gradually replaces 34.9 million incandescent bulbs in the most optimistic scenario would reduce 5.42 million tons of CO_2 over 28 years. The net present value of the program (2012 dollars) is US$69.83 million, reflecting the purchase, distribution and disposal of efficient bulbs. However, if the benefits from electricity bill savings and reduced transmission/ distribution losses are also considered, the benefit would be US$286.5/t$CO_2$ or US$159.7/t$CO_{2,}$ depending on the energy tariff. Further, the government could benefit in the short-run on the savings in electricity subsidies associated with lower sales of electricity generated by the program.

It is important to note that this potential was calculated using the information from a UPME 2006 report on the stock of bulbs. In it, the proportion of incandescent bulbs was about 88 percent. However, in a newer report (UPME & CorpoEm, 2012), the stock of efficient bulbs grew significantly: Efficient bulbs now accounted for more than 60 percent of total bulbs while incandescents only represented 40 percent. This change significantly reduced the potential to lower CO_2 emissions for efficient residential lighting.

(2) Residential refrigerator replacement and removal

Over the past two decades, there have been major improvements in the energy performance[6] of refrigerators worldwide. In Mexico, refrigerators that were sold from 1995-2000 consumed 30 percent more electricity than those of the same size sold from 2001-2007, and refrigerators sold before 1980 consumed 60 percent more than the latest models (Arroyo-Cabanas, 2009). In developing countries, refrigerator efficiency is often lower than in industrial countries, due to a large market for used models, where efficient models are unavailable, or when the latter are much more expensive. In Mexico, for example, in the states of Tlaxcala and Durango, where average personal or family income is high, refrigerator electricity use is lower because consumers can afford to buy the newer and more efficient models (Arroyo-Cabanas, 2009).

Methodology and results

The residential refrigerator measure is based on a proposed program to replace and dispose of the old models in the four most populated regions: Bogotá, Antioquia, Valle, and Atlántico. For this study, two options were considered for the program. The first was to replace refrigerators that were over 10 years old and consume 600 kWh/year, which would also involve the capture and destruction of ozone depleting substances (ODS) that are common in old models. However, this would require a dedicated program to deal with ODS when exchanging refrigerators. The program would eliminate all refrigerators older than 10 years, and replace a total of 1.11 million. As a result of avoided electricity consumption and distribution losses, this option would reduce emissions by 2.18 Mtons of CO2e. If it included avoided ODS emissions, the option would reduce more than 3.12 Mton of CO_2e.[7]

The second option considered only refrigerators 6-10 years old with an average electricity consumption of 540 kWh/year. These models usually do not contain ozone depleting substances (ODS). The program would start in 2016 and end in 2024, eliminating a total of 1.12 million refrigerators and reducing CO_2 by 1.42 million tons. The calculation assumed a cost of US$350 per refrigerator, a recycling cost of $35, and a recovery value of $40 from the sale of parts from the old refrigerator.

Age	Tariff	Cost
Over 10 years	US$0.175/kWh	+US$21.5/ton CO_2
Over 10 years	US$0.111/kWh	-US$4.69/ton
6-10 years	US$0.175/kWh	+US$4.45/ton CO_2
6-10 years	US$0.111/kWh	-US$44.60/ton CO_2

As illustrated above, there is a wide spread of costs or benefits due to the different tariff levels and age of the refrigerators. The benefit of replacement would be much greater in older refrigerators due to the benefits of eliminating ODS.

6 Depending on the country and region, there are different definitions of what qualifies as an energy efficient refrigerator. It may be defined relative to national averages, to minimum national performance standards, or as an absolute value, e.g., 350 kWh/year.

7 The tons of CO_2 equivalent reduced by ODS are calculated by their 100-year global warming potential, for each CFC molecule. See http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

Compared to the efficient light bulb program, the refrigerator replacement program did not generate as large financial and economic benefits. These are very sensitive to the cost of refrigerators, which would probably be similar to international market prices. Although more costly compared to the light bulb measure, both in terms of upfront investment and the financial return to consumers, energy savings, and CO_2 reductions in the two measures would be similar.

The proposed refrigerator replacement program is especially attractive in Bogotá, which has most of the refrigerators over 10 years old. However, the investment is most attractive in the Atlántico region due to high distribution losses reported by the network operator—the highest of the four regions (16.3 percent). By reducing residential electricity consumption, the utility would simultaneously reduce its distribution losses. With respect to the volume of emissions reduced— both from savings in energy consumption and losses from ODS—investment in the Bogotá program is most attractive. Given the region's size and the age of refrigerators, it could reduce the largest volume of CO_2 among the four regions analyzed.

As with the light bulb measure, the potential for refrigerators was estimated using information from UPME (2006), where 30 percent of older refrigerators would be replaced in Bogotá, 25 percent in Medellín, and 18 percent in Barranquilla. In a more recent report, the proportion of refrigerators older than 10 years is now only 8.6 percent in Bogotá, 11.6 percent in Medellín, and 13.3 percent in Barranquilla, reducing the energy efficiency and CO_2 emission reduction potential proportionally.

(3) Electric motors in the industrial sector

Electric motors are important for national economic productivity, since most industrial activities and a significant percent of commercial ones use electric motors. A recent study commissioned by UPME (BRP, 2007) estimated that replacing old or oversized motors could save 5 to 25 percent in a user's electricity consumption. Also, the incorporation of variable speed drives could represent 5 to 50 percent savings in the motor energy consumption, while the incorporation of static starters could save 5 to 25 percent.

Methodology and results

Two efficient motor program scenarios were evaluated. The first proposed using only new motors for all incremental electric motor demand from 2012-2040. Thus, instead of standard efficiency motors, premium efficiency ones would be used. In the second scheme, motors already installed by the end of December 2011 would be replaced. In this case, it was assumed that the motors would enter the market uniformly over 20 years (from 2012-2031), when it was assumed the entire existing motor stock would be replaced by premium efficiency motors.

The simultaneous application of both actions, ie., to replace the total existing motor stock with premium motors, and to have only premium motors for new sales, would reduce 2.946 Mton of CO_2 during the period of analysis. The cost of the avoided ton of CO_2 would be US$-64.0/ton and US$-20.1/ton, depending on the tariffs. Approximately 110,000 units have been changed and installed so far. These values imply that there would be a net benefit for society if this measure were implemented.

The cost of a national efficient motor program such as the one evaluated was estimated to be US$165 million. The cash flow of the total program would begin to show a positive annual balance after the third year (2015) for the high tariff, but the full investment would not be recovered until the 16th year (2025). Such a long payback period would create a barrier for enterprises, and implies that targeted motor replacement in specific industries may be preferable.

(4) Public street lights

EE upgrades to public street lights are a simple way to improve public services while generating cost savings for municipalities. Projects typically involve retrofitting existing streetlights with EE lamps and fixtures, and automatic controls to optimize performance and energy use.

Methodology and results

The calculations, based on Colombian data, assumed that public street lights are on for an average of 12 hours a day, which implies a useful life of three years for mercury vapor bulbs and six years for sodium vapor bulbs. The results of this exercise reduced 4,412 GWh and 772.12 ktons of CO_2 in the period analyzed, and a benefit from the reduced ton of US$-22.78/t$CO_2$ with a tariff of US$0.175/kWh. When a tariff of US$0.111/kWh was considered, the result was a benefit of US$-11.28/ton of CO_2. As with residential lights, efficient street lights have both financial and economic benefits. As an indication of the potential for energy savings through such programs, public street lights consume approximately 4 percent of total electricity in the interconnected system (SIN) (Afanador, 2009). An analysis of LED lights was not performed, but should be considered given the rapid fall in technology costs in recent years.

B. Fuel substitution

One way to reduce CO_2 emissions is to replace highly-polluting or high carbon-intensive fuels with cleaner fuels, such as natural gas. There has been an ongoing penetration of natural gas in the power, industrial, and residential sectors, but there is considerable potential to increase consumption in the country's small and medium industries. It is important to note that with fuel substitution projects, a major benefit is the improved public health associated with lower levels of air pollution, which, if included in the assessment, could significantly increase the economic benefits of these projects.

(1) Natural gas in small and medium boilers

Boilers are used to generate steam for some industrial processes and commonly use coal or natural gas as a fuel. While coal boilers have higher initial investment and maintenance costs than gas boilers, the lack of proximity to natural gas distribution centers and upfront investment and connection costs for gas can be prohibitive. Moreover, coal is cheaper, and supply is more reliable.

On the down side, coal boilers produce a much greater amount of fine particulate matter, NOx, and SOx emissions, which are problems for production processes requiring cleanliness, such as in the electronics, textiles, and food and beverage industries.

Equally important, there are other social costs not usually factored into their price. The most significant are the environmental and health costs of pollutants. For example, the emission of particulate matter (PM), especially fine and ultrafine fractions (<2.5microns; <0.1microns) causes short and long-term health impacts, such as chronic respiratory disease, bronchitis, and asthma. In a Colombian study (Larsen, 2004 in DNP, 2008), the author found an estimated average annual health cost due to urban air pollution from particulate matter to be around 0.8 percent of GDP. And, according to DNP (2008), there are about 6,000 excess deaths each year and over 7,000 excess cases of chronic bronchitis due to the country's poor air quality. Other environmental costs associated with coal combustion include acid rain from the emission of nitrogen oxide (NO_X) and sulfur oxide (SO_X), and troposphere ozone depletion from the emission of NOx and volatile organic compounds (VOCs).

GHG emissions are also lower with natural gas compared to coal-fired boilers: Natural gas boilers produce up to 52 percent less CO_2 emissions and up to 96 percent fewer particulate emissions in the production of steam.[8] Carbon payments could help level the playing field between coal and natural gas, but the differences in financial costs between the two are not very large.

Thus, proximity to gas distribution centers and upfront costs for new gas-fired boilers appear to be the major obstacles to using natural gas boilers. Conversion of existing coal-fired units to gas is a straightforward process, requiring a series of retrofits for the fuel supply and the installation of meters, but with no need to change the boiler vessel itself.

Methodology and results

The study calculated reductions based on a proposed boiler conversion program for Bogotá, where details were available on boilers in the small and medium industrial sector (*Secretaría Distrital de Ambiente, Transmilenio S.A. y Uniandes*, 2009). It measured fuel consumption for different size boilers, considering average operating conditions, using 50, 60, 80, 100, 125 and 150 BHP (Boiler Horsepower) capacities.

To calculate environmental externalities, values were used from the ExternE project (European Community, 2005) which has been applied since the 1990s in Europe to estimate the cost of externalities of emissions for different electricity generation systems, considering all stages of the life cycle of fuels. This method, which compares both technologies and fuels, found the costs of externalities per kWh generated included the impact of the emission of $PM_{2.5}$, PM_{10}, CO_2, SO_2, NO_X, and a range of other contaminants. It then calculated the effects on human health (morbidity and mortality), noise disturbances, impacts on crops and materials, ecosystems, and climate change.

The pilot program that was evaluated involved replacing 30 boilers in Bogotá over a 28-year period. It was assumed that there was a large potential for such an effort, but there was not enough data on the boiler stock to accurately assess the magnitude of the potential. Still, the evaluation produced results with regard to reduced tons of CO_2 per year, replacement costs, and the costs of the reduced ton for the number of boilers (see Table 2).

8 Assuming emission factors: 355.3 g/GJ for coal boilers larger than 100BHP and 208.91 g/GJ for boilers less than 100BHP; 6.327g/GJ for natural gas boilers larger than 100BHP and 1.23 g/GJ for smaller boilers).

Table 2 | Results of boiler replacement program for fuel substitution in Bogotá, with and without externalities

Capacity BHP boiler	Number of boilers-program	Tons of CO_2 reduced/ year	Costs of replacement, without externalities (USD/program)	US$/ton$CO_2$ without externalities	Annual externality benefit [US$/unit]	US$/ ton$CO_2$ with externalities
50	2	959	$2,060,923	$76.75	-$16,630	$41.42
60	2	1,145	$2,542,491	$79.29	-$19,925	$43.81
80	7	5,312	$12,369,015	$83.17	-$26,515	$47.48
100	14	13,229	$31,301,984	$84.50	-$33,106	$48.70
125	4	4,767	$11,280,079	$84.51	-$41,498	$48.92
150	1	1,424	$3,434,280	$86.10	-$49,736	$50.40
Total	30	26,837	$62,988,772	$83.83	-$187,410	$48.10

Sensitivity analysis identified the effect of investment and fuel costs on the economics of the project and the cost of a reduced ton of CO_2. The most important variable in the cost-benefit analysis is the relative cost of fuel, while the cost of equipment is quite small. The analysis showed that the profitability of boiler conversions is particularly sensitive to the price of natural gas. Thus, if international prices of natural gas fall, or if coal prices rise (by including externality costs), the replacement is much more attractive.

The replacement of coal boilers with natural gas boilers reduces a number of air pollutants (see the last two columns in Table 2 for an estimate of the pollutant and cost reductions). The total benefits are US$17,000 - US$50,000 a year, depending on the boiler size. Also, the value of the reduced ton of CO_2 decreases by about US$30 on average for each boiler size when externalities are included, which means the program is more economic and costs less to reduce GHG emissions for every boiler replaced.

C. New technologies for generating electricity

The third area explored for low-carbon measures was substituting electricity generation with alternative technologies. This section presents the analysis of two pilot generation alternatives—wind and geothermal electricity—that would be connected to the grid (SIN). The measures proposed consist of replacing coal and natural gas-fired generating plants with: (a) a 893MW power capacity wind park in La Guajira, and (b) geothermal plants with a power capacity of 379MW. The assumptions about the coal and natural gas plants to be replaced rely on the first scenario of the UPME's Capacity Expansion Plan 2010–2024 in Table 3.

Table 3 | Capacity expansion plan, 2010 – 2024, by technology in MW - Scenario I

Year	Hydro	Natural Gas	Coal	Co-generation	Liquids
2010	174.9	169		19	
2011	640				
2012			150		210
2013	935.2				
2014	480				
2015	400				
2016					
2017					
2018	1200				
2019					
2020					
2021			300		
2022	1300				
2023					
2024		300			
Subtotal	5,130.1	469	450	19	210
Total	6,278.1				

Source: UPME.

Table 4 summarizes the levelized costs (including both capital and operating costs) of the baseline and alternative technologies considered in the evaluation.

Table 4 | Levelized costs of fossil fuels and alternatives

	Useful life (years)	Capital costs (US$/MWh)	Fixed O&M costs (US$/MWh)	Variable O&M costs (US$/MWh)	Total (US$/MWh)
Coal	25	69.94	9.73	18.65	98.33
Gas	25	25.62	7.16	52.44	85.22
Geothermal	25	69.17	11.90	9.50	90.57
Wind	20	86.76	9.00	0.00	95.76

*All monetary figures in this section are referenced to 2012 U.S. dollars.

(1) Wind park in La Guajira

Global wind energy capacity has grown rapidly over the past decade. In 2009, newly installed capacity was more than 34GW (GWEC, 2010), representing more than 25 percent of total new generation capacity worldwide and accounting for approximately 1.8 percent of global electricity production (Wiser and Bolinger, 2010). This growth helped improve the technology and lower costs, which in turn helped spur windpower investments. In many countries, wind is rapidly approaching cost-competitiveness with fossil fuel-powered electricity generation on a levelized cost basis. Although wind power costs are still generally higher than large hydro and gas, wind has other advantages, including lower investment thresholds, faster implementation, a smaller environmental footprint, and the fact that it can often complement hydro and solar.

According to surveys in 2002, the Colombian wind regime was rated the best in South America; in fact, the only other region with similar wind intensity is Patagonia, in Chile and Argentina. Colombia's northern offshore regions have class seven winds[9] and the country has an estimated wind power potential of 18GW in the La Guajira region alone, enough to generate twice the country's current power demand (Perex and Osorio 2002).

Methodology and results

The study considered an installation of a 413MW wind park in two stages. In the first, a wind park replaced a 300MW coal plant in 2021 and in the second, it would be expanded to 893MW in 2022 and replace a 300MW natural gas plant. As a result, wind generation would be 4.8 percent of total installed capacity by 2022, up from 0.14 percent today. The installation costs were US$1,800 - US$2,400/kW, while variations in coal prices were US$40 - US$70/ton and natural gas prices from US$5 - US$10/MBTU.

The required wind capacity was determined to be equal to the energy generated by the replaced thermal plants, assuming a wind capacity factor of 0.34 would be equal to replacing coal and natural gas power production; wind would replace 1,353GWh/year from coal by 2021, and 1,430GWh/year of natural gas by 2022.

Without considering the "firm energy" revenue that coal plants receive (Box 2), replacing a coal plant with wind was found to be economic under certain conditions. This occurred despite the low capacity factor of wind plants, and is due to the much lower operating and fixed costs compared to coal. If the cost of the wind installation is under US$2,200/kW, the cost of the reduced ton of CO_2 would be negative (net benefit), as long as the price of coal is greater than US$43/ton.

The advantages of the wind plant switch when firm energy revenues for the coal plant are included (the cost of a reduced ton increased to approximately US$20/t$CO_2$), and where the firm energy revenues for wind are based on current policies. Accordingly, these revenues from the coal plant (2,365 GWh/year) are much greater than those of the wind park (1,230 GWh/year), using the current formula for each as calculated by CREG. If it is assumed that the coal price in 2021 is US$50/ton and the wind installation cost is US$2,200/kW, the benefit for reducing CO_2 would be US$3.88/ton, but with firm energy revenues, the cost of the measure would be US$13.9/ton.

9 Class seven winds are defined as winds over nine meters per second [m/s] at a height of 50 meters.

When the wind plant replaces natural gas, the economic benefit is lower, largely due to the lower capital costs of a gas plant compared to coal. However, this depends on the price assumptions for natural gas. If firm energy revenues are included, the cost of a wind activity increases by about US$10/tCO2 – smaller than for coal – because the difference between the firm energy of the gas plant (2,102 GWh/year) and the wind plant (1,429 GWh/year) is less.

Assuming natural gas is US$7.4/MBTU and the cost of wind installation is US$2,200/kW in 2022, the cost of the reduced ton of CO_2 would be US$18.5/ton, and US$28.5/ton including firm energy revenues. The wind plant would reduce CO_2 emissions by a total of 8.36 million tons over 20 years.

(2) Geothermal plants in Nariño

At present, 24 countries use concentrated heat from under the earth's surface (geothermal power) to generate energy (GEA, 2010). It is a proven technology that is expanding, and has already shown long-term commercial viability in some countries: The worldwide installed generating capacity grew at an annual rate of 20 percent from 2005-2010; and, in 2010 there were new geothermal projects in 70 countries, representing a 52 percent increase since 2007 (GEA, 2010). In Central America, geothermal projects were successfully developed, as in El Salvador (204MW), Costa Rica (166MW), and Guatemala (52MW).

For Colombia, geothermal power production could:

- Diversify energy generation with a domestic resource that provides reliable energy from a source largely independent of climate (unlike hydro, wind, and solar);
- Offer low operating and overall costs (with levelized costs lower than coal);
- Have high capacity (above 90 percent);
- Produce minimal waste and have a smaller environmental footprint than coal, natural gas, or hydropower plants, when developed responsibly.

Colombia has two potential sites that are rated medium and high (World Bank, Geothermal report 2012): (a) The Azufral Volcano which, according to UPME, has the potential for high temperatures, a good combination of cap rock and impermeability, road access, and a promising commercial potential. (b) The Tufiño – Chiles Cerro Negro region – which lies along the border between Colombia and Ecuador, is being explored and is estimated to have about 138MW of generation capacity.

Methodology and results

As with the wind analysis, the proposed measure consists of replacing coal and natural gas combustion with geothermal power generation. It would occur in two stages: (a) exploration and development of the geothermal field in Nariño (Chiles, Azufral, or Cerro Bravo areas) with a 175MW geothermal plant that would begin operating in 2021 and would replace a planned 300MW coal plant; and (b) development of more fields to expand capacity to 379MW in 2022, replacing a natural gas plant. The intervention assumes a plant with a capacity factor of 0.8 and the use of a dual flash plant.[10]

10 Dual flash plants are most commonly used to develop new geothermal fields and are capable of using more of the total flow from the reservoir than a single-flash plant, thus producing 15 to 25 percent more energy (DiPippo, 2007). However, this increase comes with a corresponding increase in plant complexity and cost.

(3) Geothermal replaces coal

The economic evaluation of a geothermal plant yielded promising results and is considered a "no-regrets" measure provided that firm energy revenues are omitted and geothermal installation costs are less than US$4,800/kW. However, even if the installation cost increases to US$5,000/kW, the value is still no more than US$8/t$CO_2$, assuming the price of coal is above $40/ton. Despite high upfront exploration and installation costs, the O&M costs of geothermal plants are lower than those of coal plants, and their high capacity factor allows the installation of less capacity to generate the same level of energy. When firm energy revenues are included, and despite the fact that geothermal has a high capacity factor, a 300MW coal power plant can receive more firm energy than a 175MW geothermal plant because firm energy in Colombia is calculated according to the plant's size. Thus, including firm energy revenues more than doubles the cost of reducing a ton of CO_2 (to US$20).

Using the same coal price as in the previous measure (US$50/ton in 2021), and assuming the cost of geothermal installation is US$4,400/kW, the cost of a reduced ton of CO_2 would be negative 12.6 US$/ton$CO_2$ without firm energy obligations or 3.1 US$/ton$CO_2$ with them.

Assuming an emission factor of 0.06 tons of CO_2/MWh for a geothermal plant, the measure would reduce 8.11 million tons of CO_2 over 25 years and contribute to 1.1 percent of the total electricity capacity (and 3.1 percent of electricity generation) by 2022.

(4) Geothermal replaces gas

Considering the same capacity factor (0.8) for geothermal, a 204MW plant would be needed to replace the electricity generated by a 300MW gas plant. As in previous cases, sensitivity analyses were conducted on the cost of reducing a ton of CO_2, using the gas price and the installation cost. As with the wind measures, the analysis is quite sensitive to gas prices. If future gas prices increase to over US$7.5/MBTU in 2022, this would reduce the cost of the geothermal plant compared to gas. Assuming a price of US$7.5/MBTU and a geothermal installation cost of US$4,400/kW, the estimated cost of a reduced ton of CO_2 would drop to US$9.2/ton$CO_2$.

As with coal plants, the firm energy of gas plants is higher than that of the geothermal plant; thus, the estimated cost of the reduced ton increases to US$17.0 /ton$CO_2$. With this measure, a total of 8.28 million tons of CO_2 emitted over 25 years would be reduced.

Based on the analysis, replacing fossil fuel plants with geothermal is currently cheaper than wind. This result holds although the costs of geothermal plants are much higher than wind plants and their emission factor is not completely zero.[11] The main reason is the large difference in capacity between the two technologies, which results in lower capital costs for installed capacity of geothermal to meet the same energy production.

D. Summary of measures

Table 5 and Figure 9 summarizes the low-carbon measures evaluated in the energy sector. It shows their total reduction potential[12] over the life of the action, the annual reduction in CO_2 emissions, and the associated costs expressed in the cost per ton of CO_2 reduced. The graph

11 While geothermal power production generally has a lower environmental impact compared to conventional fossil fuels or hydro, the fluids released during drilling contain a mix of gases (CO_2, H_2S, CH_4 and NH_3) and toxic materials (mercury, boron, arsenic and antimony) that must be carefully treated to mitigate the environmental impact of their extraction. The estimated CO_2 emission factor of a geothermal plant is 0.06 ton CO_2/MWh (DiPippo, 2007).

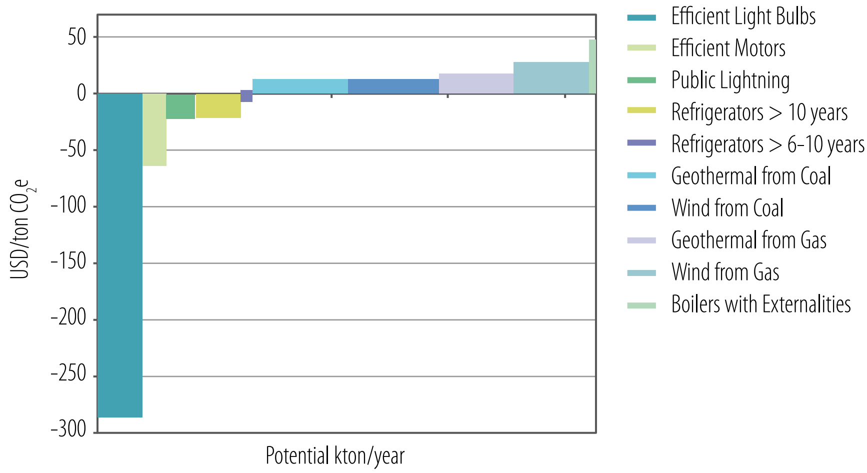
12 In some measures, the potential is low because there are no national surveys of the existing technology.

shows the marginal abatement cost curve for the measures evaluated, displaying the cost on the *y* axis (the more negative the more profitable the intervention) and the potential for reduction on the *x* axis.

Table 5 | Energy efficiency

	Measure	Reduction potential (Mton CO_2e)	Annual reduction (kton CO_2e)	Period of analysis (years)	Cost (US$/ton CO_2) (assuming US$0.175/kWh – for EE)	
Energy efficiency	Efficient lights	5.42	193.6	28	-286.5	
	Refrigerator replacement and disposal	5.31	189.6	28	-21.5	
		1.42	50.7		-4.45	
	Industrial motors	2.95	101.7	29	-64.0	
	Public street lights	0.772	128.7	6	- 22.78	
Fuel replacement	Use of natural gas to produce steam	0. 751	26.83	28	48.1	
Regarding firm energy revenues:					No	Yes
Introduction of new technologies	Wind for 300 MW coal plant	7.71	385.5	20	-3.88	13.9
	Wind for 300 MW gas plant	8.36	418		18.5	28.5
	Geothermal for 300 MW coal plant	8.11	324.4	25	-12.6	3.1
	Geothermal for 300 MW gas plant	8.28	331.2		9.2	17.0

Figure 9 | Abatement curve - energy sector



4. Overcoming Barriers to Implementation

Many of the barriers to energy efficiency and alternative energy are similar to those in other countries, including upfront costs, businesses' and consumers' lack of information, weak environmental standards for air pollutants or the failure to enforce them, and the lack of equipment in the market. Other factors that affect the economics of the projects include the low-carbon intensity of Colombia's electricity grid, and regulations related to tariffs and firm energy payments.

A. Residential lights and appliances

With respect to efficient bulbs, a CFL lasts 8–15 times longer and uses 3–4 times less energy, although the purchase price is typically 3–10 times greater than an equivalent incandescent lamp. Experience shows that CFL and other EE programs often need soft incentives (public information campaigns and marketing) to address the upfront costs.

Colombia's light and refrigerator programs could be improved through information campaigns that would identify the efficient appliances sponsored by the government. As is common with EE measures for households, consumer education campaigns are critical, and product guarantees can reduce consumers' perceived risks. Other important activities are labeling programs and government standards for appliances, and programs such as the certification of efficient lights can help increase the demand. Disposal programs that handle contaminants in CFL light bulbs should also be established. One barrier is the lack of international standards that set minimum quality and EE specifications for lights and appliances.

Although a major benefit of replacing refrigerators is eliminating ODS from the environment, which reduces CO_2, these gases must be properly handled and recovered. Thus, treatment and disposal of old refrigerators becomes a critical component and unless done properly, could eliminate the potential CO_2 reduction benefits of a refrigerator program.

B. Street lights

Despite good financial and economic returns for public street light programs, institutional constraints often hamper investments. Municipalities are responsible for providing service, which determines the source of funds (budget, fee, or both), as well as the authorization to levy a public "street light tax" and the means to collect it. Likewise, municipalities define the scope and quality of the service, along with the business structure under which it operates and is supervised. Unfortunately, it appears such municipal services are inefficient: About 47 percent of municipalities have both current and operating expenses that exceed their revenues and depend heavily on central government transfers; further, 539 municipalities (55 percent) (Afanador, 2009) have incurred debt (as of December 2008) of about US$60 million (COP$116,000). Since municipalities have autonomy when setting the street light tax, this causes major differences in what users in similar income groups pay and between municipalities; indeed, many impose high fees for lower income groups (Afanador, 2009). The rapid advancement of LED street lights presents additional opportunities for EE in cities, benefiting municipalities, utilities and the central government, and this option should be evaluated for Colombia.

C. Industrial motors

A national energy efficiency (EE) program covering all industrial motors would be challenging, especially because of the large number of small industrial firms, such as in the food and beverage sector. As in other countries, the main barriers to companies carrying out EE projects include upfront investments, the competition for resources, and management's need to attend to other priorities (along with EE projects). One barrier in Colombia is the nearly non-existent supply of efficient motors. Also, the larger financial returns that can be gained from thermal EE projects as opposed to electrical ones (given relatively low electricity prices compared to fossil fuels), have discouraged companies from focusing on efficient motor investments. Further, a barrier to implementing a national program is the fairly long payback period: For a proprietor who does not have guaranteed sales over the long term, a payback period of more than a few years can be a major impediment.

Given the difficulties involved with launching a national program, the focus initially could be on developing sector-specific pilot projects. These would tackle enterprise-level barriers, while generating experience that could be replicated to the larger industry or other sectors. One pilot could be in the textile sector—which is the third largest consumer of electricity, much of it by electric motors. Already, some stakeholders are interested in increasing the sector's efficiency, such as the Private Management Bureau of the *Asociación Nacional de Industriales* (ANDI) which seeks to increase its productivity and competitiveness. Also, the National Government Program for Productive Transformation—a group seeking to make Colombia's textile sector world-class—would also be an important stakeholder. If these motors were manufactured domestically, it could help remove one of the key barriers to more efficient industrial motors; this could be promoted through agreements among industry, motor producers, and importers. Such a program could also help progressively introduce minimum EE standards. It will be important to monitor the industry's EE developments; this could be accomplished by standardizing, accrediting and strengthening testing laboratories so the motor market can be properly controlled and efforts by national producers and importers to develop more efficient products can be fairly protected.

D. Industrial boilers

Small firms present specific challenges to adopting EE equipment, especially when capital costs are high and owners may not want to invest in new equipment when they already have functioning boilers. Studies of EE find that "consumers are more concerned with first costs than lifetime costs" (B.K. Sovacool, 2009). In particular, small and medium industries seem to need higher implicit rates of return on capital investments compared to their other productive or commercial investments. Further, there is limited availability of efficient domestically-produced boiler technologies that meet emission and efficiency standards, or boilers that allow the simultaneous use of different fuels such as coal and biomass.

Moreover, the cost of fuel and the uncertainty over the long-term availability of natural gas is a particular concern, and firms must be located close to a natural gas distributor. Further, the cost of bottling and transporting natural gas is very expensive, and boiler replacement programs can only be considered in areas where there is access to a piped gas network. Also, if an area has access to natural gas, the current and future supply must be sufficient to meet all demand in the region, including any new demands of small and medium enterprises.

Boiler interventions yield very different results depending upon whether air emission standards are in effect. For example, if externalities are ignored, coal in Colombia is cheap compared to natural gas. However, if public health and other environmental costs associated with poor air quality are included, these make replacing coal boilers with natural gas ones much more attractive. As the economy has developed, natural gas has often replaced coal and other inferior fuels as the public and businesses increasingly value cleaner fuels.

Steps can be taken to move forward with the conversion of small and medium boilers to natural gas. First, regions that already have natural gas distribution systems and a surplus of gas should be identified: eg. The Valle del Aburrá has more than 100 small and medium boilers and is close to natural gas distributors throughout the Medellín region. Second, since an inventory of boilers does not exist, surveys must be conducted to identify the number/size of existing boilers, as well as projections of future demand. This demand should be compared to the supply of natural gas. Last, where pre-conditions exist, a loan program for converting boilers, supported by industry associations, boiler manufacturers, and the gas industry, could be created to overcome initial investment barriers.

E. Wind

Under current circumstances, wind-based generation is not financially attractive. EPM had planned on building an additional 300MW plant near Jepirachi, but canceled, waiting until technology costs are lower and a regulatory framework can better promote wind energy. Key barriers have been the higher levelized costs (including capital, debt, O&M, and externalities) of wind relative to hydro and natural gas plants. Also, Colombia has few policies to support renewables, such as feed-in tariffs or a renewable portfolio standard. In Brazil, recent policies led to a large increase in wind plant capacity, and wind power costs are very competitive with other energy sources. However, in Colombia, although wind and other renewables qualify for "firm" energy payments, current rules offer significantly less payments to wind than in other countries: eg. while capacity payments to wind in the U.S. and Europe are typically 15-30 percent (Robinson, 2012), comparable payments in Colombia are just 5-7 percent. While the CREG regulations base their firm energy payments for wind on historical data, the program's goal is to provide energy at times when hydro is unavailable and during hours when power is needed. If wind were evaluated on this basis, firm energy payments would be closer to the 15-30 percent that is common elsewhere.

Given Colombia's large and high-quality wind resources and the potential for diversifying energy, the government could consider fostering wind power through various mechanisms. It could: (a) strengthen wind data collection as a public service, improve access to research and technology development, and modernize grid access to wind power; (b) more actively promote access to financial instruments aimed at reducing GHG emissions. Such funding sources include CDM, access to multilateral soft loans earmarked for alternative energy such as the Clean Technology Fund, and the growing voluntary carbon market; and (c) besides helping obtain international financing, it could offer wind developers financial incentives through fiscal mechanisms, including tax credits for investment, or through contributions to the Fund for the Electrification of Off-grid regions (FAZNI).

F. Geothermal

Geothermal power plants face several barriers. Compared to other power generation technologies, geothermal projects present unique and inherent risks, which vary by stage of project development (World Bank, 2012). For example, pre-survey and exploration activities often do not lead to successful outcomes, although they are low-cost activities that do not present substantial financial losses. Thus, the government could promote geothermal by undertaking a thorough assessment of geothermal resources. Nearly all countries with large geothermal programs have invested in upfront explorations (and often test-drilling) to reduce the risks and raise the likelihood of private sector development. Depending on the magnitude of Colombia's geothermal resources, more policies could be considered to promote this development. Test drilling has the highest risk as it implies substantial resources with an uncertain outcome. The risk is that the reservoirs may not have minimally acceptable well characteristics to support the field's commercial development. And, without positive results from test drilling, it is difficult for project developers to meet their financing needs from commercial banks; often, they must rely on equity investments which require a higher rate of return than commercial financing, leading to higher financial costs for this stage of development. The government could help, if not by directly financing the tests, then by providing other fiscal incentives, such as tax deferrals or advances against future income.

5. Conclusions and Recommendations

For various reasons, the potential for low-carbon development in the energy sector is limited. Based on the seven interventions described in this chapter, the CO_2 reduction potential for Colombia is only about 2 million tons a year, compared to the 14 million tons the government had estimated as the total reduction potential for EE, fuel switching, and renewable energy (RE) measures in industry and the energy sectors (Ministry of Environment, 2011). Besides the measures analyzed here, there are other important ones for reducing emissions. However, limited data prevented an analysis of the reductions associated with: (a) fugitive emissions such as flaring and leakages from petroleum, natural gas, and coal production; (b) EE and fugitive emissions in processing hydrocarbons (such as petroleum refining and petrochemical production); (c) cogeneration processes and EE in industry; and (d) carbon capture and storage.

The dominance of hydro is the most obvious factor for the country's low carbon footprint, especially in the power sector. However, other trends have reduced the potential for energy efficiency, switching to lower carbon fuels, and renewable energy. For example, the wide penetration of natural gas in the power sector and large industry, and the expansion of LPG to replace fuelwood and other cooking fuels, reduced the economy's carbon intensity compared to a situation where more Colombian coal would have been used domestically rather than exported. If the relative cost of using coal versus natural gas changes, say, in the power sector, or if policies change to promote more coal production, Colombia could see a significant increase in CO_2 emissions. As the analysis of alternative power generation technologies shows, it has been difficult for wind and geothermal to compete with hydropower and natural gas, given the country's favorable domestic resource endowments. However, depending on the future availability and price of natural gas, renewables could become more competitive. The cost/difficulty of constructing hydropower plants has also increased, as witnessed by cancellations and delays in several large projects. This trend, as well as growing concerns that climate change could lead to larger or more frequent droughts (Chapter 4), also raises questions about the benefits of increasing the percentage of electricity from hydro.

Still, the interventions proposed are consistent with some existing and proposed programs in the energy sector and make sense regardless of climate change concerns. Specifically, EE measures can save consumers money, improve the productivity of manufacturing, reduce peak electricity demand, forego the construction of new power generation capacity, and diversify the country's energy supply. Fuel switching, specifically from solid fuels (coal and biomass) to natural gas can have productivity benefits for some industries, and reduce a major source of local pollutants responsible for indoor and ambient air pollution. In some cases, current technology advances will lead to achieving Colombia's EE targets. But, if programs and policies were promoted that included bulk procurement of efficient equipment, more efficient technologies could be adopted more readily (such as widely used appliances and industrial equipment).

As noted in the EE analysis, regulations must be created for handling and disposing of hazardous chemicals associated with old refrigerators (ODS) and light bulbs to avoid negative environmental impacts that can outweigh the benefits. Also, the costs of environmental externalities must be included in the analyses of energy technologies where possible, which for boilers and transport (Chapter 3) are important benefits of energy efficiency and fuel switching projects. Thus, more analyses of the costs of these externalities are needed.

Limited industrial development is another reason for the low energy and carbon intensity in Colombia. If economic growth is to be achieved and unemployment reduced, this will require greater investment in manufacturing—not just in resource extraction, which currently accounts for a large share of Colombia's GDP. Programs that introduce efficient boilers or motors can support the production of equipment locally and contribute to technical renovation in many industries. Further, to replace coal-fired boilers in SMEs and promote EE measures in this sector, industry will need to support these efforts, and the use of existing credit will be required to achieve greater productivity. Recent international trade agreements may provide a new stimulus for Colombian industry to improve its productivity and economic competitiveness.

New power generation technologies can certainly contribute to diversifying Colombia's energy mix, and geothermal and wind are attractive options. The analysis found that these two are already close to being economic in Colombia, especially compared to coal plants. However, from a financial perspective, it is difficult for wind projects (and perhaps geothermal, when projects get closer to implementation) to compete with conventional technologies. Although regulations allow firm energy payments to wind power plants, recent analyses (Robinson 2012) suggest they are undervalued, perhaps significantly, compared to the contribution wind plants provide to making the system reliable. Thus, the government should continue promoting regulations to ease the entry of the full range of power plants, including distributed technologies such as grid-connected solar PV that will be facilitated by smart meters and net metering. Distributed renewable energy technologies are even more attractive in off-grid applications, where they can be used to reach unserved communities and households at least cost.

CHAPTER 3
Transport Sector

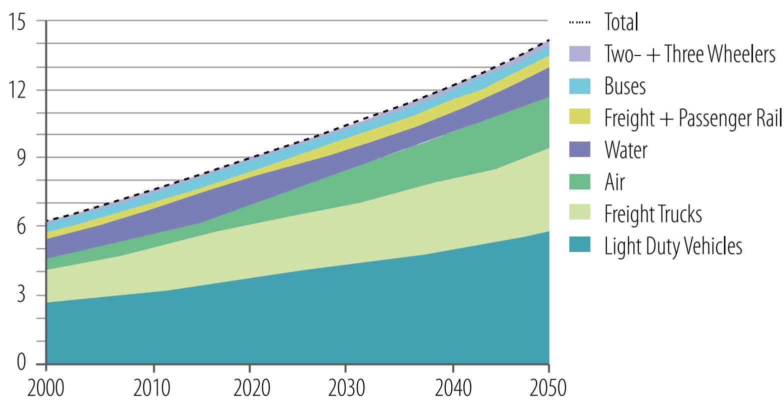
The rapid growth of the transport sector is a worldwide trend, which makes it the fastest growing source of GHG emissions in many developing countries, including Colombia. As elsewhere, motorization rates have mushroomed as incomes have grown. However, the country has already developed a large-scale urban transport model that seeks more efficient/equitable services. This chapter reviews the sector, focusing on road transport, and evaluating options to reduce emissions while meeting the growing demand for passenger and freight transport.

1. Background

The World Business Council for Sustainable Development estimates that from 2000-2050, global transport emissions[13] will grow from about 8 gigatonnes of CO_2e to 14 gigatonnes. The increase in energy consumption has been led by light-duty vehicles (passenger cars and trucks) followed by freight trucks and air transport, which together create 80 percent of the sector's emissions. The remaining energy consumption/emissions are from buses, motorcycles, and river and railway transport. By 2050, emissions' growth is expected to be driven by air transport (+400 percent), heavy vehicles (+241 percent) and light-duty vehicles (+123 percent). (Figure 10).

13 This study only takes into account the emissions related to the fuel combustion and not the full cycle of the fuel production.

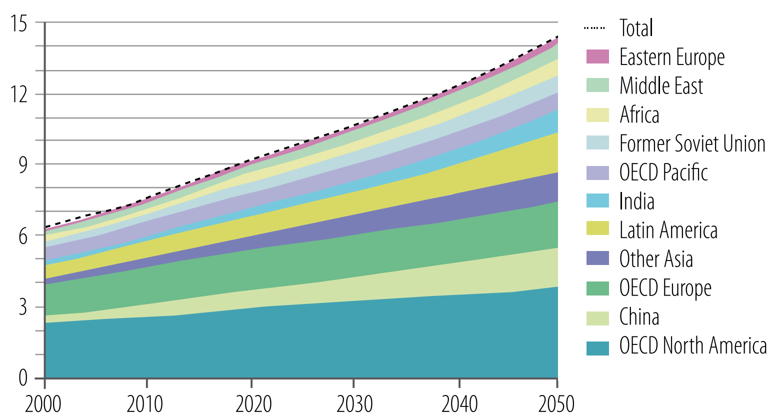
Figure 10 | Gigatonnes CO_2-Equivalent GHG Emissions/Year



Source: World Business Council for Sustainable Development, Mobility Project (2010)

North America and Western Europe are currently responsible for about 70 percent of global transport emissions (Figure 11). However, projected growth rates of transport/emissions are greater for developing countries due to higher rates of motorization related to economic and population growth. By 2050, North America, China and Europe will emit 50 percent of the CO_2 emissions from transport, and Latin America around 10 percent.

Figure 11 | Global emissions of CO_2 in transport, by country or region (gigatonnes)



Source: World Business Council for Sustainable Development, Mobility Project (2010)

According to Colombia's Second National Communication to the UNFCCC (2004), transport accounted for 12.1 percent of its CO_2e emissions. The next sections give an overview of the country's transport sector, focusing on road transport, where most of the growth in energy consumption and emissions has occurred.

A. Public transport

Urban public transport, which represents 65-85 percent of motorized trips, is the most important mode in Colombia's principal cities. However, nationwide, the urban public transport sector has been declining: eg. Public transport ridership decreased in Ibague, the capital of Tolima, at an annual rate of 10 percent from 1997-2004, while in Bogotá, the decline was 4.9 percent a year from 2000-2004. The reason can be attributed to several factors, but a main one has been the low quality of public transport.

In most Colombian cities, public buses are privately-owned, with the municipal government providing approval and oversight. However, a lack of planning and enforcement of regulations has brought many irregularities: eg. Many authorized bus companies have made a business of organizing independent bus owners and charging them a monthly fee. This typically leads to an oversupply of transport providers, traffic congestion, and reduced returns to bus owners. Also, bus companies are allowed to operate old, inefficient buses, resulting in lower quality service, the use of more fuel, and more pollutants than newer fleets.

Low-quality public transport and rising incomes have promoted a modal shift towards motorcycles, private cars, illegal buses and motorcycle taxis. In some cases, these provide more passenger comfort at a lower cost, and with less transit time. Overall, this rapid expansion has increased congestion, energy consumption, and GHG emissions.

Colombia has sought to modernize its public transport system for several years with programs to integrate/organize more efficient/equitable operations. The Transmilenio in Bogotá in 1999 was the beginning of this new approach. As it focused on bus rapid transit (BRT), Transmilenio introduced segregated bus corridors and lanes, large dedicated bus stations, prepaid access, and a modern, efficient fleet of high-capacity buses. The goal was to make public transport more efficient by giving priority to BRT buses and speeding up boarding/leaving. Transmilenio also introduced a new regulatory framework, which allowed the city to control and regulate the service.

Because of its success, Transmilenio expanded throughout Bogotá and prompted six other cities to launch similar systems (Medellín, Pereira, Barranquilla, Bucaramanga, Cartagena and Cali). It also led the government to design/promote a reorganization program especially for smaller cities that is based on Transmilenio's features. Known as Strategic Public Transport Systems (SETP, *Sistemas Estrategicos de Transporte Público*), it is being introduced in 12 small- to medium-sized cities.

Transmilenio's success caused daily ridership to exceed the system's capacity. In 2002, there were 62,000 passengers per hour in both directions (pphpd) during peak hours and the number has risen to 211,000 pphpd. However, due to this excess demand, the system experienced delays, and problems with accessibility and comfort. Thus, Bogotá launched the Integrated Public Transport System (SITP, *Sistema Integrado de Transporte Público*) to integrate all public transport in the Transmilenio system, which will consolidate and expand public transport. The main goal is to modernize the regular fleet of public buses, and in the process reduce the number from approximately 20,000 buses (many are old) to a newer fleet of around 12,000. The city also plans to build a high-capacity subway system to complement the bus system.

If implemented, these initiatives should lead to better accessibility, reduce travel time, and attract passengers away from other modes such as private cars and motorcycles that contribute to congestion, excessive fuel use, and emissions.

B. Cars

Colombia's national statistics administration, DANE, reports that the vehicle fleet in 2009 had 5.8 million units. Over three quarters were motorcycles and cars, followed by pick-up trucks and four-wheel drive vehicles *(camperos)* (14.4 percent). From 2003-2009, automobiles averaged annual growth of 9.2 percent (Research 2010), and in 2011, 327,000 new vehicles were sold—representing the largest number in one year and a 33 percent increase compared to 2010. Negative externalities from auto use on traffic congestion or human health have not been internalized in their operating costs (through road or fuel taxes). Thus, the lack of such externality charges has led to the decline of public transport and also helped spur investments and policies that benefit private automobile users (Figures 12 and 13).

Figure 12 | Composition of fleet, 2009

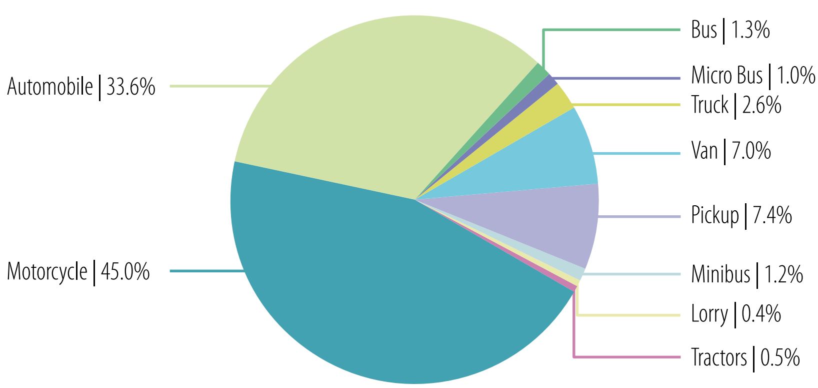
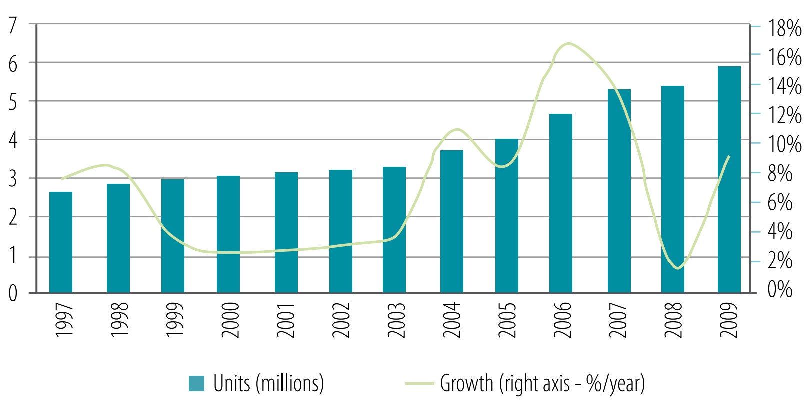


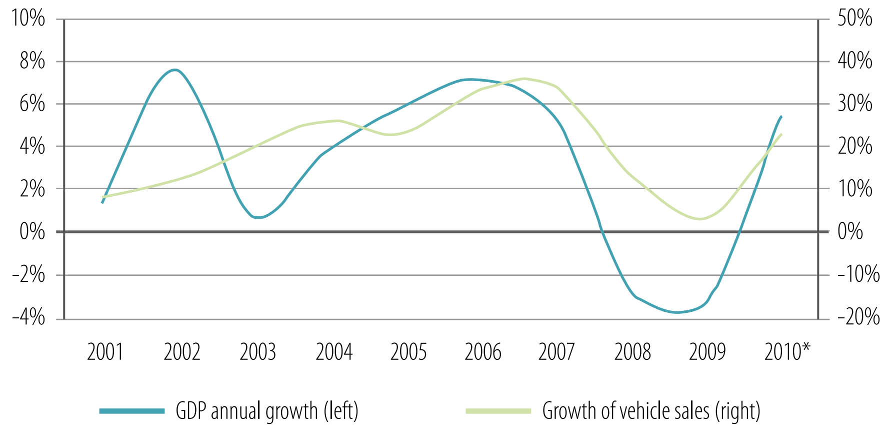
Figure 13 | Evolution of automobile fleet



Source: Ministry of Transportation

The growth of private vehicles over the past decade has been due to population and income growth and the falling real cost of vehicles and their operation. Also, the "pico y placa" program, which began in 1998 and prohibits cars during certain hours and days according to license plate numbers, has indirectly encouraged people to buy second vehicles. A study of the vehicle fleet (Research 2010) indicates that for every one percent increase in per capita GDP, sales of private vehicles increase by about 0.61 percent. This, together with forecasts by the Universidad de los Andes[14] on the rate of GDP growth for the coming years (around 4.1 percent a year from 2012-2020), indicates that private vehicle ownership is expected to rise. The effect of private automobile sales with respect to GDP from 2001–2010 is shown in Figure 14.

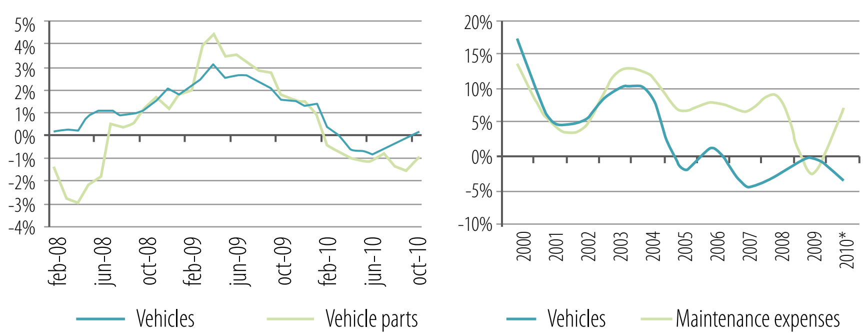
Figure 14 | Growth of vehicle sales and real GDP, 2001–2010



Source: DANE (Departamento Administrativo Nacional de Estadística)

Another factor driving the increase in private automobile sales is the reduced price of the vehicles and their parts. This was mainly caused by the appreciation of the Colombian peso, which directly affects the import of autos and parts.[15] Major trade agreements with the U.S., E.U., and Korea have also contributed to lower vehicle prices through competition and reduced import duties. The historical evolution of prices is shown in Figure 15.

Figure 15 | Variations in producer, consumer prices of vehicles



Source: DIAN (Dirección de Impuestos y Aduanas Nacionales)

14 Calculations by the Universidad de los Andes based on DANE Annual Manufacturing Survey.

15 Peso appreciation is due to the increase in foreign investment that occurred over the past decade, which in turn was prompted by positive factors, such as natural resource endowments, improved national security, and the overall increase in international investor confidence. Projects in the oil and mining sector account for a large share of the FDI (foreign direct investment).

Studies by the Universidad de los Andes (Acevedo 2009) suggest that an expanded private vehicle fleet, all other things equal, will reduce public transport, especially in medium-sized cities. They also estimate that the current 8.6 million public transport trips in Bogotá will increase slightly to 10.6 million in 2020 and then decrease to 7.9 million by 2040, mainly due to low quality transport. In a medium-sized city such as Neiva, the capital of Huila, public transport's share of total transport trips in 2009 was 61 percent.

Although the country has a low motorization rate compared to the rest of Latin America, it is growing rapidly. City growth patterns, land use, and urban planning play critical roles in whether urban transport systems are implemented efficiently. Indeed, many Latin American cities have been growing horizontally rather than vertically, which puts pressure on transport systems. As population grows and incomes rise, people spend disposable income and part of their time to buy a car and live outside the city core, resulting in sprawl. This increases average trip lengths and transport-related energy use. Thus, new or revised regulations regarding city density can greatly affect travel demand. Governments at all levels are considering what type of transport model is best suited. One option being considered is to follow the European model where priority is given to public transport, while limiting the expansion of cities so as to discourage private vehicle ownership and use.

C. Motorcycles

In the last decade, the share of motorcycles in the national vehicle fleet has grown considerably. According to the Ministry of Transport, there are about 4.8 million motorcycles, which represent about 50 percent of the national fleet (including buses and trucks, among other types of vehicles). In 2009, 340,000 units were sold, which rose to 426,000 in 2010, and 530,300 in 2011. This rapid growth is caused both by the population's increased purchasing power and by the low quality of public transport throughout the country. In fact, some motorcycles are illegally used to transport passengers at a lower fare than regular buses. In some cities, mostly in the Caribbean area, the share of trips by illegal motorcycles is as high as 47 percent (Sincelejo, Sucre). This creates problems for implementing public transport systems such as SETP.

To control the motorcycle market, Bogotá passed a law in 2009 to gradually phase out two-stroke motorcycles since they burn lubricating oils in the fuel mixture, which emit large amounts of fine particulates, and are noisy, among other negative aspects. Two-stroke engines have been banned in some Asian developing country cities, where they contributed a disproportionately large amount to urban air pollution. In the U.S., motorcycle manufacturers began switching from 2-stroke to 4-stroke engines in 1978, so as to comply with emission standards; Japan and European countries continued the trend. However, Colombian owners of 2-stroke motorcycles have reacted strongly against the measure and managed to delay the ban.

D. Non-motorized transport (NMT)

In Bogotá and other cities, non-motorized transport (NMT) infrastructure began to improve in 1998. NMT systems have mainly been developed for bicyclists and pedestrians with the aim of improving mobility and discouraging car and motorcycle use. In the main cities, pedestrian and bicycle trips account for about 17 percent of total trips.[16]

16 "Plan Maestro de Ciclorutas"

Thousands of meters of sidewalks have been built or renovated, both for pedestrians and serving as the main access to BRT systems and buses--thus benefiting public transport. If sidewalks are clean, safe and adequately lit, they encourage walking and replace many short trips that would otherwise be by motorized transport. Studies show that the highest percent of walking trips are a few blocks up to 2.5 kilometers.

Bogotá has 344 km of bicycle paths that are used by 300,000 people daily. However, the network of paths has not expanded as was envisioned in the master plan over the last eight years. Besides this problem, the paths are not well maintained, and the growth rate of bicycle users has stagnated in recent years.

Despite this problem, the bicycle is still an important urban transport mode. A recent innovation is the pedicab or "bicitaxi" for short travel distances that has become a popular feeder and connection option for Transmilenio. In 2004, there were 450 bicitaxis in areas close to Transmilenio. Since then, pedicabs have gradually increased, particularly in low-traffic zones where public transport does not provide service. Currently, an estimated 5,500 pedicabs operate in areas with poor or no public transport. Although they are technically not a legal mode of transport in Bogotá, they are a popular, efficient form of transport and complement the BRT.

E. Freight transport

Roads are the most important mode of freight transport, accounting for 64 percent of the total. Railways are second, with 33 percent, followed by waterways, with 3 percent.[17] Trucks[18] carry a range of products, while trains mostly transport coal from mines in the north to ports on the Caribbean Coast. Colombia's trucks are an average of 19 years old,[19] compared to an average of 13 years in Mexico in 2010[20] and 16 years in Brazil.[21] The advanced age affects optimum performance in terms of fuel consumption and emissions. The fleet's old age is partly due to weak or non-existent institutions for ensuring safety and environmental performance. Their low performance—high maintenance costs, fuel consumption, and accident rates—reduces freight transport competitiveness and imposes other social costs on the country. As the economy grows, the efficiency of the freight sector must be improved through new strategies and policies, such as education and training programs, as well as stricter licensing, inspection and maintenance: eg. Due to a lack of economic tools and government incentives, trailers go empty 19 percent of the time.[22] This creates an opportunity to improve the efficiency of freight transport and reduce energy consumption and GHG emissions.

To move large amounts of freight long distances, railways are the most efficient mode. Rail fares can also be three to four times cheaper than trucking rates.[23] Despite these advantages, Colombia's railways are used almost exclusively by the coal industry—although there are two main freight demand corridors between the center of the country and coastal ports that could be well served by railways. A key constraint has been the lack of public or private financing of the infrastructure, which in turn requires a clear policy and plan for development.

For its part, water transport is extremely underused, although there are 4,200 navigable km of rivers, some located near important freight corridors. Also, waterways could reduce fares up to 12 times cheaper than truck transport. A large expansion of waterway transport would appear attractive, however there are a lack of feasibility studies, assessments, and implementable plans to extend navigable water routes.

17 "Los modos de transporte en Colombia", http://godues.wordpress.com/2007/11/13/los-modos-de-transporte-en-colombia/

18 Decree 4,100 from 2004 governs the size and load limits for transport vehicles in Colombia (Regulación 4100 de 2004, Ministerio de Transporte).

19 Ministry of Transport

20 Fleet Alliance (Alianza Flotillera), Mexico

21 National Ground Transport Agency of Brazil (Agência Nacional de Transporte Terreste do Brasil ,ANNT)

22 Observatorio de carga, 2009, Ministry of Transport

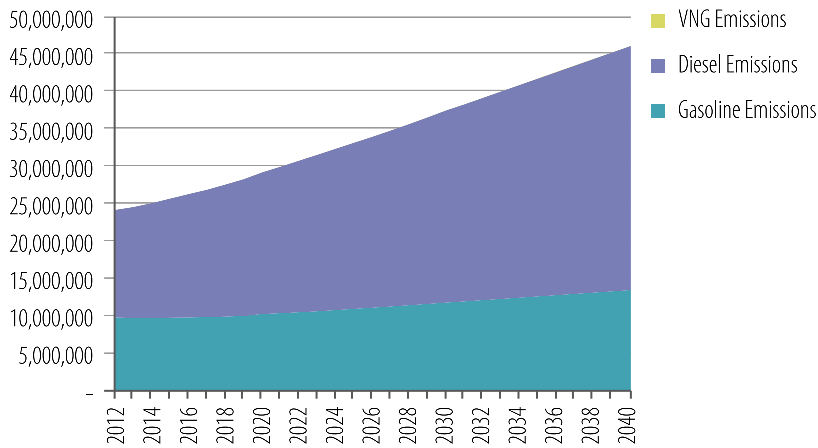
23 Ministry of Transport

2. Baseline Analysis

In 2010, UPME prepared scenarios of transport fuel consumption (gasoline, diesel, and vehicular natural gas (VNG)) from 2009-2030. Under a "moderate scenario," gasoline consumption in 2030 would be about 95,000 BPD (barrels a day), diesel would be 202,000 BPD, and VNG would be 197 MCFD. This corresponds to an annual average fuel consumption growth of 2.5 percent until 2030. If the same growth rate extended to 2040, consumption would reach 110,000 BPD of gasoline, 250,000 BPD of diesel, and 245 MCFD of VNG.

Based on these projections, the associated CO_2 emissions would increase from 24.2 million tons in 2012 to 46 million tons in 2040. The growth would be driven mainly by diesel, whose consumption and emissions would increase by 127 percent. This scenario was used as the baseline for national road transport emissions (Figure 16).

Figure 16 | Baseline tCO_2 emissions in the transport sector (tons)



Source: Authors based on Forecasts of Fuel Consumption in Colombia, UPME 2009–2030

3. Low-Carbon Measures

This section describes the results of an analysis of various ongoing and potential low-carbon measures with respect to public, private and freight transport. Many of the measures to reduce transport energy use and emissions involve changes in equipment or technology, such as replacing vehicle fleets with cleaner and more efficient vehicles. In public transport, emissions could be reduced by lower fuel consumption gained from transferring the same or greater transport demand (passengers or trips) to a smaller number of larger, more efficient vehicles. However, other benefits can be achieved by moving part of the demand from one mode to another, such as from private automobiles to BRT or subways, or from private freight trucks to rail. The study also evaluated a practice known as "congestion charges" that some countries and cities have adopted to manage demand for private transport: It involves charging vehicle owners a price to drive in congested areas or during peak hours, which (a) results in fewer trips, (b) shifts demand to more efficient modes, or (c) moves the trip time to off-peak hours. Several other measures with significant potential were not considered due to the lack of information, such as expanding freight transport on the Magdalena and Meta Rivers.

A. Public transport

The analysis of urban public transport focused on four strategies to optimize and reorganize mass public transport in Colombia's cities. They included:

- Bogotá Integrated Public Transportation (*Sistema Integrado de Transporte Público de Bogotá,* SITP)
- Bus rapid transit (BRT) in five capital cities
- Strategic public transport (*Sistemas Estratégicos de Transporte Público,* SETP) in six medium-sized cities with populations of 256,000-600,000
- A Bogotá metro

The first three strategies evaluated the extent of reduced emissions under a baseline scenario using diesel buses, and compared the use of electric and hybrid bus technologies, while the Bogotá metro was evaluated assuming the trains would run on electricity.[24]

(1) Bogotá Integrated public transport system *(Sistema Integrado de Transporte Público, SITP)*

The objective of the SITP is to reorganize the supply of public transport in a way that satisfies demand but uses fewer buses. The SITP would replace "road infighting among drivers for passengers" on the main transport corridors, and better regulate the frequency/number of buses on a given route, thus lowering costs and reducing congestion. It would be merged with the bus rapid transit system (BRT) for Bogotá, Transmilenio, creating an integrated public transport system. When completed in 2018, SITP would also incorporate the new Bogotá metro.

Without the SITP, Bogotá would continue to provide public transport with its fleet of about 20,000 buses. Besides having to comply with basic safety measures, the current bus fleet is not subject to any regulations and in its current state would contribute 1.8 million tons of CO_2 emissions in 2040. However, under the SITP, the number of traditional buses would be reduced to 12,000 and their useful life limited to 10 years. When the two are combined—reducing the fleet and providing more efficient service—the kilometers traveled per vehicle would be lowered, further reducing diesel consumption and GHG emissions.

Even more emissions would be reduced if there was a modal shift, eg. as trips by light-duty vehicles move to the SITP system. The reduced diesel consumption would also help lower the local air pollutants such as CO, SOx, NOx and PM, thus generating even more benefits. The program is calculated to reduce CO_2 emissions from public transport by 44 percent, or 1.2 million tons reduced by 2040 (2.6 percent of total transport emissions - TTE).

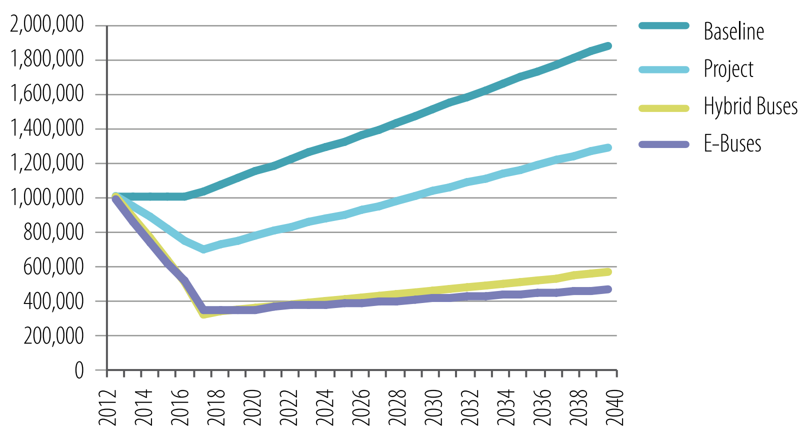
The SITP will need significant amounts of public investment in infrastructure and private investment to renew the bus fleet and modernize fare collection systems. These investments would reduce operating costs because of lower maintenance and labor expenses; also, they

24 Electricity emissions factor: 0.2849 CO_2 kg per Kwh, Decree 180947 June, 2010

would reduce energy costs from the decrease in fuel consumption. These savings would provide large financial and economic benefits, the net present value of which was found to be US$3.3 billion, not including two other benefits—reduced air pollution damages and health care costs due to lower particulate matter emissions. These two are the result of the savings in travel times related to making the cities' public transport more efficient. When these are totaled, the net cost of reducing a ton of CO_2 by the SITP intervention falls from negative US$262 to negative US$421.

The SITP was evaluated using various cleaner vehicle technologies, along with the standard diesel buses in the baseline. In the alternative scenarios, it was assumed that 60 percent of the diesel fleet would be converted to electric and hybrid buses. Compared to the baseline, this reduced CO_2 by 66 percent by 2040, if electric buses were used, and by 57 percent, if the buses were hybrid. The movement of CO_2 emissions from the baseline and the different SITP scenarios is shown in Figure 17.

Figure 17 | CO_2 emissions reduced by the SITP



Source: Authors

The cost per reduced ton of CO_2 in the SITP, including the joint benefits from use of electric buses is negative US$953, while with the use of hybrids, the cost is negative US$682.

(2) Bus rapid transit (BRT)

Bus rapid transit (BRT) systems replace traditional systems with high-capacity, more efficient buses at a fraction of the cost of expensive urban rail systems. They have many of the same efficiency aspects—pre-boarding fare collection, segregated bus lanes, platform-level boarding, stations in the median of the road with passing lanes at stations, and a centralized control center for locating buses and regulating operations. Given their affordability and flexibility when compared to rail, they have become a preferred transport option around the world.

BRT programs are currently in five of Colombia's capital cities: Medellin, Cali, Barranquilla, Cartagena, and Pereira. The program includes constructing 447 km of exclusive lanes, of which 282 km are completed and in use.

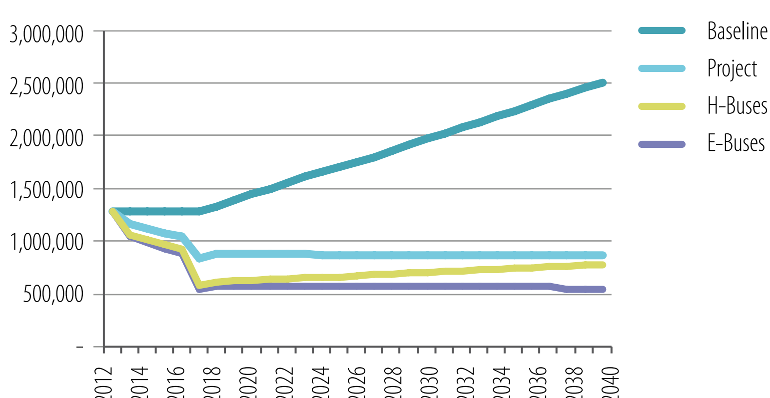
As with other public transport options, BRTs make it possible to reduce the kilometers traveled per vehicle, thus saving fuel, which, in turn, reduces carbon emissions and local pollutants. The system also reduces energy consumption. First, it meets transport demand with a more efficient system that requires fewer large-capacity vehicles. Second, it shifts a portion of overall trips from less efficient motorized modes to BRT. Under the baseline scenario, CO_2 emissions from public transport in the five cities would total nearly 2.5 million tons by 2040 (5.43 percent of TTE). Once the BRT system is completed (over three years), the amount of CO_2 that would be reduced would be 1.65 million tons a year in 2040 (3.6 percent of TTE).

To implement the BRT systems, public investments are needed for physical infrastructure for stations, road improvements and segregated lanes; private investments will also be needed to purchase buses and fare collection systems, and to manage/control the fleet. BRT is most effective when it is part of an integrated, broad urban plan that includes managing travel demand, road pricing, parking, and NMT. The investments would significantly reduce overall operating costs due to decreased maintenance and labor expenditures, and lower energy costs from decreased fuel consumption. The cost-benefit analysis found the BRT programs to be economic in all five cities; the average cost to reduce a ton of CO_2 would be negative US$142.

The BRT programs would generate other benefits such as (a) increased productivity due to savings in travel time and gains in accessibility, (b) safer roads and facilities, (c) decreased health costs due to the reduced emissions of particulate matter, and (d) reduced accidents and their costs. When these benefits are added, the average cost drops to negative US$169 per ton of CO_2.

As with the SITP, cleaner bus technologies were introduced to the BRT program to assess the potential to reduce even more emissions.[25] If 60 percent of the buses used in Cartagena, Medellin, Cali, Barranquilla and Pereira were electric, this would reduce CO_2 emissions by another 36 percent by 2040, when compared to using diesel buses. If the BRT used 60 percent hybrid buses in the five cities, this would reduce emissions by 10 percent, compared to the baseline. Figure 18 shows the difference in CO_2 emissions using the different bus technologies.

Figure 18 | CO_2 emissions through BRT



Source: Authors

25 The evaluation of cleaner technologies assumed that 60 percent of the diesel fleet would be converted to electric or hybrid buses. The remaining 40 percent would still be diesel.

(3) Strategic public transport systems *(Sistemas Estratégicos de Transporte Público, SETP)*

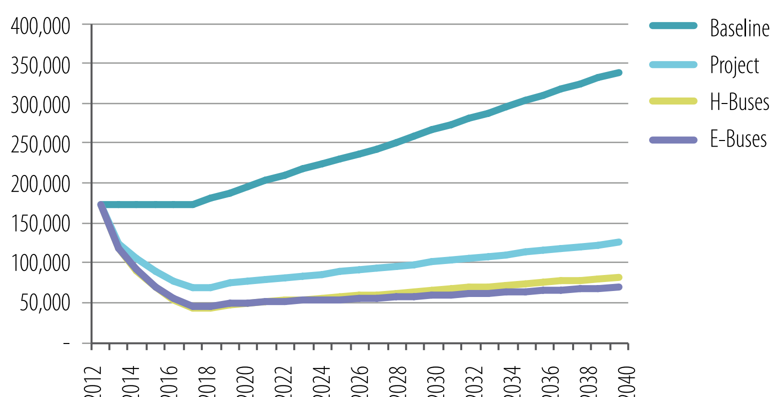
SETP aims to improve existing public transport in medium-sized cities (with 250,000 to 600,000 inhabitants) by optimizing the supply of vehicles and related systems. Its measures include introducing a unified fare-collection system, synchronizing the traffic light network, traffic and transportation information controls, transfer terminals, changing bus stops, and carrying out road construction and maintenance. All components would help reduce the total kilometers traveled by the fleet, as well as GHG emissions associated with fuel consumption.

The first medium-sized cities selected for the SETP were Armenia, Pasto, Popayan, Sincelejo, Santa Marta, Monteria, Valledupar, Manizales, Ibague, Neiva, Villavicencio and Buenaventura. Of these, the first six have already developed plans, which the study analyzed.

Public works under the SETP would include constructing new roads, bridges, transfer areas and dispatch centers, rehabilitating existing roads, installing road signs and traffic lights, and carrying out complementary works in historic centers and public space. Private investments will be needed to purchase buses, fare collection equipment and fleet management systems. Under the baseline without SETP, CO_2 emissions in the six cities would reach about 339,000 tons in 2040. With the SETP, annual CO_2 emissions would be reduced by 63 percent. In absolute terms, the six city SETP would result in average emissions reductions of about 125,000 tons a year (0.27 percent of TTE).

Other benefits include reduced particulate matter, decreased accidents, and increased human productivity stemming from reduced travel times, which would yield an average negative cost per ton of CO_2 of US$98; without them, the cost is negative US$42. Running hybrid buses would reduce CO_2 emissions by 35 percent in 2040, while running electric would reduce them by 45 percent, when compared to diesel buses. Figure 19 shows the CO_2 emissions under the various SETP options for the six cities.

Figure 19 | CO_2 emissions SETP



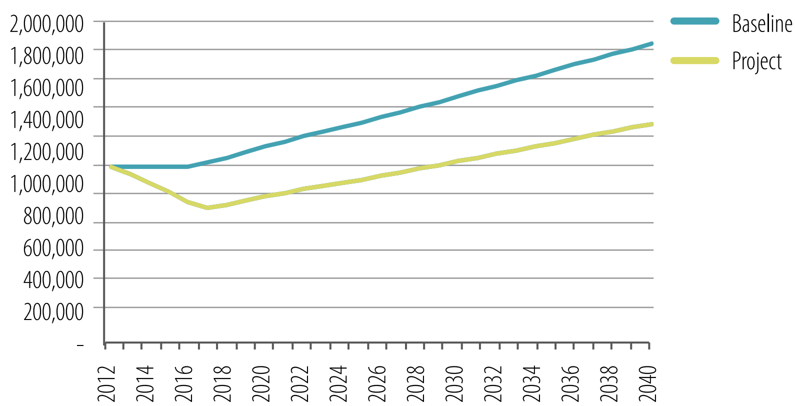
Source: Authors

(4) Bogotá metro

The Bogotá metro is intended to serve the city's eastern corridor with a high-capacity rail system that can transport up to 80,000 passengers an hour in each direction. Based on the design studies, the first metro line of 29 km would begin operating in 2018, connect the southwestern part of the city with the historic center, and then run to the northern part. The estimated cost would be about US$2.2 billion.

The metro will lower carbon emissions by reducing the kilometers traveled, which would save fuel when (a) redundant buses (those travelling the same routes) would be withdrawn from the transport system and (b) a portion of automobile drivers shift to the metro. In fact, it is expected to replace car and taxi trips to a greater extent than the BRT or SITP bus systems. Without the metro in Bogotá, and assuming the entire bus fleet continues to use fossil fuels, CO_2 emissions from public transport (including phases I and II of TransMilenio but not the full SITP), are estimated to total 1.8 million tons in 2040. With the metro, CO_2 emissions would drop to about 1.3 million tons.

Figure 20 | CO_2 emissions from a Bogotá metro system



Source: Authors

The metro will need significant amounts of investment in infrastructure such as tunnels, tracks, stations, and trains. However, these investments will ultimately reduce costs, mainly because the metro will consume less fuel than buses. However, the decreased costs (benefits) are not sufficient to outweigh the high cost of infrastructure and other investments. Thus, a simple cost-benefit analysis without including other benefits shows the program is not economic, with a positive cost of reducing CO_2 of US$260 per ton.

However, when the other benefits are considered—as with the other transport schemes, these include reduced particulate matter emissions, increased productivity from savings in trip times, and decreased accidents—the cost of reducing a ton of CO_2 is considerably less, but is still positive at US$97.

B. Private transport

The private passenger transport analysis examined the following: (a) gradually replacing gasoline-powered vehicles with electric vehicles nationwide, (b) introducing a congestion charging program for Bogotá, and (c) improving non-motorized transport (NMT)infrastructure.

(1) Battery electric vehicles (BEVs)

The main difference between a battery electric vehicle (BEV) and a traditional auto is that instead of having an internal combustion engine, it runs on an electric motor. As such, they produce benefits for private passenger transport: The two most important are lower fuel and operating costs and zero direct emissions of pollutants such as PM, NO_X, and VOCs. The distinct advantage for Colombia is that most electricity is domestically produced and clean, with an average of about 70 percent produced from hydropower.[26] The low emission factor for electricity results in the overall emissions from BEVs being much lower per km than internal combustion vehicles.[27] Three variables have a significant effect on the cost-benefit analysis: the cost of infrastructure, vehicles and market penetration.

a. Infrastructure

The main infrastructure needed for BEVs is the equipment to recharge batteries away from the home base. This requires added investment that must be considered during the economic analysis. Most important are the slow-charge points to be installed in public and institutional settings (such as commercial stations, and places in institutional facilities such as office buildings and parking garages). The cost of these points are normally paid by vehicle owners and can be installed in their residences, offices, or other parking places; however, other public charging points are needed to support a growing BEV market. With current technology, a BEV needs about eight hours to be fully recharged. The cost of slow-charge points is around US$4,000, including installation. Second, fast-charge points would be located in strategic places in cities and along highways to charge up to 80 percent of the battery's capacity in about 30 minutes. These points cost around US$30,000 a unit, and presumably could be operated on a market basis once there is a critical mass of BEVs. As battery and recharging technology changes, and as economies of scale develop, these costs are likely to drop. However, the foregoing cost estimates were the ones used for the analysis.

b. Vehicle costs

BEVs are more expensive than gasoline-fueled vehicles, mainly due to the high cost of batteries compared with a typical internal combustion engine. Also, only a small number of companies produce them. However, their number has been increasing rapidly worldwide in the past five years, and competition will continue to grow as the market expands. Part of the current problem is that BEV manufacturers are targeting only a few markets, such as California and others in industrial countries, making it difficult for countries such as Colombia to acquire BEV technology. Further, at the beginning, all BEVs would need to be imported, which would have macroeconomic effects (see Chapter 5). Still, prices are expected to drop as battery technology improves and more manufacturers enter the market. For the analysis, it was assumed all BEVs would be imported.

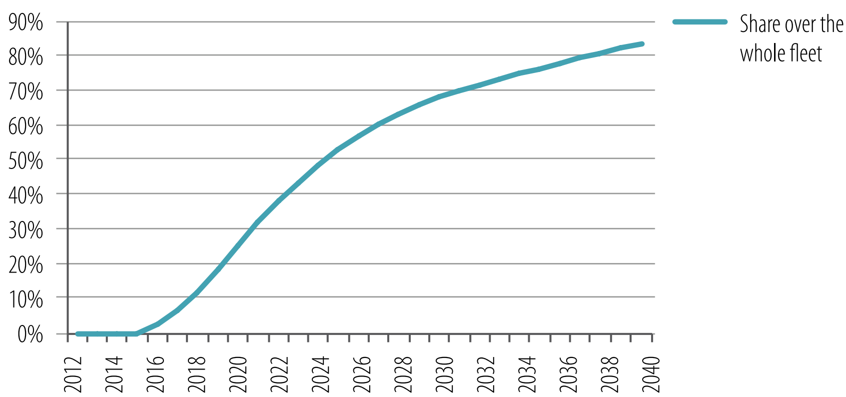
26 CO_2 emission parameters in the generation of hydro-based electricity: 0.2849 kg/Kwh (Resolution 180947 dated July 4, 2010).

27 BEVs generate 0.230tCO_2e/MJ (when using coal to generate electricity), compared to 0.160tCO_2/MJ for light-duty vehicles with gasoline engines.

c. Market penetration

Different scenarios were analyzed with regard to BEVs in the national market; these significantly affect the overall results. After discussions with Colombian transport officials and experts, it was agreed to assess the effect of a high penetration rate of BEVs. A scenario was designed in which electric cars steadily enter the market until achieving a penetration rate of 84 percent and a 90 percent share in new vehicle sales in 2040. This aggressive growth assumes a combination of incentives and policies that will encourage vehicle owners to shift to BEVs (Figure 21).

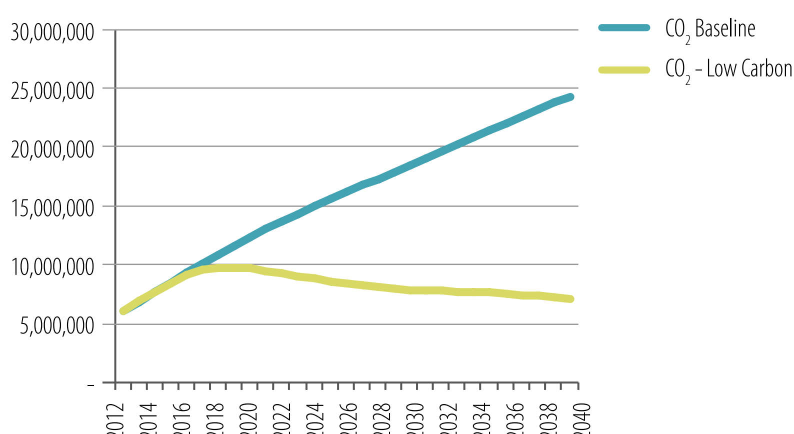
Figure 21 | Electric cars' share in national market, 2012–2040



Source: Authors

During this period, the BEVs would reduce cumulative CO_2 emissions by 221 million tons and annually reduce them in 2040 by 17.3 million tons (37.65 percent of TTE). The complete series of emissions under the baseline and "with-project" scenarios is presented in Figure 22.

Figure 22 | CO_2 emissions in the electric vehicle scenario



Source: Authors

Introducing BEVs will require large investments, both for electrical charging infrastructure and for purchasing vehicles. However, savings in operating the BEVs, especially related to the lower costs of energy used (electricity vs. gasoline) will provide both private and public benefits: The analysis calculated that the net cost to reduce a ton of CO_2 would be US$59 based on current technology costs for vehicles and charging stations (significantly less than the Bogotá metro).

(2) Congestion charging in Bogotá

Bogotá has already introduced some traffic restrictions for private vehicles that prohibit owners from driving their cars in the city two days a week from 6 a.m. to 8 p.m. The system is based on the last digit of the owner's license plate ("pico y placa"). Nevertheless, the motorization rate and congestion has continued to rise, in part through the purchase of second cars (with different license plate numbers) and motorcycles (which are not subject to the *pico y placa program*). One possible measure to counter the difficulties arising from *pico y placa* is to introduce a true congestion-charging program, whose purpose is to discourage vehicle traffic in certain parts of the city by levying a fee to allow vehicles to circulate on specific days and times.

Singapore (1975), London (2003) and Stockholm (2006) introduced similar congestion charging programs, generally in the city centers: Users of private vehicles have to pay a fee to drive in these zones during certain days and hours, usually with a higher fee during rush hours. As a result, CO_2 emissions were reduced by 19.5 percent[28] in London and 18 percent[29] in Stockholm.

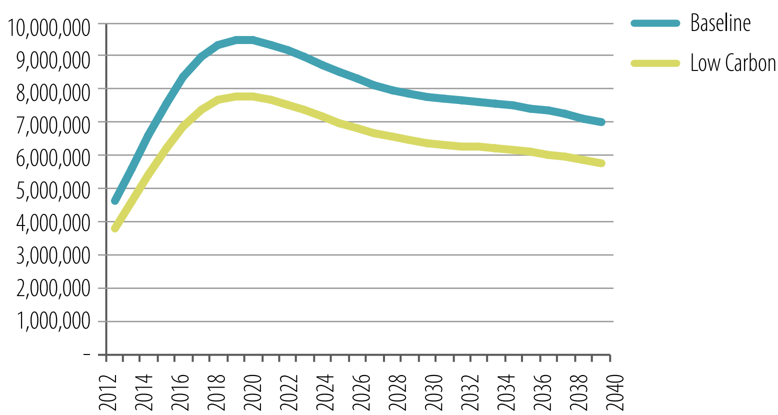
The analysis examined investments in technology, which include reader antennas and cameras at entry points, plus an identification chip for each vehicle. It also looked at the operating costs to run the system. Since the program generates revenues from congestion fees and penalties, operating costs drop due to less traffic and lower vehicle use (since it would cost owners more to drive). However, the program needs to coordinate with public transport systems so drivers who leave their cars at home have alternative ways to travel.

Introducing congestion charging is separate from the issue of electric vehicles. However, once they are marketed, BEVs would dramatically change the baseline scenario for congestion charging. So as not to overestimate the potential reductions of GHG from private vehicle interventions, the congestion charging analysis assumes that BEVs will also be introduced. Congestion charges would reduce cummulative emissions of 41 million tons of CO_2 over the period (Figure 23).

28 Sean D. Beevers, David C. Carslow, 2004, "The impact of congestion charging on vehicle emissions in London".

29 Michael Graham Richards, Treehugger, 2009, "Congestion Charge Cuts Waiting Time 50% and CO2 by 18 percent in Stockholm"

Figure 23 | CO_2 emissions based on congestion charging in Bogotá



Source: Authors

The savings in operating costs for private vehicles are greater than the costs of the congestion charging program, mainly due to reduced fuel and maintenance costs. Overall, the program is economic, yielding a value per ton of CO_2 reduced of negative US$239.

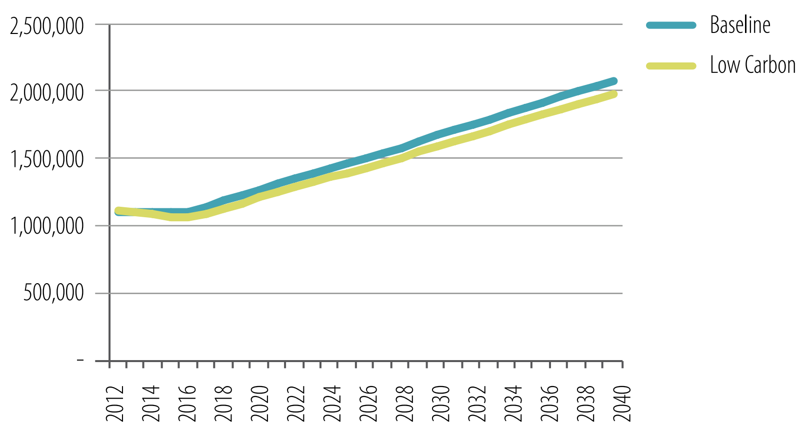
C. Non-motorized transport (NMT)

Bogotá has 344 km of cycle paths on which riders make about 300,000 trips a day. Its Master Plan for Bike Routes (PMC, *Plan Maestro de Ciclorrutas*) aims to expand the path by 40 km, which would create another 140,000 trips.[30] 90 percent would be at the expense of public transport, 5 percent from private (individual) vehicles, and the remaining 5 percent from other transport modes. The increased bicycle trips would reduce fossil fuel consumption and GHG emissions and other air pollutants (Figure 24). The measure will require public funds to construct and maintain bikeways, and private investment to purchase bicycles and helmets (their use is mandatory). These investments would reduce fuel and operating costs due to fewer motorized trips. Overall, the measure is economic, with a cost per ton of CO_2 reduced of negative US$62.

Another benefit is increased productivity due to reduced trip times, lower health expenditures from decreased particulate matter emissions, and lower occurrence of certain illnesses due to increased physical activity, such as cardiovascular problems, diabetes, obesity, hypertension and some cancers. When the analysis includes these benefits, the cost per reduced ton of CO_2 is negative US$220.

30 "Plan Maestro de Ciclo-rutas", Instituto de Desarrollo Urbano 1998, Consorcio Proyecto e Interdiseños

Figure 24 | CO_2 emissions from non-motorized transport



Source: Authors

D. Freight transport

Four freight transport schemes were analyzed: (a) renewing the truck fleet, (b) introducing a rail line that extends from the center of the country to the Atlantic Coast, (c) improving aerodynamics, and (d) improving driving techniques. It was found that GHG emissions can be reduced in this sector without limiting its economic activity. Decreased vehicle activity, together with increased productivity (ton-km) can be achieved with certain policies and adequate investment.

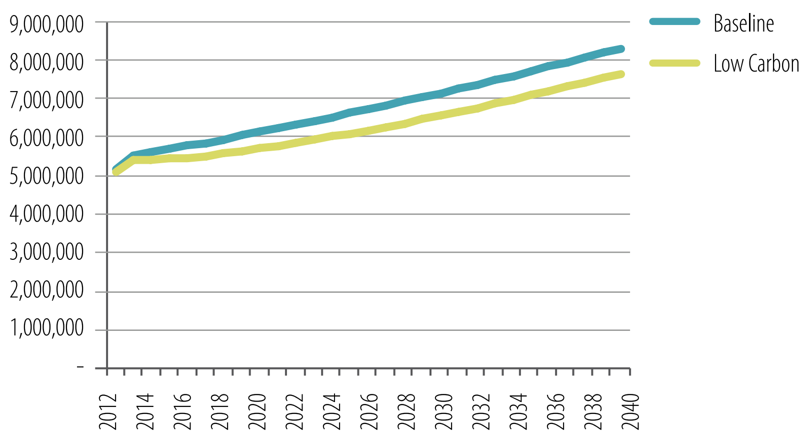
(1) Renewal of freight vehicles

As noted earlier, the freight fleet is old compared to other countries in the region. This causes (a) high levels of fuel use, GHG emissions, and local pollutants, and (b) high accident rates. These effects are compounded by the relatively low capacity of the fleet, which creates the need for more trips to haul the same quantity of freight. Other problems are the lack of (a) intermodal freight infrastructure, (b) efficient logistics, and (c) regulations, such as on weight and trailer size, that would promote a more productive freight sector. The high accident rate is related to poor roads, lack of divided highways, and sharp turning angles that, when combined with older and poorly maintained vehicles, lead to deadly outcomes.

To address this situation, the Ministry of Transportation (MoT) introduced a subsidy program for the owners of the oldest vehicles who agree to give them up, cancel their registration, and effectively withdraw them from the market. The idea is that owners can use this subsidy to help buy new vehicles. According to the newspaper *El Colombiano*, the program was able to remove 5,334 trucks during the first seven years (2005-2012). And, as it continues, the fleet will ultimately be modernized. With greater efficiency and fewer repairs, benefits include reducing GHG emissions, along with achieving better highway safety, higher levels of customer service, and lower operating costs.

This program will reduce accumulated emissions of 8 million tons of CO_2 from 2012-2040 compared to the baseline (0.8 percent of TTE). By 2040, there would be an annual difference of 656,000 tons of emissions between the scenarios (the baseline scenario has a natural replacement of vehicles but with the subsidies, the replacement rate rises). The difference in emissions between both scenarios is shown in the following graph.

Figure 25 | CO_2 emissions when old trucks are removed



Source: Authors

Under the program, nearly 158,000 trucks (about 60 percent of the baseline number) would be replaced over 28 years, with the fleet's average age decreasing from 19 to 15 years. In financial terms, the vehicle upgrade represents a large investment for the owners, which in turn means a long payback period despite the savings in operating costs from greater fuel efficiency. The cost of the measure is US$202 per reduced ton of CO_2.

(2) Railway freight transport

Railways are considered key to the government's economic and environmental program. The MoT is promoting the expansion/consolidation of a freight network that will connect the country's center with the Atlantic Coast, based on the Central Railway System, which will be renovated and add a new 912 km line on that corrider. This will be especially important for exporting coal from mines in Boyacá and Cundinamarca. The corridor should be operating in 2022 (Figure 26).

Figure 26 | Current and future railway routes

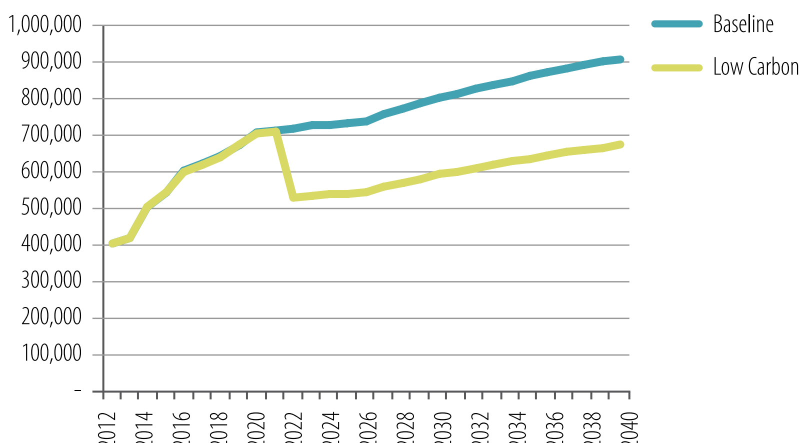
Solid lines: Current railway
Dotted lines: Railway sections to be built

Source: Ministry of Transportation

Thus, coal that is now carried on highways would be transported by rail: Based on current government and industry forecasts,[31] this translates into an estimated 10 million tons at the outset of the program and growing to 25 million tons in 2040. If the project does not materialize, the large increase in coal will continue to be hauled by trucks.

CO_2 emissions will be reduced mainly because trains use less fuel than trucks to carry the same quantities. Based on the railway's full use, cumulative CO_2 emissions would be reduced by 4 million tons during the period; by 2040, the annual difference in emissions between the measure and baseline scenarios (0.5 percent of TTE) would be 235,000 tCO_2. (Figure 27).

Figure 27 | CO_2 emissions in a shift from highways to rail



Source: Authors

31 INCOPLAN and SUMATORIA, 2008.

Railway transport also lowers operating costs due to the decrease in maintenance and fuel expenses. However, the cost of constructing the railway and purchasing rolling stock requires large investments that are higher than the above-mentioned savings. Thus, the net cost of carbon reduction is US$300 per tCO_2.

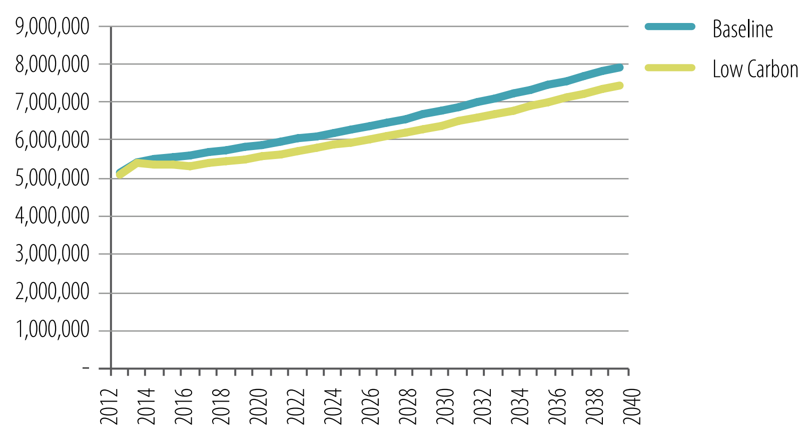
(3) Aerodynamic improvements

For freight that is transported by truck, aerodynamic drag is a major cause of energy loss at highway speeds. However, when the route is longer and the speed is higher, there is greater potential for fuel efficiency— by reducing aerodynamic drag.

The United States has a public-private program called SmartWay,[32] which helps freight carriers and logistics companies improve fuel efficiency; one measure is improving the aerodynamics to reduce fuel consumption.

The analysis examines the impact on fuel use and CO_2 emissions of installing an air deflector on the roof of the cabin; this is a device that reduces the space between the tractor and the trailer, and an aerodynamic bumper that reduces air flow under the truck. In the U.S., SmartWay estimated that as a result, fuel use was reduced by about 11 percent. In Colombia, due to geography, infrastructure and highway speed restrictions (80 km/hour), it is not expected that fuel reductions will be as high. Thus, it estimated that these would be about half that of the U.S., or about 6 percent. If introduced, the program could reduce CO_2 by 10.5 million tons from introduction to 2040. By 2040, it is expected that CO_2 would be reduced by about 475,000 tons each year (1 percent of TTE). See Figure 28.

Figure 28 | CO_2 emissions – aerodynamic improvements in freight vehicles



Source: Authors

Based on the economic analysis, the major fuel savings from aerodynamic improvements exceed the cost of their installation over the long term. While the CO_2 savings are modest, the aerodynamic program is clearly economic with a net cost of carbon reduction of negative US$98 per ton of CO_2.

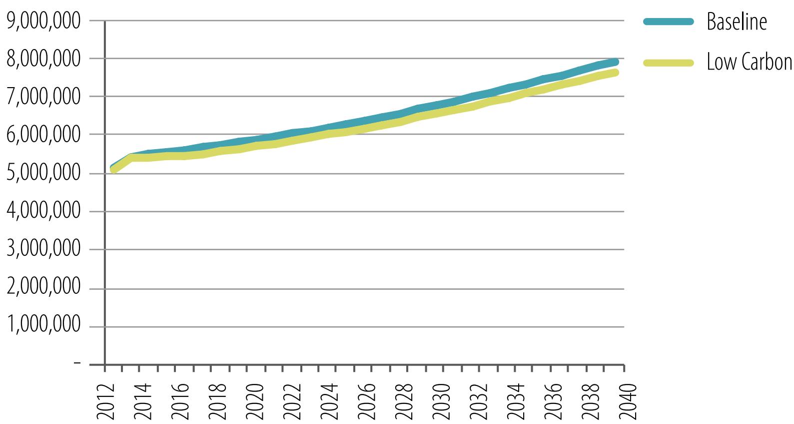
32 http://www.epa.gov/smartway/ "Smart Way".

(4) Improved driving techniques

It is thought that by teaching truck drivers better driving techniques, this could reduce both fuel consumption and CO_2 emissions. SmartWay[33] runs a course of 12 sessions promoting good driving habits, such as maintaining constant speeds when possible, avoiding rapid acceleration/deceleration, and minimizing the time engines operate at high revolutions per minute (RPMs). SmartWay estimated the program has caused a 5 percent decrease in fuel consumption.

Since Colombia's terrain is generally more mountainous than that in the U.S. and highway congestion is also greater, it is expected that driver training could generate even greater fuel efficiency than in the U.S. It is thus assumed that fuel consumption could be reduced by up to 7 percent. The measure assumes that about 200,000 freight truck drivers (half of the total) would participate. This would reduce 6.2 million tons of CO_2 from introduction to 2040 (0.62 of TTE) and by 2040, about 280,000 tons of CO_2 would be reduced a year (see Figure 29).

Figure 29 | Emissions of CO_2 – improvements in freight vehicle driving techniques



Source: Authors

The economic analysis shows that savings from decreased fuel consumption greatly exceeds the training costs, and creates a negative cost per ton of reducing CO_2 of US$158. For transport firms, the program could save a great deal on fuel costs.

E. Summary of measures

Table 6 summarizes the principal low-carbon transport programs.

33 http://www.epa.gov/smartway/ "Smart Way"

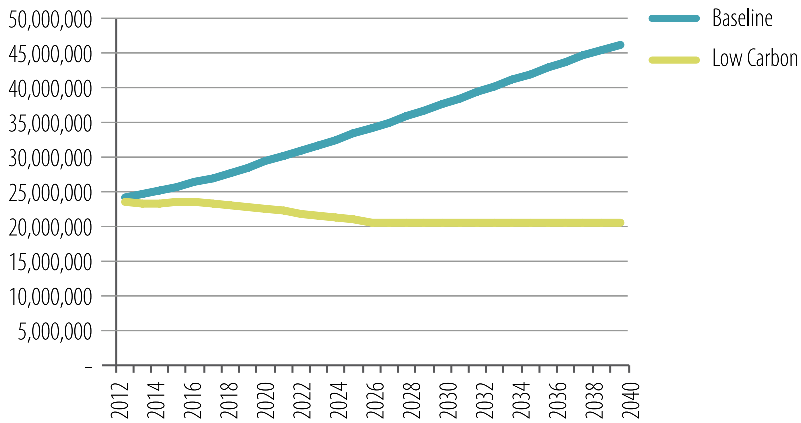
Table 6 | Summary of programs

Intervention Group	Project	Economic NPV without co-benefits (US$)	Economic NPV with co-benefits (US$)	Total CO_2 reduced (tons)	Cost per tCO_2 without co-benefits (US$)	Cost per tCO_2 with co-benefits (US$)
Private passenger transport	Battery Electric Vehicles	13,059,158,421	13,059,158,421	221,167,332	59	59
	Congestion Charging	-19,287,774,458	-19,287,774,458	41,088,643	-413	-413
Freight Transport	Truck Scrapping	1,597,546,908	1,235,602,061	7,921,526	202	156
	Aerodynamic improvements for trucks	-1,026,770,940	-1,026,770,940	14,114,956	-98	-98
	Driving techniques for trucks	-924,898,664	-924,898,664	6,193,430	-149	-149
	Railway	1,198,206,724	1,089,582,669	3,988,379	300	273
Urban Public Transport	SITP - Diesel	-748,930,269	-1,203,948,442	11,687,778	-262	-421
	SITP - Electric	-3,184,226,491	-4,520,597,202	25,604,054	-671	-953
	SITP - Hybrid	-3,131,919,930	-4,420,094,667	26,471,454	-483	-682
	Metro	796,284,071	296,822,817	3,067,421	260	97
	SETP - Diesel	-172,485,461	-403,092,607	4,111,250	-42	-98
	SETP - Electric	-267,197,198	-573,290,810	5,135,582	-52	-112
	SETP - Hybrid	-9,117,035	-278,760,701	5,005,154	-2	-56
	BRT - Diesel	-3,614,007,370	-4,304,745,168	25,502,798	-142	-169
	BRT - Electric	-4,244,792,224	-5,927,532,193	33,460,037	-127	-177
	BRT - Hybrid	-1,040,091,731	-2,010,445,716	30,194,367	-34	-67
Non Motorized Transport	Bicycle path consolidation in Bogota	-115,091,107	-408,537,163	1,853,668	-62	-220

Source: Own preparation

Assuming that all the transport programs take shape, CO_2 emissions would be reduced by 385 million tons of CO_2 from now to 2040 (and a total of 23 million tons of CO_2 in 2040). Also, if the 11 programs were introduced, overall transport sector emissions in 2040 would be less than today (Figure 30).

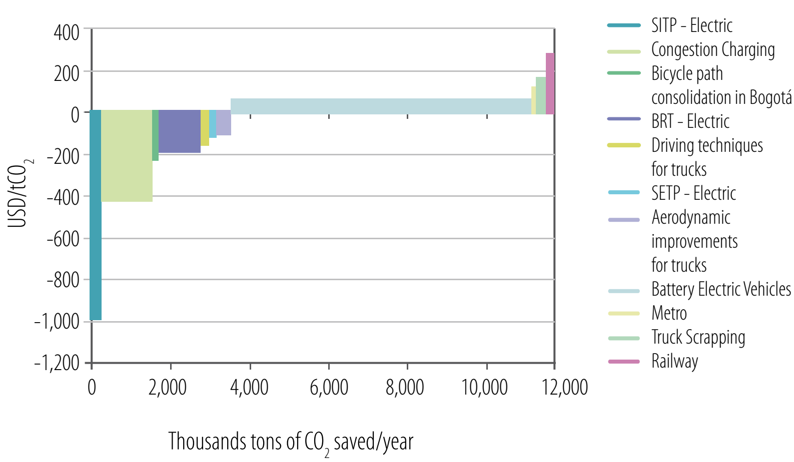
Figure 30 | CO_2 emissions—baseline (BL) scenario versus low-carbon (LC) scenario



Source: UPME and authors

Regarding costs, seven of the programs were found to be economic, including most of the measures in public transport (Figure 31). This means that Colombia could reduce CO_2 in the transport sector at low cost.

Figure 31 | Abatement curve



Source: Authors

4. Barriers to Implementation

As might be expected, many barriers hamper low-carbon transport programs in Colombia. Some are common to capital-intensive infrastructure or technology renovation projects, including high upfront costs and financing constraints. Also, some are not yet economic – such as Battery Electric Vehicles – but eventually they could be as the technology develops and capital costs fall. However, other barriers are less apparent and warrant discussion, especially for measures that otherwise have good financial and economic rates of return.

A. Political support

All public transport programs require government support; mainly it is from municipalities, but national assistance is also needed. Programs such as Bus Rapid Transit (BRT) require large public infrastructure investments for road upgrades and stations, and strong political support to move forward with land and right-of-way acquisitions, zoning and permit approvals, and to overcome opposition from various stakeholders. Indeed, Transmilenio was strongly opposed by vehicle owners and drivers when it was learned there would be dedicated bus lanes, reducing the road space for other vehicles. However, Transmilenio cleverly included a package of public transport and urban design measures, including BRT, along with policies for pedestrian and bicycle access. Still, the lack of continuity in political support can affect transport programs that need to develop over many years. Further, construction delays and the negative effect these have on the quality of existing public transport can lead to a loss of credibility and acceptance and cause those that can afford to drive private vehicles to continue using them.

B. Public information

Public transportation programs, such as SETP, BRT, SITP and Metro need a parallel information component that addresses private vehicles. Thus, the success of such programs depends not only on political support, but also on producing new social habits, integrating new public transport systems in urban areas, and educating the public about the benefits of efficient public transport. It is a serious challenge to curb car use where their purchase for private purposes has grown a great deal and is expected to continue as per capita incomes rise. Unfortunately, growing motorization, auto and motorcycle traffic can negatively affect public transport when both compete for the same space. Thus, if public transport programs are to succeed, it is vital to moderate the demand for cars among a new generation, and improve both the efficiency and convenience of public transport. In this respect, costs must be controlled so public transport is affordable; also, direct or indirect subsidies for public transport will be needed to influence consumer transport behavior.

C. Long-term planning

Investments in transport infrastructure take time to be approved and construct and require that roads, bridges, or rail lines be integrated into urban and regional space. Acquiring the right-of-way for a new urban road or transit line is usually a difficult process in which commercial or residential buildings may need to be relocated. This is a major reason why cities often choose to install elevated roads, or underground metro systems, rather than acquire new or expand existing right-of-ways. At a regional level, long-term planning for the infrastructure is critical, such as for rail or waterways. Indeed, one of the biggest challenges to expanding the railway has been the lack of prioritizing it in national development plans. While the coal industry supports extending rail capacity from coal-producing regions to ports, existing road transport providers have opposed it.

D. Enforcing environmental standards

Reducing air pollution from transport vehicles is an important benefit of many of the programs described. Indeed, many become much more attractive from an economic perspective when health and other benefits of low-carbon transport programs are included in the analysis. By setting and enforcing air quality standards, such as through vehicle inspection and maintenance programs, governments can promote cleaner fuels and vehicles. If the standards are lax or not effectively enforced, cleaner transport modes have little benefit over dirty ones. Indeed, the major improvements in municipal air quality around the world over the past 20 years were to a significant extent due to enforcing air quality regulations, which in turn helped promote better fuel specifications and cleaner vehicles.

E. Trade barriers

If the entry of new technologies is limited, such as with high customs duties, this could slow or halt the electric or hybrid vehicle programs. For now, many of the technologies are being developed in the major car-producing countries; however, given the potential advantages such vehicles could have for Colombia and other countries that have large shares of electricity from hydro or other clean renewables, the government could enact policies to ensure that new technologies be acquired from overseas without excessive trade barriers. Also, to encourage domestic programs for promoting electric or hybrid vehicles, research and development should be pursued along with the commercialization of new vehicle technologies. Current fiscal incentives for importing environmental technologies should also be considered for clean transport, including those purchased by individuals.

5. Conclusions and Recommendations

Transport is Colombia's largest producer of GHG from energy consumption and it is expected to continue in this path. Some low-carbon transport measures that could reduce the increase, have been cost-effective and have good social and environmental benefits. If the 11 transport programs described in this chapter were introduced over the next 30 years, Colombia could completely offset the expected increase in CO_2 emissions from transport, and produce less in 2040 than today. Further, reduced emissions need not be at the expense of the sector's growth or reduce transport services; rather, it could be achieved through greater efficiency and lower fossil fuel consumption.

Low-carbon public transport options are a cost-effective way of reducing CO_2 emissions because the economic benefits associated with these measures have high economic rates of return. Those from public transport projects stem from the savings in energy and operating costs, and in improved social welfare. The analysis found that the transport projects described generate positive externalities by (a) reducing congestion (time saving benefits), (b) reducing accidents (health and value-of-life benefits), and (c) lowering the burden of disease by improving air quality (health benefits). The methodologies to value these externalities are still being developed and will need to be improved, but even with imperfect, conservative estimates, the added benefits justify supporting them.

However, to realize the benefits, current motorization trends must be controlled and reversed. The rapid increase in cars and motorcycles is due to rising incomes and inadequate public transport. Reversing this trend will require public transport projects, measures to raise the effective cost of cars and motorcycles (such as congestion or other charges), and enforcing emission control regulations. Also, cities need to support projects that promote a shift from cars to NMT for short trips. As in other cities worldwide, improving public transport and encouraging NMT is not just about transport but making cities more accessible and livable.

For private passenger transport, several efforts could reduce GHG emissions. Congestion charging was found to be economic and produce the second largest reduction in CO_2 emissions among all others examined. Only the battery electric vehicle strategy has greater potential; although it is not yet economic, there are numerous benefits of promoting electric vehicle technology in Colombia. These include a dramatic drop in the use of petroleum, lower vehicle operating costs due to the use of the country's clean hydro-based electricity sources, and reduced local environmental impacts from internal-combustion engines. Given the rapid development of BEV and battery technology worldwide, its costs could decline faster than the analysis assumed and make the technology economic even sooner.

For freight transport, constructing/rehabilitating the rail system, as well as eliminating old freight trucks were not found to be economic actions at present. However, such programs could have benefits for the future competitiveness of the country's transport system and the sectors of the economy that depend on it. The rail system could complement the dominant road transport system while removing old trucks from the road would more rapidly replace the aging truck fleet and remove polluting and in some cases dangerous trucks. Aerodynamic improvements and driving techniques for trucks, which were introduced in the U.S. and piloted in Mexico and elsewhere are win-win efforts that offer other benefits, such as reducing accidents.

It is essential to include air pollution costs and benefits when assessing transport projects. Introducing public transport, as well as cleaner vehicles and fuels, reduces air pollution for all citizens, especially those who commute in polluted corridors—such as school children, workers, bus riders and drivers. Since the early 1990s, many Latin American cities have tried to improve air quality and many actions have focused on transport. However, cities still lack the information to estimate health costs from air pollution and the benefits from clean transport. Carrying out epidemiological and receptor studies, as well as dose response studies, would give more precise estimates of health impacts and allow economic benefits to be calculated (avoided health care costs are an important component). With respect to monitoring, many large municipalities lack good air quality data or modeling capabilities to determine pollutant concentrations in different areas. Thus, it is important for cities to develop the capacity to calculate emissions from various activities, pollutant dispersion factors, physical-chemical reactions in the atmosphere, and the secondary formation of air pollutants. New analysis techniques can provide good air quality data quickly and at low cost, which can help the decision-making process.

Overall, the analysis confirms that there are many low-carbon projects that Colombia can carry out in the transport sector that have positive economic (including social costs and benefits) and financial returns. The analysis included most projects/programs being developed in the country, mostly in the urban transport sector. It also provided another reason for promoting the projects, which could be part of Colombia's low-carbon development program. However, the biggest gains in reducing energy use and CO_2 emissions in the transport sector are through changes, such as drivers shifting from private vehicles to public transport. Policies such as congestion pricing were also found to be powerful mechanisms to promote these choices. The conclusions in other sectors also apply in transport--that low-carbon projects have good economic returns and reduce CO_2 at low cost.

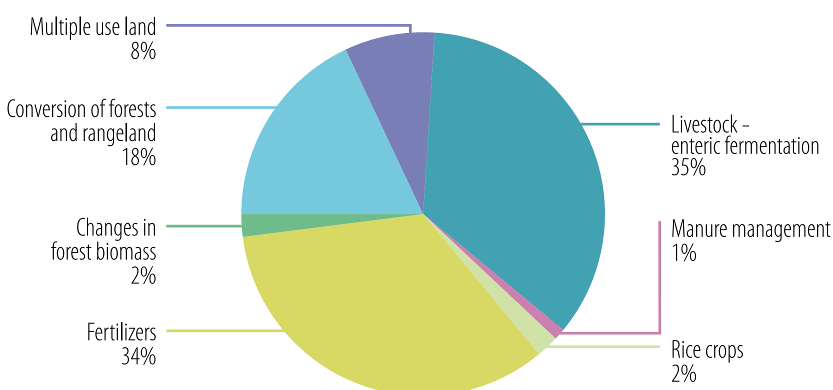
CHAPTER 4
Agriculture, Forestry and Other Land Use

1. Background

A. AFOLU: Large GHG emissions

Colombia has a total area of 114 million ha, 49 percent of which are forests, 0.6 percent is uncultivated land, 2.5 percent is water, 0.3 percent is urban land, and 2.6 percent is other. The remaining 45 percent is used for agricultural, forestry and livestock activities (AFOLU). Based on 2008 data, among the AFOLU components, livestock (enteric fermentation) account for 35 percent, the use of nitrogen fertilizers for 34 percent, and the conversion of forests and rangelands for 18 percent (Figure 32).

Figure 32 | Sources of GHG emissions from AFOLU in Colombia



Source. Authors based on IDEAM data (2008). National Inventory of Greenhouse Gas Sources and Sinks 2000–2004

The livestock sector contributes the most to current and projected future GHG emissions, given the large cattle herds and projected expansion over the next decades. From 2010-2011, the herds, which produce methane, increased from about 24 million to 28 million animals. Methane (CH_4) has global warming potential (GWP) that is 21 times higher than CO_2.

According to the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), when compared to the 1990s, methane emissions from 2000-2004 increased 14 percent. It is thought they have actually increased more, but the data are not reliable.

In 2010, annual and perennial crops occupied only 4.9 million ha compared to more than 39 million for pastures. Still, crop fertilizers are the second-largest source of GHG emissions in the sector. The largest amount is from nitrous oxide, a gas that has a GWP 310 times that of CO_2. In some regions, fertilizer emissions are compounded by incorrect use (amounts, applications, placement and timing) due to limited knowledge and adoption of agricultural best practices (ABP).

When forests and natural rangelands are converted for agriculture and livestock activities, extensive deforestation creates huge emissions: From 2005-2010, about 240,000 hectares were converted each year, with the practice most prevalent in the Pacific and Caribbean regions and the Amazon, particularly in Caquetá, located on the agricultural frontier.

There are other causes of deforestation, one of the most common being the selective extraction of timber to generate income for individuals and communities. Once high-value trees are harvested and processed, the remaining forest is typically cut down, the biomass is burned to improve access to the land and release nutrients, and the land is then used for crops or pasture.

Various institutions using different methodologies have estimated the extent of deforestation in Colombia over time (see Table 7).

Table 7 | Deforestation by regions, 1990-2010

Period	Indicator	Pacific	Orinoco	Caribbean	Andean	Amazon	Total
1990 - 2000	Forest 1990 (ha)	5,249,261	2,335,094	2,368,779	12,565,035	41,924,100	64,442,269
	Average annual deforestation (ha)	14,043	24,058	34,302	87,660	119,802	279,864
	% of forest loss – annual average	0.27	1.03	1.45	0.70	0.29	
2000 - 2005	Forest 2000 (ha)	5,227,673	2,182,517	2,014,227	11,716,837	40,669,967	61,811,221
	Average annual deforestation (ha)	29,254	28,696	47,313	97,293	112,565	315,120
	% of forest loss – annual average	0.56	1.31	2.35	0.83	0.28	
2005 - 2010[34]	Forest 2005 (ha)	5,035,400	2,123,340	1,807,073	11,151,591	40,096,203	60,213,607
	Average annual deforestation (ha)	22,149	9,307	40,018	87,090	79,797	238,361
	% of forest loss – annual average	2.20	2.19	11.07	3.90	1.0	

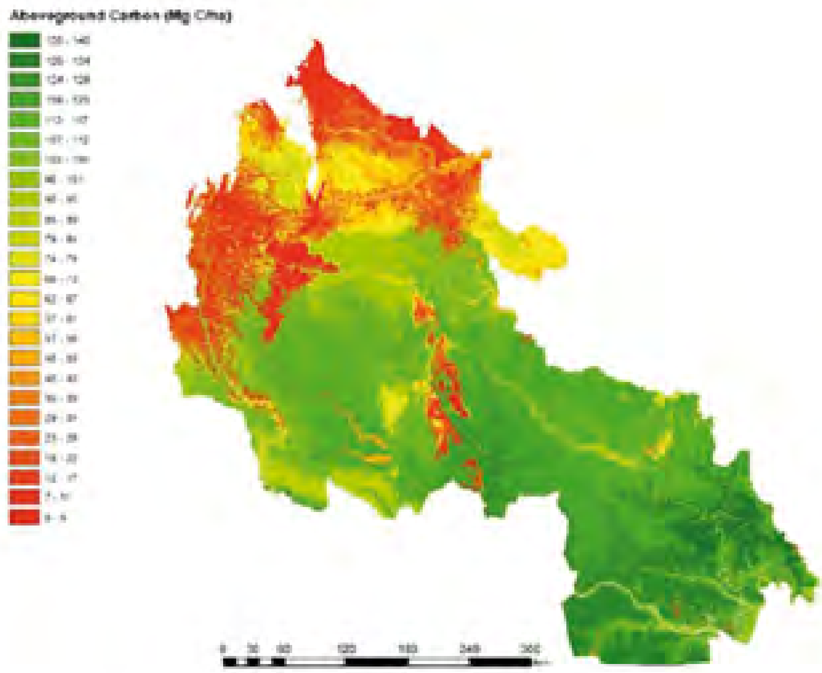
Source: IDEAM 2011. Technical Report on the Quantification of Historical National Deforestation.

The deforested area was greatest in the Amazon (1990-2005) and Andean regions (2005-2010), followed by the Caribbean, Orinoco and Pacific regions. However, when related to

34 The area with forest cover in Colombia in 2010, estimated by IDEAM, is 58,633,631 ha.

the region's total forest area, deforestation was greater in the Caribbean area, followed by the Orinoco, Andean, Pacific and Amazon regions. Figure 33 is a high resolution map of above-ground carbon density and the deforestation frontier (low carbon stocks in red) in the Colombian Amazon.

Figure 33: Above-ground carbon density (ACD) for 16 million ha in the Amazon region



Source: Asner et al (2012) High-resolution Mapping of Forest Carbon Stocks in the Colombian Amazon.

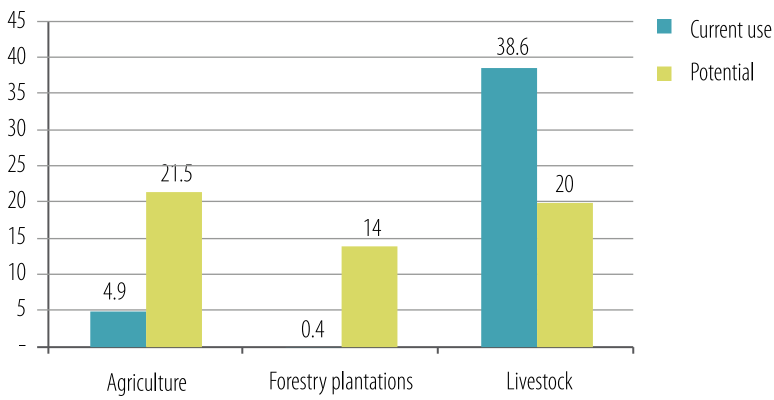
In the northwest corner of Colombia, heavy deforestation and degradation have driven ACD to as low as 0-6 miligrams of carbon per hectare (mg C/ha) in many areas. Near the center of the area studied, sandstone plateaus are capped by short vegetation with low ACD. Carbon stocks increase to the southeast, where elevations are lowest and annual rainfall reaches 3,000 milimeters a year (Tian et al., 2000). Median ACD in these wetter forests reaches 130 mg C ha and, over many areas, forest cover is uninterrupted, suggesting low to no human use.

Once the forest is cleared and converted to other uses, the cropping and pasture systems are largely low-input and extensive. Such inefficient land use has economic and social implications: eg. A large part of livestock activity has these characteristics, with an average carrying capacity of less than 0.6 livestock units per hectare (LSU/ha). Only 4 percent of the cattle herd is used for dairy production or improved cattle breeding, thereby limiting the sector's job creation and economic profitability. Based on data from agricultural research in Colombia, of the estimated 39 million ha used for grazing and livestock, 18 million ha could be freed up for alternative uses. Similarly, low productivity cropping systems demonstrate significant inefficiencies. Indeed, current levels of agriculture and forestry productivity could be maintained using five times and 13 times less land, respectively.

Inefficient land use creates pressure to continually clear more forests and expand the agricultural frontier, which is linked with low levels of productivity and marginal job creation: Government data show that agriculture only generated 2.4 million jobs in 2011 and livestock far less, with only 0.6 million.

Figure 34 shows the area (ha) used for the main productive activities and the difference between the current and potentially more efficient land use, for which a major imbalance exists.

Figure 34 | Current vs. potential land use



Source: MADR presentation, July 2011

B. Improved practices: A need for land-use planning

There is an urgent need to reverse these practices and optimize the use of land: eg. If the number of head of cattle per ha was increased through improved grazing and pasture management, it would free up land for more productive activities that also benefit the ecosystem (improved hydrological flows would lessen flooding, and reduced soil erosion would alleviate the loss of soil nutrients and soil carbon). Based on FEDEGAN studies, developing silvopastoral or pasture-improvement projects could increase the carrying capacity[35] of current pastures to 3.0 and 1.0 LSU/ha respectively, compared to a baseline of 0.6 LSU/ha. These improved, more intensive production systems could also make livestock activity more competitive through economies of scale and the corresponding lower costs, which is critical within the context of the Free Trade Agreement (FTA) signed with the U.S. and Europe.

Most Colombian livestock production occurs on degraded pastures that have unfertile soil and low levels of carbon content. However, if beef and dairy productivity was increased (through legal frameworks and policies), this could release some land for other uses that could mitigate climate change and prove economically, socially, and environmentally beneficial. Such alternative land use systems include forest and rubber plantations, oil palm and fruit trees, and even ecological restoration processes where environmental services are critical both to make the agricultural sector sustainable and to benefit downstream urban populations and tourism.

According to the Ministry of Agriculture and Rural Development (MADR),[36] Colombia has 17 million ha of land suitable for plantation forests or agroforests, but only about 1.5

35 Maximum stocking rate possible which is consistent with maintaining or improving vegetation or related resources

36 http://www.investincolombia.com.co/Adjuntos/Forestry_Sector_Booklet_2009-10-20.pdf

percent of that potential (253,066 ha) is now in use. Of the 17 million ha, 5 million ha do not need to be improved in order to be developed for forestry projects, while 12 million ha do.

At present, 53.3 percent (60.7 million ha) of Colombia's total land area is covered by native forests. Developing forestry plantations is a long-term national plan, whose goal is to plant 1.3 million ha by 2025. Further, the country is investing in rubber plantations to meet national demand for manufacturing rubber products. In 2008, the country produced 2.8 tons of natural rubber but consumed over 9.6 tons of technically specified rubber (TSR) and 7.6 tons of latex.[37] In addition, palm oil to meet national requirements for biofuel and vegetable oil, is being produced from plantations that grew from 80,000 ha in 1990 to over 280,000 ha in 2010, with palm oil totaling 900,000 tons in 2010.

The conversion of pastures to fruit orchards is an alternative with economic and environmental net benefits whose development has been below its potential. Despite the consolidated production chains and promising international markets (enhanced by the free trade agreements), fruit production represents only 5 percent of agricultural plantations: In 2010 there were about 16,000 ha and 20,000 ha planted with mango and avocado, respectively.[38]

Besides promoting more productive land use, it is necessary to restore key ecosystems such as *páramos*, wetlands, and Andean forests in order to prevent floods and landslides, ensure that the water supply is sustainable, and lessen the effects of climate change. Although private investors do not find restoration activities attractive and the costs may vary widely depending on the ecosystem's condition, the general population enjoys the environmental benefits and the effort can be an important social investment.

Based on this analysis, the forestry sector appears to have the largest potential as an alternative to present land use in terms of profitability, investment returns, available area for expansion, and reducing GHG emissions. Other benefits would come from increased forest plantations, since, besides being a source of carbon sequestration, growth in the commercial forestry sector would decrease pressure on natural forests from which part of the timber needed to meet internal demand is extracted. Forestry can also generate new jobs for communities involved in destructive deforestation.

C. Agriculture: Difficulties mitigating GHGs

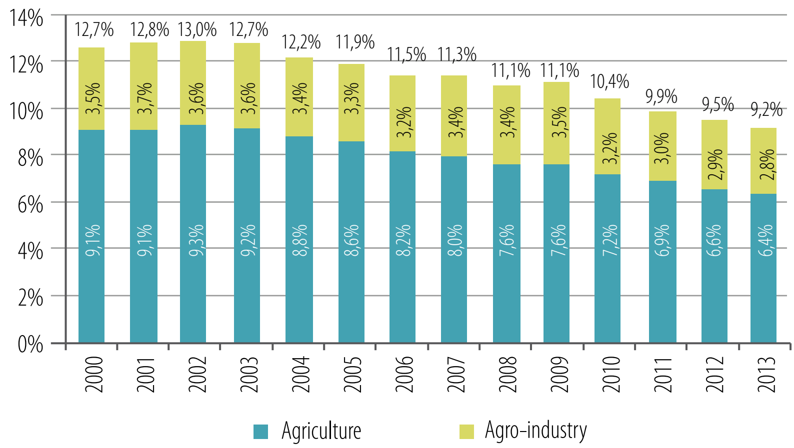
Agricultural activities (not including livestock) use less than 25 percent of the land suitable for crops. The sector (crops + livestock) grew 2.2 percent in 2011, while national GDP grew 5.5 percent. Growth mainly came from live animal and animal product activities (4.2 percent), followed by other agricultural products (3.8 percent). In contrast, coffee production declined by 11.2 percent.[39] In recent decades, agriculture has been declining as a share of total GDP, not only due to the growth of dynamic sectors like oil and mining, but because agriculture is stagnant. Worse, climate change is expected to further weaken the sector unless measures are adopted and farmers are helped to adapt to changing temperature and precipitation patterns. Agricultural GDP, as contribution to national GDP, has reduce between 1990 to 2010 (Figure 35).

37 Boletín informativo Ministerio de Agricultura y Desarrollo Rural octubre 2009. Dirección de Desarrollo Tecnológico y Protección Sanitaria.

38 Periodico El Tiempo marzo 2011 consultado marzo 2012 http://www.eltiempo.com/colombia/llano/ARTICULO-WEB-NEW_NOTA_INTERIOR-9001087.html

39 Ministerio de Agricultura y Desarrollo Rural. Estadísticas del sector agropecuario, marzo de 2012. Dirección de Política Sectorial.

Figure 35 | Agricultural GDP as a contribution to national GDP, 1990-2010



With 75 percent of suitable agricultural land underutilized, there is significant growth potential in the medium to long term. This could create jobs, if the necessary investments were made to increase productivity and value-added processes. Based on national studies, the Orinoco region has the highest potential for large-scale agricultural development[40] followed by the northern region, where more intensive use of pastures could release underused and low productivity pasture lands for other agricultural production systems.

Three aspects will influence the sector's composition in terms of land area and emissions. These are: (a) implementing the FTA treaty with the US, (b) encouraging large investors in rural areas to take advantage of improved security, and (c) developing new agro-industries in the Orinoco region.

Sectors with comparative advantage, such as flowers, fruits and vegetables, will benefit from the trade agreements in contrast to those that are not efficient enough in terms of costs and production, such as rice and corn (maize), both of which are large-scale crops that use high levels of fertilizer. For this reason, efficient fertilizer technologies need to be adapted and disseminated to rice and corn growers over the next 3-5 years.

Colombia and other countries in the region may benefit from climate change with respect to rice production. A 2011 World Bank study showed that unlike corn, soybean, and wheat, which are expected to suffer significant negative yields by 2020, and certainly by 2050, rice productivity is projected to potentially increase, especially in Colombia. This suggests that special care is needed to nurture the rice sector while productivity-enhancing and cost-reducing policies and technologies are introduced to counter cheap rice imports from countries where it is heavily subsidized.[41]

Also, the comprehensive development of the Altillanura, a significant part of the Orinoco region, could be a new carbon sink (sequestration) or instead release significant GHG due to land cover changes and the release of soil carbon. The net carbon effect will depend on the

40 It is estimated that only in the Altillanura, part of the Orinoco region, does agroforestry have high potential for an area of around 3.5 million hectares (Draft Document CONPES: "Sustainable Integrated Development of the Colombian Altillanura" DNP, March, 2012)

41 Rice Subsidies** in the United States totalled $12.9 billion from 1995-2010. http://farm.ewg.org/progdetail.php?fips=00000&progcode=rice

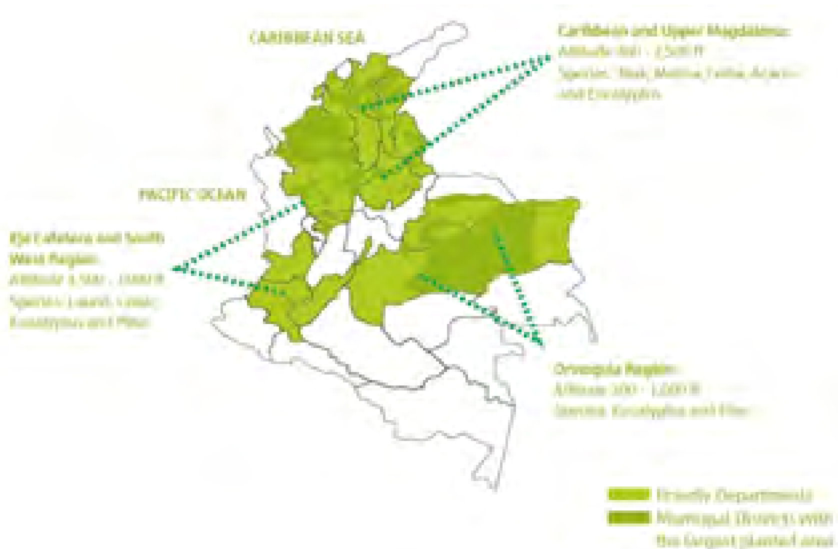
combination of activities introduced. Development in Orinoco and other regions will partly depend on state actions and private sector involvement. Both need to support the sector to overcome competition challenges posed by mining and those linked to a lack of transport infrastructure, services and a labor force, along with low soil fertility.

2. Baseline Analysis

A. Forestry: Huge carbon sequestration potential

From 1999-2010, forest plantations increased from 145,759 ha to 324,080 ha, a rise of 178,321 ha in planted area over 11 years. If the trend continues, the plantation area in 2040 would be about 770,000 ha and include pine and eucalyptus varieties with low levels of technological innovation and genetic improvement. As a result, the average annual sequestration would be about 6 million tons of CO_2 equivalent with commercial forestry plantations accounting for about 162 million tons by 2040 under the low expansion - low technology scenario (Figure 36).

Figure 36 | Potential zones for forestry development (MADR, 2011)



Source: FAO, Calculations MADR.

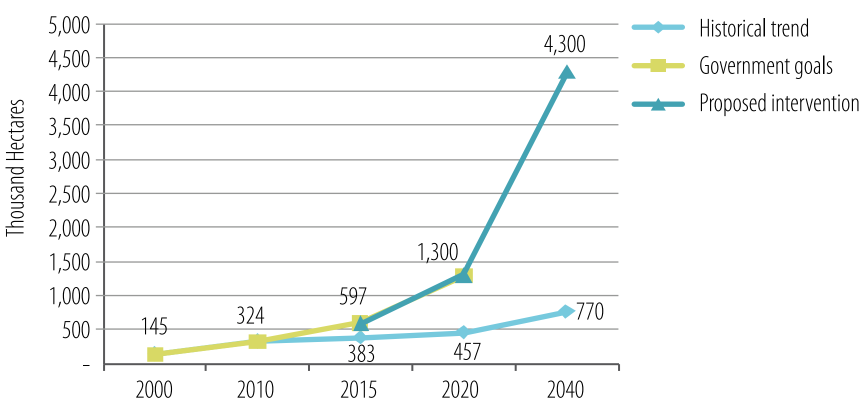
With the right policies and incentives, Colombia could significantly accelerate development of forest plantations, expand exports, and improve soil and biomass sequestration of carbon. Although harvested biomass returns sequestered carbon to the atmosphere, up to 30 percent of that which is sequestered in trees is transferred to below-ground biomass in the roots that contribute to stable soil carbon pools. Colombia's ecological conditions are very suitable for forest plantations (Table 8).

Table 8 | High productivity of forest plantations

Species	Country	Rotation	Yield (m^3/ha/yr)
Softwoods			
Pinus tecunumannii	Colombia	16	30-40
P. radiata	Chile	20-25	10-25
P. patula	Colombia	16	12-22
Pinus spp	Brazil	15-20	16
Pinus spp	USA (southeast)	25	10-15
Hardwoods			
Eucalyptus hybrids	Brazil	7	45
E. grandis	Colombia	7	30-40
Eucalyptus spp.	Uruguay	8-10	27-30
E. globulus	Chile	10-12	20-30
E. globulus	Portugal	8-10	12

Source: CONIF 2002, CENPAPEL 2004.

Figure 37 | Forestry plantation area, 1999-2040, trends, government goals and proposed measures in Colombia



Source: DNP–DDRS proyections

Rubber plantations also suffer from a low growth rate. From 2002-2010, 33,213 new ha of rubber were planted, which translates to an annual average increase of 3,690 ha. Assuming the sector continues its relatively slow growth, and without a significant change in investments or policies, the country would only have about 150,000 ha planted with rubber by 2040. The added 107,000 ha planted after 2011 would reflect an average sequestration of 610,000 tons of CO2e a year, which would represent a reduction of 17.83 million tons of CO2e by 2040 (Figure 37).

(1) Deforestation and forest degradation

IDEAM has estimated CO_2 emissions from deforestation from 2005-2010.[42] During this time, nearly 351,000 tons of CO_2 were sequestered through forest regeneration.[43] Thus, during the five years, 64 million tons of CO_2 were estimated to have been emitted into the atmosphere--or 13 million tons of CO_2 a year.

These estimates are very conservative for the following reasons: (a) the data only include carbon from above-ground biomass of the forest (IPCC defined the "*shoot-to-root ratio*" of 0.37 as accounting for root biomass, assumed it would decay to CO_2, and would yield 37 percent higher emissions); (b) carbon losses associated with the over-exploitation of timber from natural forests, and accompanying changes in soil use were excluded; and (c) losses in the stock of organic soil carbon after deforestation were not considered. If these items had been included, it would have significantly increased the estimate of annual carbon loss from deforestation—which could thus be almost 50 percent higher than calculated by IDEAM, and total about 20 million tons of CO_2 a year.

Historical deforestation trends are presented in Table 9. It should be noted that estimates for the last two periods (2000–2005 and 2005–2010) were more reliable than those of the first (1990–2000) because of improved remote sensing and computational/statistical methods, as well as better quality of information (Figure 38).

The data show that from 2000-2010, deforestation dropped from 315,000 ha a year to 238,000 ha, which is nearly a 24 percent decrease in the rate over the past 10 years. When constructing a baseline into the future with these data, the net loss of forest would reach zero in about 40 years (2050). This would only be possible if current deforestation trends continue and were not reactivated by new forces such as illegal mining, road construction, or land speculation. However, climate variability and change could also decrease the forest area over time. For example, a recent World Bank study suggested that modified rainfall patterns and stress from prolonged drought could reduce Amazon forest biomass density. In turn, changes in evaporation and precipitation could further accelerate droughts and destabilize the tropical ecosystem as a whole, reducing its biomass carrying capacity or "dieback."[44]

B. Livestock: A growing sector needing efficiency gains and reduced land use

The area for livestock production has historically been larger than those used for other activities in the sector: From 2000-2006, the pasture area increased 5.6 percent, from 36.7 million ha to 38.8 million ha (Table 9). Although the area continued to increase, the expansion rate fell to 0.8 percent over the next four years, along with an increase in the carrying capacity

42 Based on carbon contents of the different types of forests, taking into account the regional deforestation rates presented in Table 7. IDEAM, following IPCC 2006 guidelines, estimated CO2 emissions caused by deforestation in Colombia from 2005-2010.(*IDEAM, 2011. Estimate of carbon dioxide emissions generated by deforestation during the 2005–2010 period.)*

43 The change from other types of cover (e.g., agriculture and grasslands) to forests.

44 http://www.mendeley.com/research/assessment-risk-amazon-dieback-1/

per ha, which rose from 0.67 LSU/ha to 0.71 LSU/ha.[45] This coincides with the Strategic Plan for Colombian Livestock 2019 (*Plan Estratégico de la Ganadería Colombiana 2019, PEGA*) in which the sector recognizes the need to intensify land use, setting an ambitious target of releasing 10 million ha by 2019. This release of pasture land would be accompanied by a significant increase in the cattle herd: In 2010, it totaled 27.8 million head, according to ENA (*Encuesta Nacional Agropecuaria*), and based on the PEGA estimates, it is expected to almost double by 2019, to 48 million head.

PEGA goals are consistent with the Direction of Rural Development (DDRS) projections of DNP, which estimate the growth of the cattle herd at 20 percent to 2030, accompanied by a 21 percent reduction in pasture area. Dairy and meat products are expected to grow through an increase in the carrying capacity per ha, which, according to the DDRS-DNP, will need to reach 1.09 LSU/ha. Further, PEGA calls for increased exports to neighboring markets by 2019: 50,000 tons of high-value meat, 400,000 tons of regular meat, and 1,254 million liters of milk a year.[46]

Table 9 | Area under pasture, head of cattle, and sectoral load capacity, 2000–2010

Year	Area under pasture (ha)	Head of cattle*	Load capacity
2000	36,730,384	n.d.	0.66
2001	37,609,796	24,789,875	0.65
2002	37,813,436	24,765,293	0.65
2003	38,302,387	24,799,259	0.65
2004	38,682,587	24,921,742	0.64
2005	38,944,373	25,699,399	0.66
2006	38,804,661	26,129,019	0.67
2007	38,866,386	26,703,159	0.69
2008	39,152,358	26,877,824	0.69
2009	39,185,705	27,359,290	0.70
2010	39,112,224	27,753,990	0.71

Source: MADR. Ministry of Agriculture and Rural Development (MADR). 2011. Statistical yearbook of the agricultural, livestock and fishery sector, 2010. Yerimpresos. Bogotá: MADR; *Encuesta Nacional Agropecuaria 2001-2010

The herd's composition affects emissions, since the production of CO_2e varies depending on the cattle's age and gender (see Table 10).

45 *MADR. Ministerio de Agricultura y Desarrollo Rural (MADR). 2011. Anuario estadístico del sector agropecuario y pesquero 2010. Yerimpresos. Bogotá: MADR. Número de cabezas tomado de Encuesta Nacional Agropecuaria 2001-2010.*

46 *Plan Estrategico para la Ganadería Colombiana* PEGA 2019. P.110

Table 10 | Herd composition in 2009 with emissions related to age group

Age group	$KgCO_2$ eq per cattle head	Number of cattle per age group
Male		7,782,149
< 1 year	442.3	1,990,782
1-2 years	892.3	2,737,325
2-3 years	1,282.8	2,375,365
> 3 years	1,325.5	678,675
Female		14,840,377
0-3 months	211.8	475,073
3-8 months	510.0	1,153,748
8-12 months	567.8	520,318
1-2 years	601.8	2,782,570
2-3 years	934.2	2,556,345
> 3 years	2,351.9	7,352,321
Total		22,622,527

Source: FEDAGAN. Cattle census 2009

When the herd increases, so do the methane emissions from cattle (known as enteric fermentation). However, when more efficient production systems are introduced along with improved pasture or silvopastoral programs, emissions can actually be reduced (per unit of product).[47] Results from some ongoing research programs to reduce methane emissions from ruminant livestock show that:

- Increasing the efficiency in which animals use nutrients to produce milk or meat can reduce CH_4 emissions. This can be done by using high-quality feed and highly digestible forages or grains. However, emissions associated with producing and transporting the improved grains or forage must also be included.

- Rumen[48] modifiers, such as ionophores, improve dry matter intake efficiency and suppress the production of acetate, which, in turn, reduces the hydrogen released. In some studies, CH_4 was lowered by 10 percent, although the effect of the ionophores was short-lived with respect to reducing CH_4. Thus, more research is needed on the continued use of ionophores.

47 *Plan Estrategico para la Ganadería Colombiana* PEGA 2019. P.110

48 The rumen is the first chamber of the digestive channel of ruminant (cud-chewing, cloven-hoofed) animals. It is the primary site of microbial fermentation of ingested feed.

- The grinding and pelleting of forages can reduce emissions by 40 percent, although the costs may be prohibitive.

- Dietary fats could reduce CH_4 by up to 37 percent. This occurs through the bio-hydration of unsaturated fatty acids, enhanced propionic acid production, and protozoal inhibition. The effects vary and lipid toxicity to the rumen microbes can be a problem. This strategy can affect milk components negatively and create income losses for producers.

- Low methane potential in cattle and sheep has a genetic basis and is inherited. This indicates it is possible to breed low-emission cattle.

- Various tropical legumes, alternative and new forages, and plant extracts can reduce methane production in the rumen.

There are several new approaches to reducing CH_4 that are promising but not yet practical. For example, the microbial composition of the rumen can be altered: Removing protozoa has been demonstrated to reduce CH_4 emissions by 20 percent. Also, it may be possible to encourage acetogenic bacteria to grow so they remove hydrogen instead of the methanogens. Acetogens convert carbon dioxide and hydrogen to acetate, which the animal can use as an energy source. Research is also being conducted to develop a vaccine, which stimulates antibodies in the animal's rumen that are active against methanogens.

The problems with some of these strategies to reduce CH_4 are their potential toxicity to the rumen microbes and the animal, the short-lived effects due to microbial adaptation, volatility, expense, and the need to produce a delivery system for these additives to cows in pasture.

In Colombia, the most promising approaches to reducing CH_4 emissions are related to improving forage and feed quality and breeding livestock that emit less methane.

C. Agriculture: Annual and perennial crops

Colombia has a relatively diversified agriculture sector with a balance between annual and perennial crops (see Table 11). Despite the sector's generally low growth, the planted area and productivity of crops such as oil palm, sugarcane, and cacao have increased in recent years. This is expected to continue in the medium term due to favorable prices, high demand, and the increased availability of land in the high plains *(Altillanura)*. Also, the area planted with fruits such as mangos and avocados has modestly increased: By about 4,000 ha and 200,000 tons for avocado and about 2,000 ha and 150,000 tons for mango (Agronet 2012). Further, the area and production of mechanized and irrigated rice increased slightly by 30,000 ha from 2005 and 2010 for mechanized and 10,000 ha for irrigated (Agronet 2012).

Table 11 | Area planted with annual and perennial crops, 2010

Annual crops	Planted area (ha)	Perennial crops	Planted area (ha)
Cotton	44,069	Banana, export type	44,000
Rice total	431,578	Cacao	91,970
Barley	7,698	Coffee	649,838
Maize	359,484	Sugarcane	219,309
Potato	143,110	Sugarcane, for panela	185,401
Sorghum	11,378	Mango	17,128
Soybean	30,325	Orange	36,943
Tobacco	9,540	Other citrus	25,466
Wheat	9,192	Other fruit	116,049
Vegetables	67,757	Palm oil	403,684
Total	1,114,131		1,789,788

Source: *Encuesta Nacional Agropecuaria* 2010, MADR-DANE-CCI

DDRS-DNP projections estimate the land area for crops will increase by over 35 percent from 2010-203: Fruit trees (210 percent), sugar cane (99 percent), palm oil (50 percent) and cocoa (40 percent). Much of this expansion is expected on land now used for inefficient livestock grazing in the Orinoco region and by general land conversion away from inefficient practices.

Fertilizers represent 34 percent of the emissions from the agriculture/livestock sector. However, there is little information about fertilizer use for the principal crops and potential mitigation measures. According to Econometría,[49] 79 percent of fertilizers in 2006 included urea (nitrogen), diammonium phosphate (DAP – nitrogen and phosphorus), and potassium chloride (KCL - potassium),[50] which are imported from countries such as the U.S. and Venezuela. Still, most of the crops are under-fertilized.

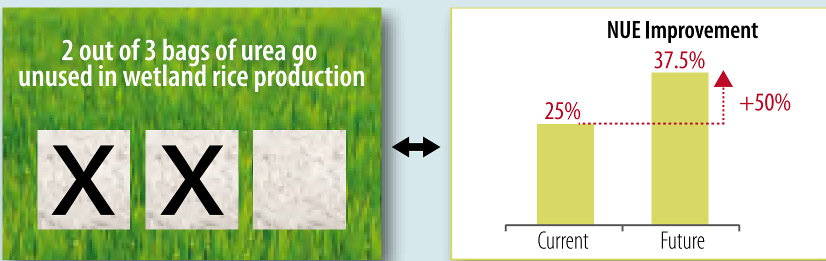
Fertilizer consumption in the medium and long term will depend on the crops grown, competitiveness of respective crops, government priorities, domestic and international market demand, and the effect of the free trade agreement (FTA): eg. Large-scale corn production in Orinoco plantations would increase the use of nitrogen fertilizers and in turn, nitrous oxide emissions. Conversely, a predominantly forest based development in Orinoco, which requires significantly less fertilizer, could not only reduce these emissions, but also sequester carbon and create added methane sinks in the forest soil.

49 *Econometría Consultores. Ministerio de Agricultura y Desarrollo Rural, Cámara Procultivos (2007) en Universidad de Los Andes, 2011. Proyecto para realizar análisis y diseñar instrumentos que apoyen la formulación de políticas para el desarrollo productivo y permitan el aprovechamiento de externalidades positivas generadas por el crecimiento de la economía minero-energética.*

50 *Universidad de Los Andes, 2011. Proyecto para realizar análisis y diseñar instrumentos que apoyen la formulación de políticas para el desarrollo productivo y permitan el aprovechamiento de externalidades positivas generadas por el crecimiento de la economía minero-energética.*

As previously noted, GHG emissions from annual and perennial crops are mainly from the use of nitrogen fertilizers. If no mitigation policies are adopted, the sector's expansion would likely lead to increased fertilizer use and emissions of nitrous oxide. As such, from a climate mitigation perspective, it is important to analyze alternatives for optimizing the use of fertilizers and agricultural best practises (ABPs) that reduce emissions. Significant opportunities exist to improve the nutrient use efficiency (NUE) of nitrogen fertilizers such as urea, as well as to develop a new generation of fertilizers (see Box below for improved NUE for nitrogen in flooded rice systems and environmental/economic benefits).

Box 5 | Improved nitrogen nutrient use in flooded rice, globally (IFDC, 2012)



Improved Yield	Investment Productivity	Environmental sensitivity
+15%*	$7-8 billion per year**	$1.5 billion/yr carbon tax offset***

**IFDCUDP experience*

*** @100 MMT urea per year currently*

**** $25/MMT CO2 GHG equivalent*

Reliable statistical information on fertilizer use is urgently needed. Current estimates based solely on the area cultivated are unreliable because fertilizer applications vary depending on the type of crop and soil conditions. In addition, the large variety of crops produced, the lack of aggregate information on the use of nitrogen fertilizers, as well as that on crop-specific management effects of GHG emissions create problems for developing measures to reduce emissions. Thus, the starting point for developing low-carbon agriculture should be an inventory of carbon and consolidation of materials about the latest recommendations for different crops, the contents of locally available fertilizers, and the use patterns for key crops (coffee, rice, fruits and potatoes).

A major challenge both now and in the future will be to significantly improve land use efficiency and transform environmentally-degrading livestock production to more sustainable systems. Despite strong political commitment to approve the transformation/conversion agenda and strengthen productive agriculture, PEGA has been delayed, commercial plantations as envisaged in the National Reforestation Plan have been slow to expand, and DNP growth targets for cultivated areas in the 2019 Agriculture Vision have not been met.

3. Low-Carbon Measures

This section describes eight measures to sequester/reduce CO_2 emissions(Table 12). These involve: (a) silvo-pastural systems (ISS); (b) pasture improvement; (c) commercial forestry plantations; (d) rubber plantations; (e) avoided deforestation; (f) efficient fertilizers (rice); (g) fruit tree plantations (avocado and mango); and (g) oil palm plantations. Other measures that could significantly reduce emissions, such as sustainable management of natural forestry and ecological restoration, are also mentioned. However, insufficient information limited the analysis of their costs and potential to reduce GHG in Colombia.

Table 12 | Measures to reduce GHG in AFOLU

Agriculture			Agroforestry	Forestry	
Annual	Perennial	Livestock	Tree+Livestock	Natural	Plantation
Efficient fertilization (case study: rice)	Oil Palm		Intensive silvo-pastoral systems		Commercial forestry plantations
	Rubber plantations	Pasture improvement		REDD+	
	Conversion of pastures to fruit tree plantations				
Crops in histosols	Cacao	Nutritional complements			
Low-carbon agricultural practices	Ecological restoration				

Source: Authors (2012)

As with all sectors in this study, the main criteria for analyzing low carbon measures is the availability of detailed, current information. This condition is especially relevant in AFOLU because of its decentralized information system, where material is gathered by various agencies with little coordination. A second criteria is that the measures must have good potential to reduce GHG, and be financially feasible. A third was that their costs not be high and that they could be conducted by private investors—not requiring high outlays for the government. The fact that Colombia has a comparatively low level of global emissions means that mitigation actions are more likely to occur if they have net financial benefits. The evaluated measures also offer benefits in terms of climate change adaptation, rural jobs, and others.

A. Livestock

(1) Silvopastoral systems

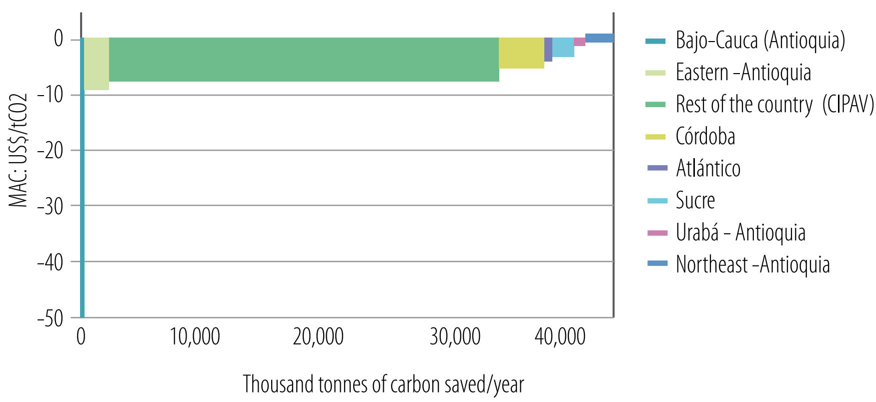
Silvopastoral systems (SS) are a form of agro-forestry that combines pasture for livestock with leguminous trees/shrubs and timber or fruit trees. Intensive silvopastoral systems (ISS) are a type of SS that combines densely planted Leucaena shrubs with improved, highly-productive pastures and timber trees. ISS is an alternative for turning low-productivity large ranches into more efficient production models with higher animal-carrying capacity per ha. When tree and shrub components are included, this improves the quality of the pasture by producing biological nitrogen fixation (by the leguminous trees/shrubs), shade for livestock to reduce heat stress, improved forage quality through the high protein content of leguminous species, and improved carbon sequestration when compared to traditional pastures. ISS presents an interesting mitigation option given the large area (around 20 million ha) currently occupied by low-productivity pastures. According to FEDEGAN, ISS could increase the average carrying capacity from 0.71LSU to 3.3LSU per ha. At present, it is estimated that ISS occupy about 5,000 ha, especially in the Department of Cesar, which has 55 percent of the country's total ISS area. The departments of Tolima, Quindio, Valle and Guajira also use ISS.[51]

Colombia can expand ISS to about 3.8 million ha in various areas. The most suitable production systems vary by region: For the Urabá and eastern parts of Antioquia, the proposed ISS involves low timber density; for northeast Antioquia, and for the Lower Cauca, it involves high timber density. For the north coast (Sucre, Córdoba and Atlántico), a system was proposed with animal feed production from species that includes fruit trees combined with timber production from native species. An ISS is also proposed for timber trees, and has a high potential to be replicated in the rest of the country, (extensively in Tolima, Huila and Caquetá, and in some warm parts of Caldas, Cundinamarca, Santander and Boyacá).

The GHG mitigation potential of converting 3.8 million ha is estimated at about 28.9 million t/CO_2e/year. However, the potential could be even greater if the regions not yet included in the assessment due to lack of information would be added.

The cost for the systems would be about US$215 million a year, with a per hectare cost from $720-$2,213. The cost of avoided tons of CO_2 is from $-49 to $0.6/t$CO_2$e (see Figure 38).

Figure 38 | MAC curve - silvopastoral systems



Source: Authors (2012)

51 Data provided by CIPAV

ISS has positive economic, social, and environmental benefits. Regarding economic impacts, the ISS can increase animal carrying capacity per ha, increase milk and meat productivity per head, and support households with added income from wood and timber sales. The systems are relatively labor intensive, and would generate much needed rural employment. Environmental benefits include conserving bio-diversity, regulating water use and improving soil fertility. Another benefit, given the higher average temperatures from climate change, is that there would be more shaded areas for livestock, which can reduce heat stress and increase animal productivity, especially in the dry season.

Despite the potential benefits, ISS has not yet been widely adopted. First, farmers lack the technical assistance to help them adapt the systems to site-specific climate and soil conditions. Also, the initial investment per ha is significantly higher than the prevailing pasture system, and small ranchers have little access to rural credit. Moreover, the ISS is a relatively recent innovation and most ranchers are not yet aware of it, or, if they are, of the way to manage it, or the economic and environmental benefits. Thus, there have been few regional trials, which further limits the diffusion of the information needed. In addition, ISS demands more attention than traditional ranching to ensure a smooth process. Colombia is investing significant resources into ISS, with strong backing from FEDEGAN and multilateral (the GEF) and bilateral agencies. As a result, technical barriers are rapidly being overcome through research and demonstration plots developed by CIPAV, and adoption rates across the country are rising.

(2) Improving pastures

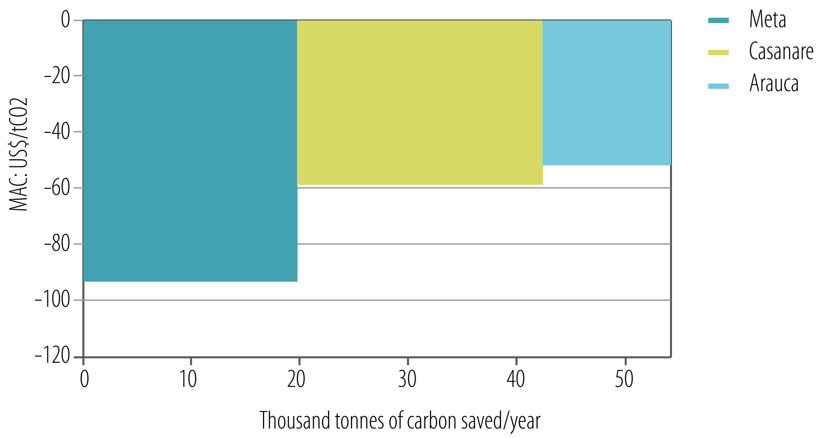
Attempts to improve pastures involve recovering degraded areas through various methods such as pasture rotation, fertilization, and varying the numbers of animal stocks. According to FEDEGAN, these efforts increase the soil's fertility, which, in turn, increases the production of forage by 50-100 percent. Also, CORPOICA and CIAT research has shown that planting deep-rooted, improved grasses leads to significant below-ground carbon sequestration.

Launching efforts to improve pastures is crucial since a significant part of livestock production occurs on degraded pastures; thus there is a large potential to sequester carbon in the soil and increase productivity. However, as no official land inventory exists, the exact amount of degraded land is unknown. But, CORPOICA[52] estimates that 50 percent of livestock pastures in Córdoba, Sucre and Atlántico are degraded (performing well below potential productivity).

Due to limited information on carbon sequestration to improve degraded pastures elsewhere, the study was limited to the departments of Arauca, Casanare and Meta: It estimated that in these areas, the potential for net carbon capture was 54,000 tCO_2e in just over 51,000 ha. The value of the measure was found to be $4 million a year, with a cost per ton of CO_2e from negative $103 in Meta to negative $62/$tCO_2e$ in Arauca (Figure 39)—thus producing high financial returns. If the study considered other regions where the program could be introduced, the GHG mitigation potential would increase substantially.

52 Federico Holmann, Yasmin Socrro Cajas Giron, Wilson Barragan H., Blas Dagor Panza T., Roger Ayazo B., Rafael Soto M. Produzca más. Diagnosticando y monitoreando el nivel de degradación de su pradera. CORPOICA 2011 p.16.

Figure 39 | MAC curve - improved pastures



Source: Authors

Since improved pastures contribute to soil fertility and productivity, they increase the profitability of livestock. However, as with the ISS alternatives, intensively improved pastures have not been widely accepted because of a lack of knowledge and access to credit to finance the systems. In some cases, producers adopted only part of the technology, eg. they only used improved seeds but did not change their management of the soil and pastures. This resulted in sub-optimal performance that can have a chilling effect on other ranchers.

(3) Supplementing livestock nutrition

Livestock nutritional supplements involve changing the bovine diet in ways that affect the animals' methane emissions. Methane is produced during the animals' digestive process and represents food energy turned into waste gas that the animals do not use.[53] Researchers examined the relationship between animal nutrition and methane and found that a high-quality diet reduces CH_4 (methane) emissions during this process. According to Kinsman et al.,[54] the emissions per animal are greater in developing countries partly because of deteriorated pastures, a low-quality diet, and animal malnutrition. The authors calculate that in these countries, average per animal methane emissions were 55kg CH_4/year, compared to 35kg CH_4/year in developed countries.

In general, little data exists about the effects of dietary changes on methane emissions, especially under tropical conditions. Thus, it is not possible to define the amount of GHG reduction potential for the proposed measure or estimate its costs. However, it is clear that at the macro level, the sector will increase GHG emissions significantly if steps are not taken to reduce methane emissions per head of cattle.

Besides reducing GHG, enriching the diet can raise productivity, making the measure economically attractive. But, to introduce it on a large-scale, information must be more available and progress must be made in studying the effects of different elements on diet, and of variations in climate and productive models.

53 Juan C Carmona, Zoot Esp; Diana M Bolívar, Zoot MSc; Luis A Giraldo, Zoot MSc El gas metano en la producción ganadera y alternativas para medir sus emisiones and aminorar su impacto a nivel ambiental and productivo.

54 Kinsman R, Sauer FD, Jackson HA, Wolynetz, MS. Methane and carbon dioxide emissions from cows in full lactation monitored over a six-month period. J Dairy Sci, 1995; 78 (12): 2760-2766.

B. Forestry

(1) Forest plantations

Forest plantations have fast growing species that can ensure an adequate supply of biomass to meet the demand for timber and paper. The type of species and level of technological innovation from genetic improvement will determine the market price of wood, its end-use (such as for paper, chips, furniture, construction), and its profitability. Also, the species' compatibility with the environment will determine production costs and productivity by species/region as well as the water and soil requirements.

The proposed measure would produce 4 million new ha of forest plantations from 2012-2040: 6 percent in the Andean region, 19 percent in the Caribbean region, and 75 percent in Orinoco.

The historical distribution shows that the biggest challenge is in Orinoco, where the current planted forest cover is not representative of national levels but has significant future potential.

Experts say the Orinoco region could be a prime area to develop forests in the medium term. With appropriate research into adapting technological solutions from the country's interior to Orinoco, the region could contribute significantly to the national goal of 4 million new ha. At present, large scale projects only account for 20,000 ha a year.

Besides the financial/economic implications, the large-scale expansion of commercial forestry would reduce climate change greatly: It is estimated that plantations could sequester 44 million tons of CO_2e/year. But achieving the 4 million ha target means multiplying the size of current plantations (424,000 ha) 10 times. This will require large investments, particularly in Orinoco, where over half the targeted land is located. In addition, efforts to create large plantations will need to consider environmental and social issues to ensure the measures are sustainable in the medium to long term. Thus, the technical and policy issues must be analyzed to produce the rural employment and other benefits.

The potential risks produced by large plantations include the broad impact of single-species plantations. Recent CIAT studies on the likely effects of climate change suggest that average temperatures in the Orinoco and Amazon regions may rise significantly over the next few decades, which means that natural forests and plantations will need more water; this, in turn, could stress the species and make them more susceptible to pests, diseases, and forest fires. Fortunately, a great deal of scientific and field-based experience exists[55] on how to design, implement, and manage large plantations so as to reduce biological, environmental, and economic risks. Examples of these practices include: (a) diversifying species by mixing blocks of single species, (b) protecting drainage lines with native vegetation that is more resilient to drought and fire, and (c) simulating hydrological functions from micro-watershed to basin scales to identify "hot spots" and adapting plantation designs. Available data on forest species from Colombia suggest that several coniferous and hardwood species would be environmentally and economically suitable for developing diversified (rather than monoculture), resilient, and productive plantations. Thus, a new generation of forestry plantations must involve: (a) real stakeholder participation, (b) attention to ecosystem integrity, (c) targeted protection and enhancement of high conservation values, and (d) a contribution to economic development.

55 http://www.fs.fed.us/research/publications/producci%F3n_forestal_para_am%E9rica_tropical/ap%E9n.h.pdf

To incorporate advanced scientific findings and improve management practices so as to produce environmentally resilient, socially beneficial, and economically profitable plantations, policymakers must adopt policies that will attract investors. Colombia's data suggest that potential investment returns in forestry are highly profitable, regardless of their GHG mitigation potential. Such activities could thus be considered "win-win." For this reason, government support should focus on ways to attract investment (eg., with direct incentives to offset the high initial costs of creating and maintaining plantations until financial returns begin, and risk-management instruments, especially for high value, slower growing species), rather than on financing forest development directly.

Despite the potential benefits from expanding forestry plantations, little has occurred over the past 20 years. Government policies designed to strengthen the sector exist, but no dedicated agency leads and coordinates forestry issues. The government needs to ensure investment security, infrastructure, and other public assets. The country has some financial instruments to support the needed investments, such as the Certified Forest Initiative (CIF) and investment tax benefits, but they are not adequate. To make the CIF attractive to large-scale investors, the fund needs more resources and greater simplification of processes. For example, from 1995–2011, only 173,000 hectares were created with CIF support, and the government's total investment was $252 billion Colombian pesos (about US$125 million).[56]

About US$450 million in private investments is needed for the 4 million ha each year. The carbon abatement cost is negative in the Orinoco, Caribbean and Andean regions, at US$2.61, US$2.70 and US$6.01 per ton of CO_2 respectively. The cost and the GHG mitigation potential are shown in (Figure 40). Among existing financing sources, the CIF[57] reimburses project developers for upfront investment costs and managing the plantation during the first five years, and offers tax breaks.

Besides the carbon mitigation benefits, developing forests has positive externalities: They create jobs, increase the nation's capacity to meet domestic demand for timber, and strengthen forestry and research institutions, which can create better-quality seeds, raise growth rates, and improve productivity and sequestration.[58]

(2) Rubber plantations

Rubber is a crop with low profitability and has traditionally been planted in the southeast, usually in a monoculture plantation or along with livestock activities. The rubber plantation measure would plant 260,000 ha from 2012-2040, mainly in the Amazon and Orinoco regions with plantation sizes of 80,000 ha and 180,000 ha respectively. These regions have available land, favorable climate, a rubber-planting tradition, and offer an attractive investment opportunity for the local population and national/international investors.

The GHG mitigation potential per ha is greater than of forest plantations since the product is harvested seasonally and not the woody biomass itself (as with timber), thus providing a longer and more sustained carbon sequestration life cycle. To achieve a target of 260,000 new ha, the current area will need to increase by more than five times, with annual investments of US$20 million - $80 million. The measure has positive financial returns and generates a negative cost per ton of CO_2e, from US$-1.05 in the Amazon to US$-0.67 in Orinoco (Figure 40). The effect on the regional economy occurs in the seventh year, when the plants begin to generate revenue from rubber sales.

56 CONPES Document 3763 Distribution of resources for the Certified Forest Initiative for commercial purposes (CIF Reforestation) effective 2013. It includes amounts allocated to establish and maintain forestry plantations and CIF administrative and monitoring activities. In 2012, 445 projects were approved to create 556,000 hectares. The Amazorinoquia region had the most resources allocated (40 percent) followed by the coffee region (23 percent).

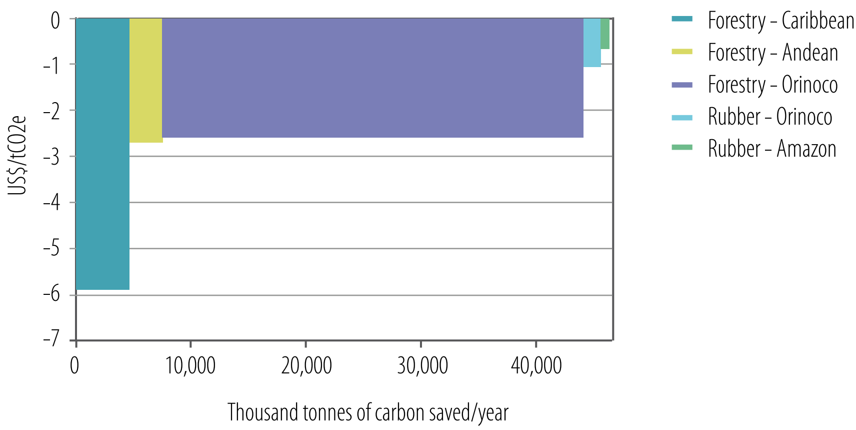
57 The Certified Forest Initiative was created by Law 139 in 1994.

58 According to sector experts, the first genetically improved seeds would be obtained 4-5 years after the research begins, and the second generation would take 6-15 years depending on the species and quality of the first clones.

The Orinoco region would sequester about 3 million tons of CO_2e from these plantations, and the Amazon, about 1 million tons. In 2040, the crop would be replanted due to the decrease in the original plantation's productivity. Harvesting the new planting would release emissions of 50 percent of the previously stored carbon.[59] The potential for regional sequestration is illustrated in Figure 40.

Expanding the rubber sector would provide positive externalities: eg. It would create jobs in a sector where the country already has experience and capacity. However, the availability of labor is a barrier in some low population density regions, such as Altillanura. Further, despite the potential economic and environmental benefits, armed conflict has been a barrier for rubber expansion, particularly in the Amazon region where producers have been reluctant to plant large areas—and must be resolved.

Figure 40 | MAC curve - forestry and rubber plantations



Source: Authors

Forest plantations in the Caribbean region show the lowest cost per reduced ton of CO_2, while those in the Amazon region have a higher but still negative cost. Regarding mitigation potential (measured on the horizontal axis), measures in the Orinoco region offer by far the largest, which relates to the potential scale (hectares) of the effort.

(3) Oil palm plantations

Oil palm plantations could contribute significantly to mitigation due to their rapid growth, high biomass accumulation, and perennial nature. Interest in Colombia has also been stimulated by the government's biodiesel mandate program, begun in 2008.

Colombia is the main oil palm producer in the Americas. Commercial production began 50 years ago, and is currently in the north, central, eastern and western zones (Ospina, 2007). These plantations account for less than one percent of total agricultural land, or about 0.3 percent of the total country area (FEDEPALMA, 2011). In 2010, they covered 404,104 ha (approximately 160,000 ha for biodiesel production (FEDEPALMA, 2011)), contributing 2.6 percent of agricultural GDP and 0.22 percent of total GDP (MADR,

59 It is assumed that 50 percent of the carbon stored in timber would be released into the atmosphere at the time of logging.

2011). The eastern zone had the most plantations, with around 39.1 percent of the total area planted in the country. The oldest are in the north (28.5 percent) and central regions (28 percent). The western region has 4.5 percent of the country's oil palm area (FEDEPALMA, 2011).

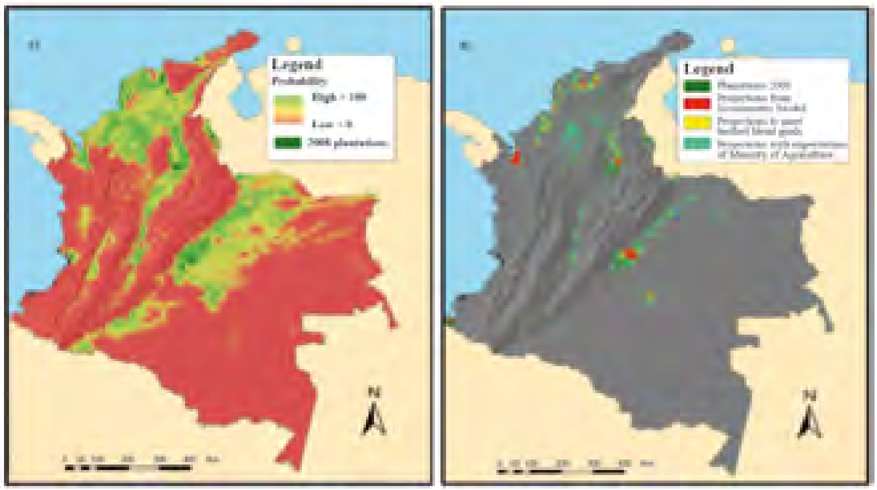
In 2009, the Ministry of Agriculture set a target of 3 million ha of oil palm plantations (Bochno, 2009) partly due to government mandates for biodiesel blending, along with offering economic incentives such as price supports, subsidies, tax exemptions, and preferential taxes (DNP, 2008). These tools were created to aid the biodiesel industry by reducing the risk and uncertainty in the prices of both raw materials and energy inputs.

Several problems have limited the plantations' development. (a) In some cases, they were created in regions with armed conflict and where there were clashes over land rights (Seeboldt and Salinas, 2010). According to Fajardo (2009), the expansion of the plantations was allegedly associated with a cycle of "land expropriation, peasant expulsion, commercial plantation implementation" in some parts of the northern zone. (b)Although limited in area, their expansion in the western region was mainly in previously forested areas (Seeboldt and Salinas, 2010). However, due to the high humidity and cloudiness, the "bud rotting" disease reduced plantations from 33,700 ha in 2006 to 18,000 ha in 2010 (FEDEPALMA, 2010b). In addition, poor infrastructure and land ownership disputes in Afro-Colombian communities have presented obstacles to development (Seeboldt and Salinas, 2010; BID-MME, 2012).

When the international biofuels market expanded and a national biodiesel program was created, this stimulated a good deal of interest in biodiesel production. Colombia set the ambitious goal of replacing 20 percent of diesel with biodiesel by 2020 (DNP, 2010). By 2010, most regions had launched the mandatory 7 percent volume blend, lower than the initial goal of 10 percent. The increase in domestic production of biodiesel subsequently reduced oil palm exports (FEDEPALMA, 2011). To meet the 20 percent national goal, another 600,000 ha were needed, for which the government began a subsidy program in several areas (Consulting Biofuel, 2007). According to this study, 1 million ha (400,000 existing ha and a projected 600,000 added ha) were projected for total oil palm plantations, with most of the growth in Meta, Tolima, Antioquia, Cundinamarca, Vichada, and Urabá (Figure 41).

A 2013 study by Castiblanco, Etter and Aide used econometric simulations to assess the projections for oil palm expansion based on the government's biofuel goals and the MOA figures (Figure10). The study incorporated government policies/subsidies and projected a growth of approximately 650,000 ha of oil palm by 2020, which is close to the 743,000 ha estimated by the palm growers association (FEDEPALMA, 2010a); but it is much lower than the 930,000 ha needed to meet the demand of a 20 percent blend in biodiesel and the MOA's goal of 3 million ha in production. Besides the projected 1 million ha expansion by 2020, the added 2 million ha needed to reach government goals would require major investments from the government and private investors. Also, recent free trade agreements with the U.S. and EU could indirectly reduce future oil palm plantations because the production costs of biofuels are currently higher in Colombia than in the U.S. and EU (Infante and Tobon, 2010; USDA, 2008).

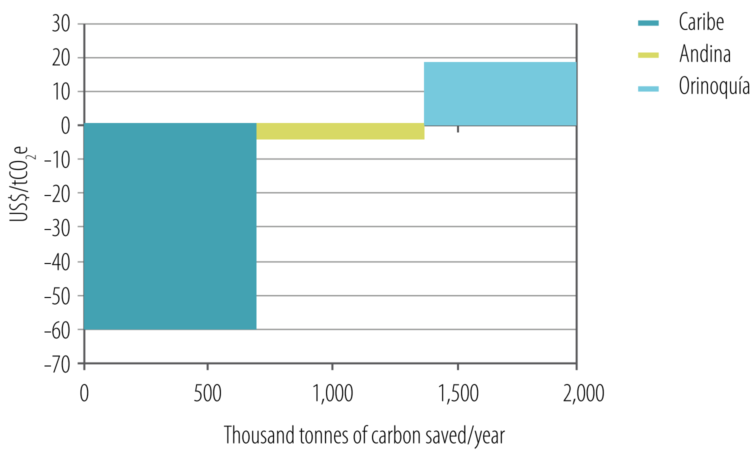
Figure 41 | Spatial model of future oil palm expansion: (a) probabilities according to the logistic model; (b) most probable spatial expansion in 2020, based on the total projected area from the econometric model (647,687 ha), the calculated biofuel blending goals (930,000 ha), and the MOA expectations (3,000,000 ha)



Source: Castiblanco, Etter and Aide (2013).

Palm oil production generates a negative cost per reduced ton of CO_2e from US$-5 to US$-60 in the Caribbean and Andina regions, respectively (Figure 42), but a positive cost in Orinoco.

Figure 42 | MAC curve - oil palm plantations



(4) Sustainable management of natural forests

The goal of sustainably managing forests is to maintain/strengthen the economic, social and environmental benefits of natural forests, along with the goods/services for the population. The program for natural forests will focus primarily on the Andean and dry forests.

Sustainable management can generate significant CO_2 mitigation since nearly half of the country is covered by natural forests that are managed without any type of sustainable strategy (FAO 2010). Such practices strengthen carbon sequestration capacities, contribute to GHG mitigation, soil protection, water regulation, biodiversity conservation, and provide an alternative livelihood for populations in or near natural forests.

The precise mitigation potential of the forest management measure cannot be defined, partly because of a lack of information on forest classification and status. The government has not yet presented a forest strategy describing priority zones appropriate for this type of activity. In 2010-2011, it was clear that destructive development had already weakened the resilience of some of the county's ecosystems: The torrential rains associated with "La Niña" highlighted the fragility of Andean forests and the negative effects of selective logging and large-scale cattle ranching, as evidenced by landslides and extensive flooding.

Besides reducing GHG emissions, the measure could generate positive externality benefits in terms of biodiversity, soil/water conservation, and increasing the resilience of forest ecosystems—which raises their capacity to deal with extreme climate events.

Although individual projects have been undertaken,[60] a national strategy for sustainable natural forests is needed to set protocols and management plans for the different types of forests and to propose alternatives for sustainable use according to social/environmental conditions. The Ministry of Environment and Sustainable Development (MADS) identified the need for this program, which, in 2009, began to update the National Forestry Development Plan. In 2010, the MADS described the loss and degradation of the forestry heritage, and of productivity and competitiveness, as well as the need to overcome problems of inadequate, uncoordinated institutional structures, weak financial capacity, and low levels of development in science, technology and innovation for forestry management. Conservation, restoration, strengthening of institutional capacity and sustainable use of forests were identified as the main actions needed to create sustainable forest management.[61]

C. Land use

(1) Reduced emissions from deforestation and degradation (REDD+)

REDD+ projects are proposed as a measure to control deforestation and forest degradation from poorly managed selective logging. REDD+ benefits acrue to the communities living in and around the forests and to private investors who buy and sell carbon credits from REDD+ programs. Under them, communities are given financial incentives to conserve forests and halt deforestation. In some cases, revenues from these programs can compensate for income no longer earned from the sale of timber or from transforming forested areas for crops.

Nearly 50 percent of the country's forests have been titled to Afro-descendant and indigenous communities and it is assumed that the most competitive REDD+ projects would be carried out in these areas. A conservative assumption is that REDD+ projects could be implemented on 2.5 million ha in the Amazon and Pacific coastal regions.[62] In addition, it is assumed the projects would be spread equally between the two regions, would mainly be carried out in forests with similar carbon stocks, and the current deforestation trends in these two regions would continue (see Table 7). Under these assumptions, the proposed measure would avoid deforestation of some 27,500 ha on the Pacific Coast and 12,500 ha in the Amazon region each year. On an aggregate scale, this would prevent nearly 40,000 ha a year of deforestation.

60 According to CAF, scattered, uncoordinated efforts were carried out to restore forest ecosystems on 161,892 ha.

61 *Manejo Forestal Sostenible en Colombia. Retos y perspectivas.* Viceministro de ambiente Carlos Castaño, 2011. Retrived from: https://www.dnp.gov.co/LinkClick.aspx?fileticket=-CU3W64dgqU%3d&tabid=190

62 On the Pacific Coast alone, nearly 5 million ha have been titled to Afro-descendant communities.

Based on IDEAM data, current annual deforestation of about 238,300 ha results in atmospheric emissions of nearly 20 million tons of CO_2 a year. Thus, REDD+ projects in part of the 2,500,000 ha of existing forest could prevent deforestation of 40,000 ha a year, corresponding to almost 3.35 million tons of prevented CO_2 emissions. The increase of REDD+ projects in the available 2,500,000 ha of forest would be introduced gradually until 2018.

For proposed REDD+ projects to be eligible under the UNREDD program, certain conditions must be met. These are: (a) the existence of a threat or real risk of deforestation or forest degradation in the area; (b) the existence of organized communities with solid governance structures; and (c) the autonomous decision of forest communities to commit themselves to the REDD+ project's conservation objectives. Also, to complement the economic incentives generated by the sale of carbon bonds, and to mitigate the financial risks of these projects, REDD+ projects may include added productive activities, such as managing and conserving biodiversity, or improving hydrological functions. These activities aim to generate more income through the sustainable use of forest resources. However, their complexity is one reason why the proposed REDD+ measure only extends to 2018, when the full 2,500,000 ha of REDD+ projects would be launched.

REDD+ projects represent a potential measure that could generate very low or no costs for the government, very low and generally decreasing costs for most communities, and extra income for communities. The size of the income will determine the ability of REDD+ projects to replace deforestation and other damaging activities that curently benefit individuals but which are hopefully in decline as rural communities adopt more sustainable forest management practices.

(2) Ecological restoration

Ecological restoration consists of aiding, introducing or accelerating processes that restore ecosystems which are degraded and have lost their capacity to provide services. The extent of degradation determines if restoration is economically and technically viable. If the goal is to simply recreate a degraded area, restoration is needed; but if it is to recover the services once delivered, it must be rehabilitated further. Finally, if it is to regain the ecosystem´s environmental usefulness, additional efforts and costs are typically required.[63]

Although no details exist about the level of carbon sequestration in different ecosystems, restoration offers an opportunity to mitigate problems because of the large extent to which the country's ecosystems have been degraded, and in the case of the *páramos*,[64] they may store as much as 300 tons of CO_2/ha in their soils.

Given the lack of details on costs and CO_2 sequestration potential in the major ecosystems, the degree to which emissions can be reduced cannot be estimated. Based on the National Restoration Plan, the most degraded ecosystems are natural forests, wetlands, páramos, and secondary vegetation, particularly in Antioquia, Boyacá, Córdoba and Magdalena. The cost of the measures vary widely, from US$2,500 per ha to US$10,000 (for highly degraded areas).

The strategy for ecological restoration should focus on those that have been destroyed and rebuild areas whose recovery is necessary for critical ecosystem services. In the latter, actions can be from US$2,000-US$5,000 per ha, excluding the cost of purchasing the land.

63 http://www.minambiente.gov.co//contenido/contenido.aspx?catID=1239&conID=7434

64 *Páramos* are high-altitude wetlands supporting wide biodiversity and containing peat soils. A large percentage of the world's *páramos* are located in Colombia.

Besides mitigation benefits, restoring the ecology can help with overall adaptation to climate change, since experts say that healthy ecosystems are more resilient: eg., The recovery of slopes and pastures degraded by intensive livestock activity could serve as filters for rivers, decreasing the amount of sediment and the likelihood of landslides, and preventing floods. Moreover, restoration has positive externalities in terms of increasing and protecting biodiversity. Experts say that damaged ecosystems are a major cause of the loss of biodiversity, which, among other negative effects, can lead to the loss of pollinator species that are vital to both natural systems and agricultural production.

To support restoration, the concept of paying for ecosystem services (PES) has gained momentum, backed by legal and regulatory policies over the past decade.

(3) Cropping systems in organic soils (Histosols)

Histosols, also known as peat soils, are composed mainly of organic material with high levels of moisture and store large amounts of carbon. When histosols come in contact with oxygen, oxidation occurs, which releases carbon dioxide. Histosols are generally covered by water and frequently drained by farmers to plant agricultural products. And, according to Wetlands International,[65] those in the (humid) tropics are estimated to store 10 times more carbon than ecosystems on dry land.

Colombia is among 76 countries with the highest carbon storage in histosols (peatlands) with an estimated one billion tons. Also, it is one of several developing countries that have had a 50 percent increase in carbon emissions from peat soil (predominantly because of their drainage, for agriculture) from 1990-2008.[66] (Joosten 2010).

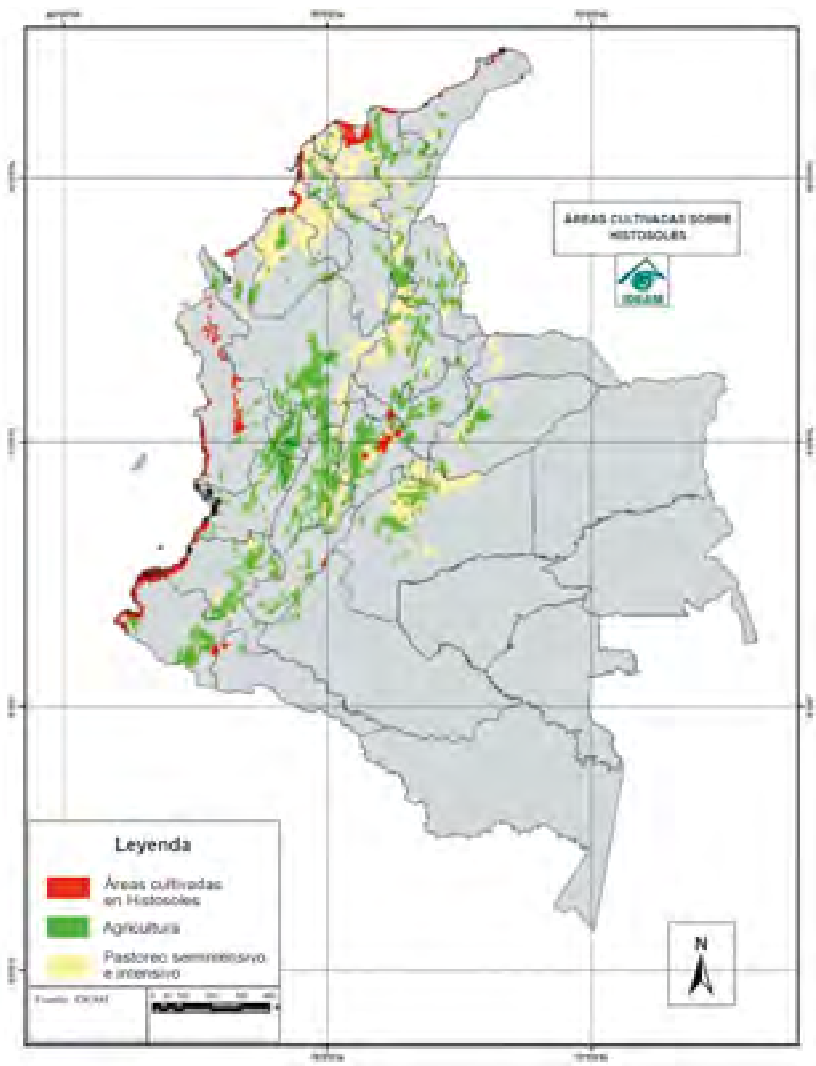
The proposed action would identify the location of histosols and create a program to prevent their drainage/removal for crops, thus conserving the carbon stored in the soil. Moreover, identifying and conserving them presents a good mitigation opportunity since histosols occupy a small portion of the country's territory but store significant amounts of carbon. At present, a large part of páramo soils are histosols that are used for potato crops.

Based on information for current histosol cropping (IGAC2003), IDEAM estimates that 1,124,349 ha were used in 2004, releasing emissions of about 42,540 tons of carbon (Figure 43).

65 www.wetlands.org

66 Hans Joosten, Greifswald University Wetlands International, Ede, August 2010

Figure 43 | Distribution of histosols in Colombia



Source: IDEAM, 2007. Based on soil maps from IGAC, 2002 and 2003.

Recovering/conserving histosols has positive environmental impacts besides climate mitigation: They house many animal and plant species (many endemic to Colombia), and also regulate and filter water resources. Farmers must be made aware of their importance for biodiversity and ecosystem services that are critical to sustain agricultural activities. However, it is likely that many histosols are on privately owned land, and as with ecological restoration, it will difficult to protect them from agricultural exploitation without policies and incentives.

D. Agriculture

(1) Efficient fertilization of the rice crop

Most Colombian rice farmers apply fertilizer according to a "calendar" method, applying certain doses in particular time intervals. Despite the convenience of this practice, many unaccounted factors must be considered to determine proper fertilizer levels, including soil characteristics, previous fertilizer use, the dominant vegetation, climate conditions, plant physiological requirements, expected returns from production, planting systems, crop varieties and densities, susceptibility to disease and "lodging" (when stems bend over to the ground). Lacking this information, fertilizer is often wasted.

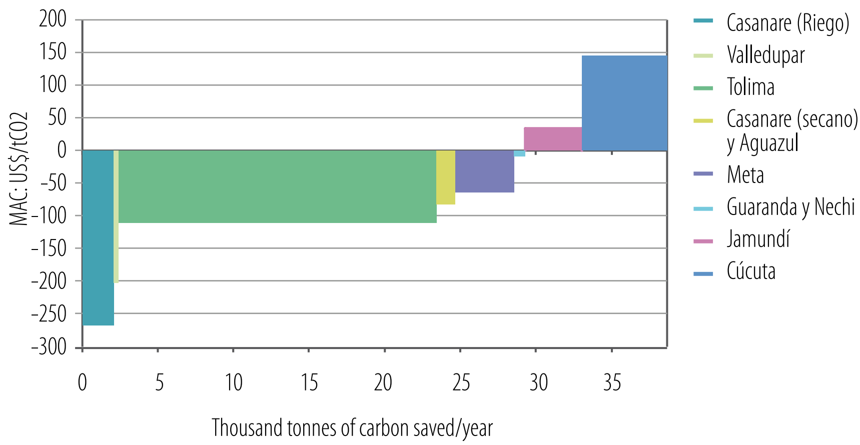
Globally, the ways plants absorb or take up fertilizer (called nitrogen use efficiency, or NUE), varies a great deal—from 25 - 34 percent for rice and 40 - 60 percent for other crops, with a global average of about 50 percent (Mosier, 2002). Global cereal NUE is reported to be 33 percent and it was estimated that an increase in NUE by one percent is worth as much as US$234 million in fertilizer savings (Magen and Nosov, 2008) .

To make fertilizers more efficient in rice production and reduce GHG emissions, two measures are proposed. For dry-grown or irrigated rice (unlike permanently flooded rice fields), the most appropriate measure is to help farmers through technical assistance (TA) about fertilizer use. For flooded rice plantations, the soil characteristics must be assessed to determine the appropriate regimen. In the former, the study proposes a measure that would cover about 150,000 ha of plantations, and assumes the fields would be managed with close support from TA personnel. In the second, 22,000 ha would be assessed for their land and soil suitability and, based on the findings, converted to flooded rice plantations. The municipalities targeted for the TA program include Nunchía, Villanueva, Espinal, Ibagué, Ambalema, Campo Alegre, Venadillo, Saldaña, Villavicencio, Puerto López, Fuente de Oro, Granada, Valledupar, Yopal, Villanueva, Aguazul, Guaranda and Nechí. Those targeted for flooded rice plantation measures are Jamundí and Cúcuta. Both measures seek to produce a better balance of nitrogen in the soil and reduce the need for fertilizers without adversely affecting yields and production levels. The TA approach would cost US$5 million and the soil assessment US$1.5 million. Cost efficiency for the carbon abatement potential varies, widely, with the cost per ton of CO_2 equivalent from negative US$267 in Casanare, to US$145 in Cucuta (Figure 44).

The measures produce benefits that have not been quantified, such as the potential to save water by improving the use of fertilizers. Such savings can be valuable for individual project developers given the high fixed costs of irrigation systems for large-scale projects. The benefits can include environmental improvement or potential alternative uses for the water. As with the TA program, benefits can also accrue from reduced contamination of water sources and eutrophication.[67]

67 Eutrophication—the over-enrichment of water by nutrients such as nitrogen and phosphorus—has becomes one of the leading causes of poor water quality. The two most acute symptoms are hypoxia (or oxygen depletion) and harmful algal blooms, which among other things can destroy aquatic life in affected areas.

Figure 44 | MAC curve: Efficiency of fertilizer use in rice



Source: Authors

Rice producers have benefited from free, state-provided TA for many years, which has created some problems. First, producers have come to expect the services will continue to be free. Second, public and in some cases private TA has not been sophisticated enough to determine optimal levels of fertilizer use, and some TA providers have simply promoted the "calendar" method. Also, high, inefficient levels of fertilizers have been promoted by technical personnel representing fertilizer companies.

Many farmers practice a trial and error approach to fertilizer levels or copy the techniques of neighboring farmers. The lack of solid advice, coupled with low efficiency of fertilizer nutrients, has resulted in lower than expected crop returns and has contributed to the perception that fertilizers are not profitable.

(2) Increase in fruit production: avocado and mango crops

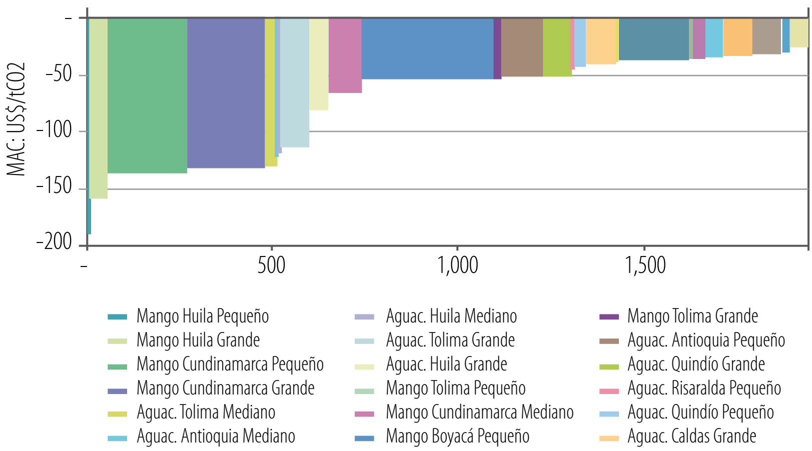
From 2000-2005, the average annual growth rates of avocado and mango exports worldwide were 13 percent and 7 percent respectively. In 2007, the trade balance for these exports in Colombia was negative: The deficit was US$1 million for avocados and US$6 million for mangos. Still, the crops could be produced in many areas now under extensive pasture systems.

This study evaluated the possibility of expanding areas with these crops: It found that a measure to cover 395,000 ha by 2040 would bring a total net carbon sequestration of slightly more than 1,900 tCO_2/year. The departments of Antioquia, Caldas, Huila, Quindío, Risaralda, Tolima, Boyacá and Cundinamarca were identified as the most promising areas.

Planting fruit trees, which has a long tradition in Colombia, is an attractive option even without considering its mitigation potential. Such plantations can be profitable and create jobs. The productive life span is estimated at 25 years for avocados and 30 years for mangos. Investment and O&M costs, as well as revenues, vary by region and the project's scale. Investments in both can be US$1,200-US$6,000/ha, while income can be US$2,000-US$12,000/ha/year depending on the quality of the site, and availability/distance to materials (seedlings, nutrients, fencing, labor).

Figure 45 shows that for both plantations, benefits exceed costs in all areas and at all scales of production (small, medium and large). The cost-effectiveness of all evaluated options is from US$-188 to US$-25/tCO2e.

Figure 45 | MAC curve: Mango and avocado crops



Source: Authors

Besides financial returns and potential GHG mitigation, the measure has positive indirect impacts associated with job creation, particularly during harvests. Despite the social and environmental benefits of such plantations, several challenges remain: (a) in the rural economy, the required investment is considered high; (b) the return on investment only begins around the seventh year, (c) the lack of sophisticated financial markets makes such long-term investments unattractive in developing countries, and even less attractive in countries where rural security is an issue; (d) the concept of avocado and mango as commercial crops is still relatively new in Colombia, and producer experience and technical knowledge is still limited, and (e) significant technical and institutional barriers exist for rehabilitating degraded pastures into productive cropping systems.

E. Summary of measures

Table 13 summarizes the results of low-carbon measures in the AFOLU sector, demonstrating that most of those proposed have benefits that are greater than the costs (“win-win”).

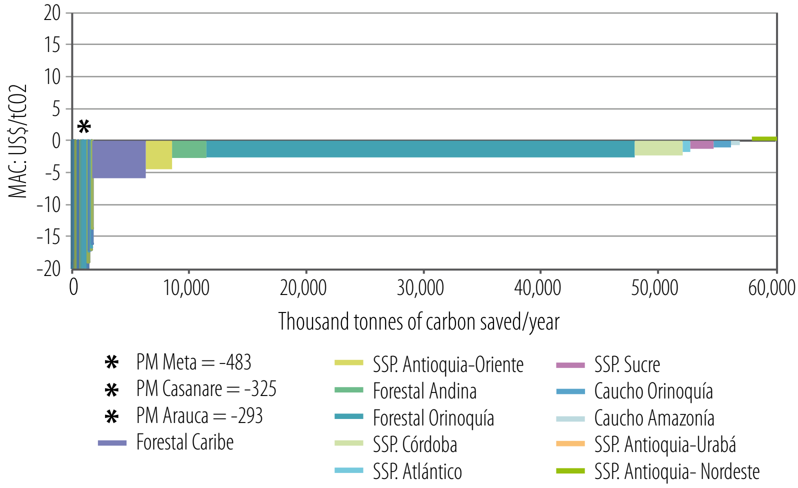
Table 13 | Investment, cost and potential mitigation from measures 2012–2040

Measures	Potential area evaluated (ha)	Investment per hectare ($/ha)	Abatement potential (thousands of tCO2eq/year)	Cost-effectiveness (US$/tCO2eq)	
				Min	Max
Intensive silvopastoral (ISS) projects	3,739,109	3,514 -4,018	28,895	-49	0.6
Improving pastures	51,487	3,143	54	-103	-62
Commercial forestry plantations	4,000,000	4,123-7,523	44,037	-4.4	-2.7
Rubber plantations	260,000	4,644	1,786	-1.05	-0.67
Avoided deforestation (REDD Projects)	2,250,000	-	65,874	-0.2	-0.2
Conversion of pastures to fruit production	395,000	1,184-2,966	1,938	-188	-25
Efficient use of fertilizers	170,000	1,000	38	-267	145
Oil palm plantations	1,000,000	4,734-6,908	1,971	-59.97	18.3
Total measures	11,866,000	-	145,040	-	-

Source: Authors

Based on the economic analysis of the measures proposed and for changes in land use, six of the eight showed a negative cost (net benefit), without considering externalities. However, the results vary widely in the costs per ton of reducing CO_2e. The wide variation also exists for the same measure in different geographic areas, from US$-188 to US$-0.67 per ton reduced. Intensive silvopastoral (ISS) projects and the use of fertilizers have positive and negative mitigation costs, depending on where the action occurs, proving that not all are profitable or cost efficient. Since location and conditions matter, they should be considered in public policies for prioritizing resources.

Figure 46 | MAC curve: AFOLU



Source: Authors

4. Overcoming Implementation Barriers

In 2010, two papers[68] identified policies to strengthen agricultural production and value added, and improve the sector's competitiveness. The findings demonstrated the need to increase sector productivity, reduce production costs, promote research and domestic consumption, and improve the quality standards of the products to increase access to foreign markets. Besides helping to overcome production barriers, more efficient land use and sustainable production practices would create more benefits, such as reducing GHG.

If the proposed measures are to be launched, conditions that have favored large-scale cattle ranches and limited the competitive expansion of the agricultural and forestry sectors must be changed. Developing these sectors will depend on the proper combination of land, capital, labor, and technology. The key barriers to each are described below, along with a general analysis of other barriers to low-carbon development. Overcoming them will depend on public policies that often may generate resistance from those benefitting from the status quo and may require building consensus with broad sectors of society.

A. Land

Colombia has created the following goals regarding displaced persons: Secure land tenure, restitution of land rights, and protection of property rights .

The country has a history of violent land takeovers, beginning in 1948 and erupting in a civil war fueled by armed conflict between the Revolutionary Armed Forces of Colombia (FARC) and paramilitary militias established by landowners, local elites, and drug traffickers. Colombia has one of the highest rates of internal displacement in the world: According to government figures, about 3.9 million people were internally displaced in 2011, and, based on Observatory on Human Rights and Displacement (CODHES) estimates, there were about

68 CONPES 3675. The national strategy to improve productivity in the dairy sector, Política Nacional para Mejorar la Competitividad del Sector Lácteo Colombiano, and CONPES 3676, Consolidación de la Política Sanitaria y de Inocuidad para las Cadenas Láctea y Cárnica.

5.3 million. This has fueled the country's rapid urbanization and created massive informal urban settlements where residents lack tenure security and basic infrastructure. In 2004, 1.3 million households (16 percent of urban households) lived in such settlements.

According to the Commission of Support to Public Policy on Forced Displacement, over 83 percent of internally displaced persons (IDPs) lost assets (livestock and equipment), and 42 percent lost land. Excluding land assigned by law to ethnic minorities and indigenous peoples, the estimated amount of dispossessed land is 6.6 million ha (or 12.9 percent of total farm land) from 1980-2010.[69] Overwhelmingly, small peasants have been the victims: 73 percent of dispossessed land was from plots up to 20 hectares, and 26.6 percent was from medium plots of 20 ha-500 ha.[70]

Also, in rural areas, land distribution is inequitable: Less than one percent of the population owns more than half of Colombia's highest quality land. Land tenure is insecure, particularly for indigenous peoples and families of households headed by women who have been forcibly displaced at disproportionately high levels. Successive government actions to foster land reform have been largely ineffective due to corruption within government institutions, as well as a lack of financial and human-resource capacity. In the early 2000s, the Government de-emphasized land reform and shifted the focus to rural development through the expansion of agribusiness.

Rural land tenure is still characterized by high levels of informality. A large proportion of tenants who claim ownership do not have property titles registered in the National Public Registry. This situation is most typical among small property owners, although it also affects larger land holdings. It has been estimated that about two thirds (68.7 percent) of the total number of hectares in the country are held without property titles. Although many of the untitled lands may have only the recognition of neighboring tenants of their historical possession, others may have (a) some form of private document, such as a promise of a future transfer ("*promesa de compra-venta*"), (b) a private transfer note ("*nota de compra-venta*") that refers to the actual transfer and possession, or (c) a non-registered-deed ("*escrituras de notaria*"), which would need to be registered in the National Public Registry to legally constitute ownership.

These issues are associated with attempts to increase palm oil and forest plantations, and other productive uses of rural land. Thus, to expand agriculture, the government must ensure the security of land tenure for current and future owners/possessors.

(1) Issues, challenges and opportunities

a. Rural land rights

A well-targeted land-rights program could help correct inequitable land distribution, increase agricultural productivity and environmental sustainability, and reduce rural violence. And, a window of opportunity may have opened since conflict in rural areas has decreased and a Peace Agreement with the FARC may be possible. However, the history of failed reforms points to the critical role of political will.

First, the rural cadastre should be completed. Next, the government and donors could explore avenues to expand pilot land and property rights projects that have proved successful

69 Draft Strategy Note, Armed Conflict and Forced Displacement in Colombia- The Search for Durable Solutions, July 2012, World Bank, unpublished

70 UNDP. "Colombia Rural": pp. 277-278.

in formalizing and restoring property rights in rural areas: eg., The government could make better use of adverse possession laws to secure the rights of informal tenants and revisit policies to encourage large landholders to sell land or enter into long-term leases to make land available to small-scale farmers and laborers. If successful, such pilots could be replicated in other areas that are stable or relatively stable.

b. Impediments to land market efficiency

Tax incentives and government subsidies support the wealthy's large landholdings even when the land is under-utilized. They create land-market inefficiencies, block the distribution of land rights to the most productive users, and continue socio-economic disparities in rural areas.

As a preliminary step towards greater land-market efficiency and more balanced rural land distribution, the government should remove tax incentives and subsidies that provide distorted support to large landholders.

c. Resolving disputes

Colombia's land disputes hinder rural development and poverty reduction. Thus, new efforts are needed to mediate and resolve conflicts based on land and natural resources. The government and donors could support Colombia's para-legals in order to launch a comprehensive, expedited land-mediation initiative to resolve land tenure issues.

d. Internally displaced persons (IDPs)

Colombia has 3.1 million officially registered IDPs. Thus, a priority must be to provide them with secure tenure and connect them to government services and job opportunities. The Law of Victims and Restitution of Land of 2011 requires the government to restore land to IDPs and provide support services and reparations in rural areas. However, much work must be done to fully implement these programs.

For many IDPs, return to their place of origin is not feasible or even desired. Thus, the government could introduce a comprehensive urban integration strategy, including the formalization of informal settlements where IDPs live, along with job training and technical and legal assistance. The restitution program for IDPs includes a component focused on women and indigenous and Afro-Colombian communities, who are a large proportion of the displaced.

e. Gender

Although the government has enacted laws that promote women's rights to land and property, female-headed households are especially susceptible to poverty and forced displacement. Thus, a focus on implementing these laws (to protect women's rights to land) could improve living conditions for women and children. The government and donors could launch gender training within land-administration bodies along with a legal awareness/legal aid campaign to increase awareness of women's rights, and to empower women to exercise them.

B. Capital

(1) Lack of security

For investors, security is a critical factor. The armed conflict, which was mainly in rural areas, is considered the main reason why investors have eschewed agricultural investments. Although national and foreign capital invested in rural areas has begun to increase in recent years, due to reduced violence, the trend must continue, which will require not only the presence of the armed forces in various areas for some time to come, but also a local police force and improvements in public institutions and infrastructure.

(2) Long-term credit and legal stability

To attract investments, the financial sector must offer long-term funding and the legal system must enforce contracts. Financing is critical when projects need large investments (relative to local financing needs) that are only recovered in the long term. These factors partly explain why forestry projects have attracted low levels of investment although they offer relatively high rates of return over the longer term. Further, access to credit for many smallholders is limited by a lack of knowledge and high transactions costs.

(3) Limited infrastructure

A key factor affecting Colombia's competitiveness is the lack of investment in telecommunications, transport, energy, water, and other public works' infrastructure. This creates a vicious cycle in which poor infrastructure leads to limited investment in rural areas which, in turn, discourages investments in infrastructure. Strong leadership and investment by the State is often needed to get out of this pattern. Several mega-projects are being introduced, and if well-implemented, will help increase private investments in the agricultural and rural sectors. The development of multimodal connectivity in Altillanura, the rail project in Carare, and increased navigability of the Meta, Putumayo and Magdalena rivers are some of the projects that will positively affect the development and competitiveness of agriculture and forestry.

Besides transport infrastructure, the country lacks adequate irrigation in many departments. Of the 6.6 million ha of potential land available, only 900,000 ha have improved irrigation and drainage infrastructure (Leibovich & Estrada 2008). The absence of such systems limits crop productivity, means production costs cannot be reduced, and makes the areas vulnerable to increasing short-term climate variability and medium- to long-term climate change.

(4) Smallholder access to credit

Small farmers face barriers to obtaining credit for agricultural investment. These include: (a) most credit programs are provided through the commercial banking sector that has various requirements which disqualify most smallholders, (b) the transaction costs to process credit applications are prohibitive and (c) they are vulnerable to climate and pest risks due to their lack of adequate insurance and other risk-mitigation instruments. According to Leibovich & Estrada, the resources available for credit through FINAGRO are limited and often given to medium and large producers that already have greater access to the commercial banking sector. Moreover, for the conversion of productive systems to occur, access to subsidies like the ICR (*Incentivo a la Capitalización Rural*) is contingent on access to credit through the commercial banking sector. Last, small farmers often have little understanding of banking requirements as well as the benefits and risks of agricultural loans.

C. Technology

(1) Limited research

Colombia has many institutions that study agriculture, livestock and forestry issues, such as CORPOICA, CONIF, CIAT, universities, and research centers (*Centros de Investigación,* CENIs). However, investment in research as a proportion of agricultural GDP has historically been low as have innovations in agricultural technologies and improvements in yields.

Investment in research and development (R&D) by the public and government sectors decreased from 1990-2006, from 71.4 to 71.1 and 42.5 to 34.5 (equivalent to 2005 dollar values) respectively. While NGOs and academia increased their contributions, the increase was insignificant (US$4.5 million and US$2.8 million 2005 dollars over 16 years).[71] Given the historical research deficit undermining the country's competitiveness, the proposed creation of the Fund for Science and Technology with 10 percent of revenue from mining royalties, could help develop technology and innovations.

The Amazon and Orinoco regions have long been considered marginal in terms of agricultural and forestry development and little research has been conducted there. However, these regions contain a large part of the carbon mitigation potential. Thus, it is necessary to better understand their soil characteristics and hydro-meteorological cycles as well as to develop suitable technology packages. To this end, agencies like Brazil's EMBRAPA, which has had a good deal of success in developing globally competitive agriculture in ecosystems similar to those in the Orinoco and Amazon regions, could help. Moreover, Brazil has many lessons on how to avoid land conversion practices and other pitfalls that have negative environmental/economic impacts.

(2) Technical assistance (TA) and technology transfer

To achieve gains, it is important that currently available technologies be adopted or properly introduced. However, TA in the agricultural sector is still in its early stages. This is particularly problematic for producers who are not associated with trade associations, such as those producing coffee. Thus, farmers have generally not introduced silvopastoral projects, converted to fruit production or expanded forestry and rubber plantations because they lack the TA. Thus, farmers must be trained and pilot projects developed for demonstration and replication.

Regarding the new REDD+ initiatives, regional environmental authorities and local/regional governments lack knowledge about the features, objectives, and project management mechanisms.

(3) Vulnerability to climate change

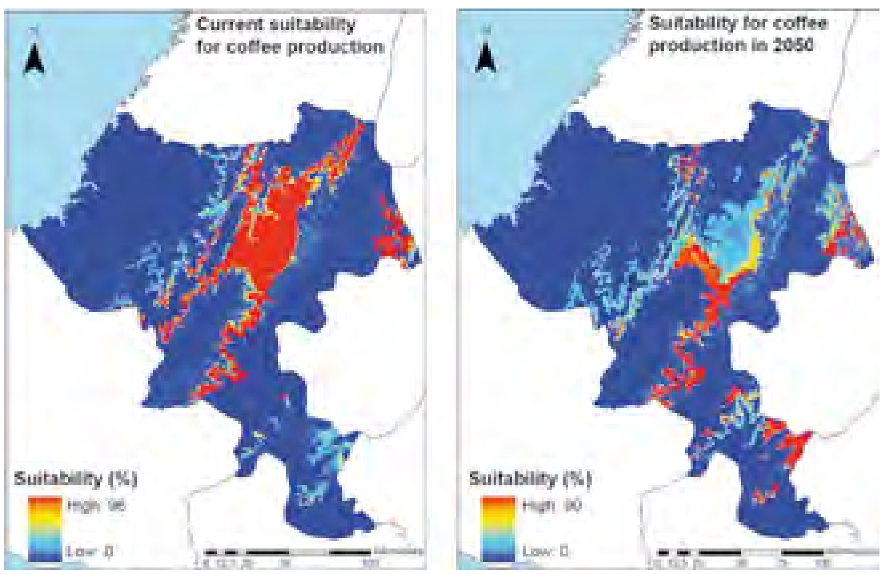
Because agriculture represents 10 -14 percent of national GDP, and 3.7 million of 47 million Colombians rely on it for income, climate change effects are a serious concern. According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability to climate change is defined as the degree to which geophysical, biological, and socio-economic systems are

71 Reporte ASTI (Agricultural Science and Technology Indicators) para Colombia a 2006. Consultado abril 2012 http://www.asti.cgiar.org/data/

susceptible to and able to cope with its adverse impacts. Thus, farmers (particularly small ones), are vulnerable and need to cope with changing precipitation patterns, extreme weather, and the increased risk of droughts, floods, pests, and fires.

For example, Colombia is the world's fourth largest producer of coffee and the world's second largest Arabica coffee exporter. The upper Cauca river basin is a strategically important part of the coffee zone, which produces 45 percent of the crop. Because the cultivation of weather-sensitive coffee requires ideal conditions—the correct mix of temperature, rainfall and dry periods—local growers need to adapt to different weather and climate patterns. They already face challenges as yields decrease due to rising temperatures and more intense and unpredictable rains, two features that will become more common. According to CENICAFE, the national coffee research center, average temperatures in the coffee regions have risen nearly one degree over the past 30 years, and in some mountain areas, more than two. Such changes mean that the land suitable for growing coffee will decline significantly by 2050. As temperatures rise, areas considered suitable are at higher altitudes; however, there is limited land there, and competition with other land uses, such as forests and protected areas, could arise. In areas that are no longer suited for coffee by 2050, farmers will need to find alternative crops or change occupations (Figure 47).

Figure 47 | Areas suited for Arabica coffee production over time, due to climate change in Cauca, Colombia



Source: CIAT 2011

It should be noted that fruit trees and other perennial crops are good options for diversifying crops and replacing coffee over the longer term. Such crops provide many environmental benefits such as biodiversity, water, groundwater recharge, erosion control, and carbon sequestration.

Agriculture will be one of the sectors most affected by climate change, however most current technologies and production models have not considered the effects. Thus, during extreme climate events, such as La Niña in 2010–2011, there were huge drops in the yields of several crops, including coffee. Given this challenge, new technologies that can adapt crops to climate change must be developed.

D. Labor

(1) Violence and abandoned farms

The main consequence of the armed conflict has been the out-migration of the rural population to the cities. Often, crops were abandoned and peasants who still held property titles were prevented from returning to their farms due to the lack of the necessary capital to recover them and make them productive. Others became accustomed to urban life, acquired jobs and now do not intend to return to rural areas. Reversing urbanization is difficult, even without the "push" factors that accelerated it. However, some of the population could be encouraged to return through schemes such as land restitution, granting seed capital, TA, credit, connections with marketing channels for products, and physical security. At present, where land suitable for large-scale production is available (eg., Altillanura), labor is scarce; but it is expected that the demand could gradually be satisfied (workers would migrate to the areas) if salaries and social services were competitive.

(2) Low education levels in aging population

The current rural population is aging without being replaced by younger workers. Moreover, due to the significant investments made to provide primary and secondary education nationwide, farmers' children now have more education than their parents, increasing the opportunity cost of working in traditional low-skilled agriculture.

(3) Mining/energy booms and labor costs

The current energy and mining boom has raised expectations and caused inflation in those regions. Besides changing young people's aspirations, the boom may raise the risk of "Dutch Disease", whereby the prices of inputs such as land, freight, labor, and materials increase, and pulls labor away from "lagging sectors" (such as agriculture or manufacturing). For many rural residents, it is economically more attractive to get even a temporary job in mining or petroleum than to work the land.

(4) Others

a. Traditions

Barriers that prevent new technologies and production processes from being adopted are often cultural. In particular, it is difficult to convince cattlemen using traditional methods to participate in schemes to improve pastures or to shift to silvopastoral systems. Such barriers must be addressed through education and training programs, and demonstration projects.

b. Lack of information

A key barrier to analyzing low-carbon options in agriculture and forestry is the lack of information: The country is lagging in studies of fertilizer consumption by type of crop and optimum use, and of estimating emissions from deforestation and degradation. Also, there is little understanding of how carbon is captured and stored in soils, and how this varies by different uses and soils. Thus, programs such as REDD+ can increase knowledge.

c. Crop diversification and GHG strategies

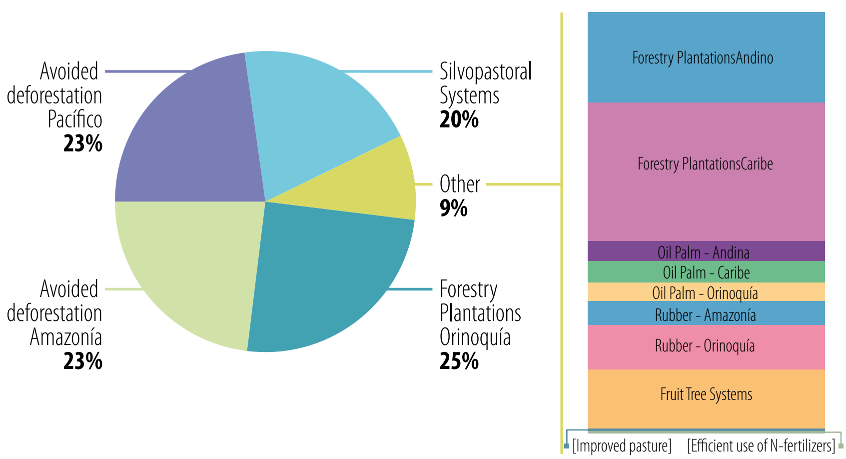
Because Colombia's agriculture is highly diversified and no one crop dominates production, it is difficult to introduce standardized projects nationwide, such as on the efficient use of fertilizer or for best practices. Thus, there must be a common agenda across agricultural sub-sectors that promotes new technologies that use less fertilizer and produce higher economic returns.

F. Conclusions and recommendations

This chapter described how enlightened natural resource management (conserving forests and preventing deforestation) and expanding new forestry, silvopastoral, and plantation crop systems could reduce GHG emissions (Figure 48), improve rural incomes and environmental services, and create resilience to climate change effects.

In agriculture, silvopastoral systems offer more sustainable practices to produce livestock and contribute to biodiversity by creating biological corridors.[72] Besides providing shade, the planting of leguminous trees and forage species offer higher quality nourishment to livestock which reduces the need for nitrogen fertilizers (and their GHG emissions) as well as the herds' methane emissions. Also, multi-crop production systems are less vulnerable to market and price shifts, and to the effect of pests and diseases, although they require more intensive management than monocrops.

Figure 48 | AFOLU categories and their GHG mitigation potential up to 2040, using 2012 baselines



Source: Author calculations

Deforestation that is prevented contributes to sustainability and resilience by preserving biodiversity and forest habitats, and helps maintain the ecosystem functions of soil and water. To avoid further deforestation, measures are required:

72 Biological corridors refer to contiguous parcels of land that facilitate the movement of animal species to access food or breeding habitats.

(1) Promoting forest plantations to avoid pressure on timber resources in natural forests

(2) Providing incentives for alternatives to slash and burn agriculture by giving titles to land; its use can then be intensified and prevent forests from being cleared

(3) Exercising greater command and control at federal levels

(4) Making institutions that provide credit for AFOLU (eg., local development banks, as in Brazil) accountable for any illegal deforestation.

Ironically, one of the risks of low-carbon development is the impact of climate change, ranging from the effect of droughts and floods on hydropower production, to the impact of temperature changes and water availability on crops, livestock, and tree production systems. However, many of the resilience attributes described earlier in the low-carbon AFOLU measures offer potential "win-win" opportunities to not only lower GHG emissions but also enhance the resilience from field to landscape, and thus would lessen the effects of climate change.

The main conclusions are:

(1) Harnessing the synergies between climate mitigation and adaptation (resilience to climate shocks) is a high priority. To properly assess the costs/benefits and prioritize AFOLU measures, Colombia must make state-of-the-art assessments of the potential climate change impacts over the next 3-5 decades on agriculture and forestry.

(2) Due to the relatively low level of agricultural R&D in recent decades, the research agenda and TA capacity are in their early stages (especially when compared to Brazil and Argentina). Thus, improving national R&D and TA capacities is a critical goal: Action is urgently needed to improve agriculture and forestry management and ensure the success of innovative low-carbon activities.

(3) Agriculture and forestry are at a turning point and experiencing a major revival due to (a) the recent Free Trade Agreement (FTA) with the US, (b) the revival of annual and plantation crops and livestock production in the Orinoco region, and (c) rapidly increasing demand from national/international investors due to improved security.

(4) The AFOLU sector contributes the most to the country's GHG emissions due to extensive livestock production, inefficient use of fertilizers, and deforestation resulting from the expansion of agriculture, timber, and mining. That said, the sector also offers the largest potential for cost-effective carbon emission reduction and sequestration (mitigation) through sustainable land use practices.

(5) Locally adapted silvopastoral systems and improved pastures should be a priority for the livestock sector since such practices can be more productive, less environmentally damaging, profitable, and make better use of land than extensive livestock. A more intensive agricultural sector will require an improved and more efficient use of fertilizers and rapid adoption of "best practices."

(6) Restoring degraded ecosystems is recognized as a national priority. However, there is little information on the economic benefits relative to the costs of restoration. More

studies are recommended so that appropriate policies/programs can be developed. To this end, south-south collaboration would be useful, to learn from the experiences of Brazil, Costa Rica, and Mexico.

(7) Perennial tree crops are a highly promising, low carbon option. Forests, oil palm, rubber plantations, silvopastoral systems, and perennial fruits (avocado, citrus, mango) are economic and provide significant potential for carbon sequestration.

(8) Large-scale development of perennial plantation crops will require careful legal and fiscal policies: This means strengthen and accelerate the implementation of the Governments policy of restoring land seized by armed elements to the rightful owners in order to promote a more equitable and efficient land market. Other policies needed include infrastructure and institutional development in the areas being expanded, but in an environmentally and socially sustainable way.

(9) Opportunities exist to significantly reduce emissions linked with ruminant livestock (enteric fermentation) and nitrogen fertilizers. Low carbon policies that bring more efficient use of resources (thus reducing emissions) and develop productive activities (eg., silvopastoral systems) should be priorities.

(10) To avoid deforestation, measures are needed to: (a) promote well designed and strategically located forest plantations to deflect pressure on natural forests, (b) remove perverse laws and policy links between land titling and deforestation (including slash-and-burn agriculture), (c) strengthen command and control measures, (d) provide forest certification of origin agreements, and (e) create incentives for conservation.

(11) To tap the significant carbon sequestration potential of the AFOLU options, it is crucial to (a) continue improving rural security and protecting/restoring land rights, (b) enhance the efficiency of land markets, and (c) ensure equitable participation by all groups, especially marginalized indigenous and Afro-descendant communities.

CHAPTER 5
Macroeconomic Analysis

1. Background

This chapter will assess the low-carbon activities described earlier within a macroeconomic context. Ultimately, Colombia needs to know how low-carbon development might affect macroeconomic indicators such as national income and employment. Beginning with a review of the cost-benefit methodology used in the sectoral chapters, the analysis describes how the macroeconomic assessment was conducted for various low-carbon activities, and discusses the findings.

The preceding chapters evaluated the costs of low-carbon measures, the potential for reducing GHG emissions, and the externalities (eg., reducing air pollution in cities), and discussed some of the barriers to implementation. An important limitation of the cost-benefit methodology was the partial analysis of each measure, which did not assess potential spillover effects on the larger economy. Because this study aims to provide an overall perspective of a low-carbon strategy, the macroeconomic analysis offers a broader view—determining if actions in one sector spell higher costs to the economy, and thus reduce national income and employment, or have other negative (or positive) impacts.

One example of the positive effects that cannot be evaluated in a cost-benefit analysis involves the forestry sector. While plantations are one of the most promising activities in terms of cost and mitigation potential, particularly in Orinoco, the sector's growth will mean increased demand for inputs, which in turn will contribute to the income of other sectors. Also, a considerable increase in labor will be needed to expand forestry, which will generate a greater flow of resources to households, exerting pressure on production and further increasing GDP. This chapter introduces a different tool to evaluate these effects.

A. An applied general equilibrium framework

To explore the macroeconomic impacts of a low-carbon development, this study used an applied computable general equilibrium model (CGE) developed by the Department of National Planning.[73] Such models are typically built with an "intermediate" level of aggregation,[74] and include different types of economic agents, such as consumers, producers, the government, and the external sector.

73 The model was developed in the Study of Economic Impacts of Climate Change in Colombia (*Estudio de Impactos Económicos del Cambio Climático en Colombia, EIECC*), conducted by the Subdirectorate of Sustainable Environmental Development of DNP.

74 "Total" aggregation is understood as ignoring the existence of sectors, and works with aggregates such as consumption, investment, and government expenditures. Economic growth models tend to be built with this level of aggregation.

The model explicitly considers the relationships that characterize an economy, and has proved effective for understanding broad and long-term macroeconomic growth and structural change. In economic language, such models overcome the limitations from partial equilibrium exercises (such as cost-benefit analysis) through the use of an integrated, consistent analysis of the economy, known as "general equilibrium." Here, all elements of the economic system are connected with each other, and feedback from one part to another is explicitly considered. The model's specific features are described in Box 6.

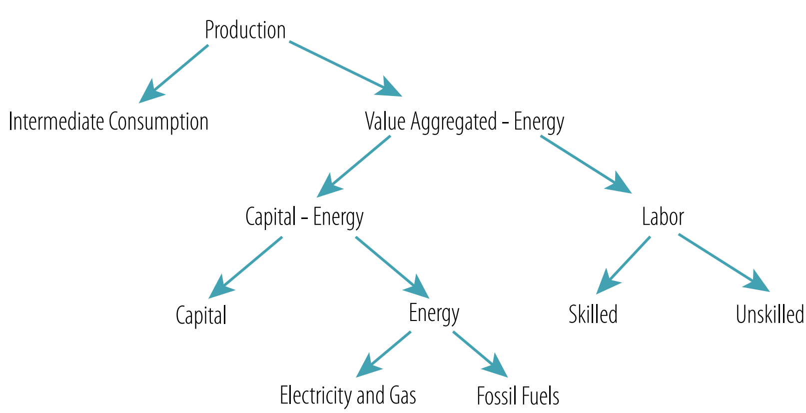
Box 6 | Applied General Equilibrium Model (MEG4C)[75]

The *MEG4C* is a Recursive Dynamic General Equilibrium Model used to analyze the economic impacts of climate change and related issues in Colombia. It considers the different links that characterize a complex economic system so as to obtain a more complete picture of the consequences of climate change, and develop/apply better public policies.

It is based on the *GREEN* model (General Equilibrium Environmental Model) developed by the OECD to quantify the effects of policies to reduce GHG emissions (Nicoletti, Bourneaux, & Oliveira-Martins, 1992). The MEG4C model is based on neoclassical economic theory. As such, the decisions of agents (sectors and households) stem from a utility maximization process, and prices are assumed flexible to ensure equality between supply and demand in the market for goods and factors of production.[76] The partial disaggregation of the model is in 15 sectors, two of which are energy,[77] and has four agents: (a) households, (b) sectors, (c) the government, and (d) the external sector.

The model has a structure of production as shown in Figure 49. It assumes no substitution within the goods in the intermediate consumption bundle and between it and the value added – energy bundle. In the other stages of production, the substitution possibilities are modeled using a constant elasticity of substitution (CES) production function.

Figure 49 | Structure of Production



75 The following describes only the model's key features. For a more in-depth description, see SDAS-DNP, 2010.

76 An exception is the market for unskilled laborers, in which rigidities are introduced to endogenously generate unemployment (with the wage curve following the efficiency wage literature).

77 Non-energy goods are agriculture, livestock, forestry, fisheries, mining, water and sewerage, food and beverages, construction, machinery, manufacturing, commerce, transport and services, while the energy sectors are fossil fuels, electricity and gas.

The trade portion of the model follows the standard specifications of other CGEs. With respect to exported goods, the sectors optimally allocate the supply to the domestic or the foreign market, given the maximization assumption and a constant elasticity of transformation (CET) function. The import of goods is modeled following the Armington assumption (Armington, 1969), while the allocation of demand between domestic goods and imported goods is obtained from the cost-minimization of a CES function. The foreign market is composed of just one region, which groups all of Colombia's different trade partners.

For final consumption demand, households are modeled through a unique representative household, which maximizes an Extended Linear Expenditure System (ELES) function. Household income is used to pay taxes, consume goods, and contribute to savings.

There are three main macroeconomic closures that characterize the model: (a) investment-savings, (b) public investment, and (c) the external account. In the first case, a neoclassical savings-driven closure is used. While households' saving rates are fixed, investment adjusts so as to equilibrate market factors. For public investment, a fiscal neutral closure is used; public savings are fixed, and some of the taxes endogenously adjust. For the external account, it is assumed the exchange rate is fixed, while the external balance is free to adjust.

To calibrate[78] the model, four main data sources were used: (a) the System of National Accounts (2005) to build the Social Accounting Matrix,[79] (b) government data for the external and fiscal account, (c) the main macro assumptions of this study to project the growth rate of real GDP, and (d) the Greenhouse Gas Inventory for 2004 (IDEAM, 2009) to obtain the emission coefficients.[80]

The temporal structure of the model consists of a static component and a dynamic one. The former is calibrated to the Social Accounting Matrix for 2005, and is solved one period at a time. For the latter, a recursive dynamic is used; in each period, some variables and parameters are updated according to the results obtained from the static module; others are calibrated to obtain a path for specific macroeconomic variables (real national GDP, public savings, fiscal account, external account, unemployment, population growth). With this new data, the model's static component is used again to obtain a new equilibrium for the next period.

B. From cost-benefit analyses to macroeconomic evaluations

The link between the cost-benefit analyses and macroeconomic evaluation "should be understood as a mapping problem between two different analytical structures." (Villalba Pardo F. D., 2011) Each tool has its own variables and relationships, with the former focusing on the microeconomic decisions of households and enterprises, and the latter contributing to a broader understanding of the economy as a whole. To understand the difficulties involved with a link of this type, it is important to examine how the connection is made and the quantitative variables are linked.

First, it is necessary to associate each relevant variable from the cost-benefit analysis with the corresponding variable of the CGE. For the former, nearly all low-carbon measures contain four key variables: Investment in capital, changes in the demand for energy products (derived from petroleum, other minerals or electricity), changes in O&M costs, and reduc-

78 "Calibration" is the process needed to make the model reproduce data from a base year as a solution. This is achieved by adjusting certain parameters, some of them according to exogenous data (such as elasticities), and others according to data from the Social Accountability Matrix (see next Footnote for a brief description of this concept).

79 "A social accountability matrix SAM (*matriz de contabilidad social*) is an organized means of describing the set of economic transactions performed in an economy during a determined period of time (generally one year)." (Pardo & Corredor, 2008). For a detailed description of the construction of the SAM used, refer to the document cited.

80 The emissions coefficients are associated either with the consumption of energy goods (by the sectors and households), or with the gross output of the different sectors.

tions in GHG emissions.[81] Although the link with the macroeconomic analysis may appear simple, since all these variables are more or less represented in the CGE,[82] the problem arises when trying to change some elements of the CGE according to the cost-benefit analysis. This chapter describes the approaches to address this.

Another problem concerns the magnitude of the variables. The degree of aggregation differs from one structure to another, and it is necessary to establish proportionality factors that determine the weight of the cost-benefit analysis variable on the CGE variable. For example, all measures proposed in the transport sector only involve land transport, while the CGE considers the larger more aggregated sector, including air and water transport. The proportionality factor may be determined by calculating the weight of the transport sector within the CGE's transport sector.[83]

The other part of the linkage problem is more complex. The key result of the cost-benefit methodology is a measure of the cost-effectiveness of the actions, expressed as the cost (in U.S. dollars) to reduce a ton of CO_2-equivalent.[84] Thus, there are two different groups of variables: those used to determine the cost of the activity, and those to identify the tons of CO_2 reduced. Both are obtained by comparing the "with" and "without" project cases. The first element of the linkage is to define a baseline scenario for the CGE, which is achieved by simulating the model up to 2040 without considering the changes due to the proposed mitigation measures. All the exercises are contrasted with the baseline scenario.

A problem arises when using the CGE to jointly reproduce the cost results and the tons of CO_2 reduced at the same time. Under the cost-benefit methodology, the costs are calculated based on technological or behavioral changes, and the CO_2 reductions are the result of these changes. This implies that the relationship between costs and emission reductions stems from the assumptions and parameters used to analyze the interventions. But, trying to jointly reproduce the costs and emission reductions in the CGE raises several issues. The partial nature of the cost-benefit methodology does not consider the effects of feedback from the activities that may alter the results in terms of reduced emissions.[85] This feedback is examined in the CGE by virtue of the general equilibrium analysis. The difference between the two analytical approaches restricts the joint use of these same parameters, meaning that the cost and reduced emissions indicators from the cost-benefit analysis and those from the CGE will not be exactly the same.

For this study, the two elements of the cost-benefit methodology were produced separately. Thus, one exercise seeks to reproduce the changes in the cost structure of different activities (for example, demand-side measures and the growth in the forestry sector), and another seeks to reproduce changes in reduced emissions (CO_2 taxes).

Another issue related to linkage, is the nature of changes in the variables associated with the different actions. In general, all the measures entail changes in the structure of household demand of a sectors' production. With households, consumer goods such as lighting and appliances are replaced with those that are more expensive but also more energy efficient. In the case of supply, the various measures imply changes in technologies and production. These, together with the time period of the study (30 years), brought significant changes in the overall structure of the Colombian economy.[86] As an approximation, the study exogenously alters some of the model's parameters.[87] This approach may appear inconsistent

81 Co-benefits may be very important for some measures. However, these are beyond the scope of the CGE.

82 The first two variables are represented in the CGE by the demand for capital and energy products, while the third can be included in the demand for any specific intermediate consumer good(s).The last variable, emissions reductions, is more complex, and will be addressed in the discussion of the macroeconomic exercises and their results.

83 For example, if the land transport sector represents 50 percent of the aggregated transport sector, and the reduced CO_2 emissions from land transport are estimated at 30 percent for 2030, then the emissions reduced in the aggregated transport sector should be approximately 15 percent.

84 For convenience, the use of the term CO_2 refers to CO_2-equivalent emissions.

85 For example, a measure such as electric vehicles involves reducing emissions by replacing gasoline with electricity. However, this measure may generate greater reductions than expected if one considers that the higher cost of imported goods (assuming the electric cars are imported) will have negative effects on the economy, reducing household disposable income and decreasing the consumption of all goods. If the reduction in gasoline is higher than expected, the reduced emissions will correspondingly have to be higher.

with economic theory, where the ideal is to try to change the behavior of agents through various incentives (such as prices or taxes). However, such an approach is limited with regard to this study's objectives. The incentives traditionally used in the context of general equilibrium models are fiscal variables like taxes or subsidies that are adopted by policymakers.[88] However, it is clear the government has a broader range of tools beyond these two that are not easily represented in CGE models. Within the framework of the present study, and due to its "long-term" nature, it was reasoned that many of the proposed measures will not occur simply because of changes in taxes.[89] As a partial compromise, the effect of CO_2 taxes is evaluated in the second part of the chapter.

C. Macroeconomic assessment of low-carbon measures

As mentioned in the previous section, the macroeconomic analysis consists of two exercises: The first aims to reproduce the "cost structure" of some measures, and the second presents the reduced GHG emissions. Several of the limitations are unique to this study, which affected the range of the analysis.

Given the problems that arise when trying to exogenously generate changes in the investments of different sectors,[90] it was decided to analyze only a small number of measures, namely those related to demand-side management.[91] These can be modeled without the need to consider exogenous changes in investment. Although this clearly reduces the scope of the macroeconomic analysis, this approach was believed to be better than trying to force the model to obtain results regarding investment decisions by changing structural parameters such as the elasticity of substitution. The macroeconomic analysis of low-carbon development strategies is a growing field of research and at the moment lacks a consensus about the appropriate tools to simulate mitigation measures within a CGE model.

For the second exercise, taxes are levied on energy products in order to reduce GHG emissions. Here, only measures involving energy consumption were evaluated, since GHG emissions from the agricultural and forestry sectors are related to changes in (a) soil use, (b) agricultural production methods (such as silvopastoral projects), and (c) pastures, which do not vary by taxes on energy consumption. The methodology used to calculate emissions is constructed by relating them with gross domestic output or the demand for particular energy goods, where the relationship is positive; an increase in these variables generates an increase in emissions. In agriculture and forestry, emission reductions are not accompanied by those in the production of agricultural or forestry output or in the demand for energy goods, and instead, productivity increases are sometimes accompanied by more efficient use of resources, such as land, which is not considered in the *MEGC4*.

(1) Demand-side measures

This section evaluates measures that directly affect household demand for final goods. It considers situations where households replace old electrical devices with more modern and expensive ones that consume less energy. These include replacing incandescent light bulbs with fluorescent bulbs, or old refrigerators with newer, more efficient ones. With electric vehicles, the measure results in the added expense to buy new vehicles, in the infrastructure to charge them, and in electricity consumption, while households reduce expenditures on petroleum fuels and O&M expenses. These three measures were modeled independently,

86 Two examples prove this: (a) the changes in urban transport systems (BRT, SETP, SITP) assume a radical change in a city's' transport organization, in the infrastructure they use, and in energy consumption, and (b) the proposed development of forest plantations envisages a forestry sector substantially different from that of today and also determines a significant change in Colombia's economic geography.

87 The following section details the proposed changes and the CGE's current limitations for incorporating them.

88 Although taxation tools can be altered by policymakers, significant changes in a country's tax structure are subject to a democratic process involving debate, and therefore are not really of immediate use by policymakers.

89 Two measures show this clearly: (a) the difficulties that limit the entry of foreign investors in the Orinoquia region (forest plantations) are related to issues of security and land tenure, and (b) changes in urban transport, such as those proposed for the city of Bogotá (SITP), do not presume changes in tax variables but instead coincide with a strategy for structural change in the urban transport sector.

90 The model is constructed in a way that the investment variable is endogenously determined. This limits the possibility of exogenously changing the values of the variable in a straightforward way.

91 Although only 20 percent of the measures were analyzed, in terms of emission reductions, the percentage is above 60 percent.

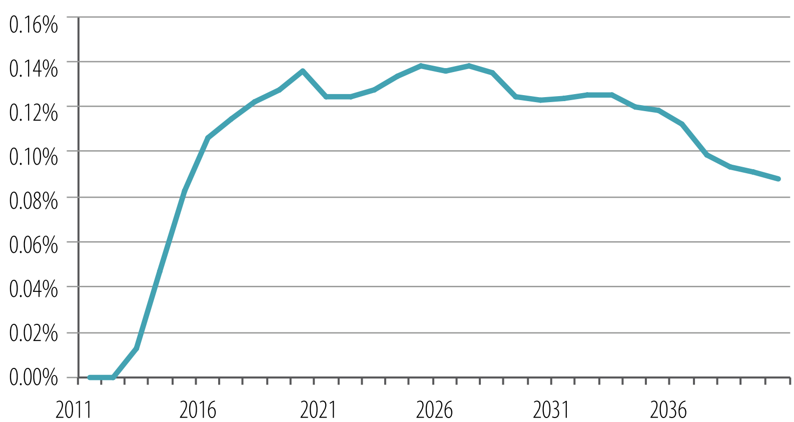
using a common methodology.[92] The main idea is to change household demand for certain goods, according to the results of the cost-benefit analysis, assuming that prices as well as household income remain constant (ie., are the same as in the baseline scenario).

a. Efficient light bulbs[93]

With this measure, households reduce their electricity consumption while increasing their expenses for efficient bulbs. To determine the proper proportion to which the consumption of goods varies, electricity expenses are associated with the electricity and gas sector, and expenses for bulbs with the CGE's manufacturing sector.[94]

Figures 50 to 52 present results from changing the minimum parameter of expenses for electricity and manufactured goods (Footnote 92). The first of these figures shows the behavior of national GDP (percent change between the scenario and the baseline scenario), while the other two show the percent change in sectoral GDP and household consumption.

Figure 50 | Percent change in national GDP



There are several explanations for the state of national GDP. Figure 53 shows that energy consumption drops sharply in the first years after a measure is introduced, which reflects the sharp drop in demand for electricity for lighting. This drop releases resources that households use to increase consumption of other goods. On the GDP side (Figure 51), the energy sector's GDP is the only one that drops, which is again explained by the sharp drop in household energy demand. Household electricity consumption for lighting as a proportion of the energy sector's GDP is about 3.5 percent; thus, the proposed action has a considerable impact on energy demand.

The state of unemployment follows a pattern similar to national GDP. A sharp drop is observed until 2020, when the maximum reduction is reached (-0.12 percent); at the end of the period, there is a 0.07 percent reduction in the unemployment rate.

92 Household decisions on consumption for each of the goods stem from maximizing a utility function, which represents household preferences. In the case of the CGE, the functional form used to represent household preferences is a LES (Linear Expenditure System), which yields a demand function for each of the final goods (BF_i), such as that shown in equation 1:

$$BF_i(P,Y) = \theta_i + \frac{\beta_i}{P_i}\left(Y - \sum_{j=1}^{n} \theta_j P_j\right) \quad (1)$$

In it, the first term, θ_i, represents the minimum consumption that households must make of product i. The next term determines the expenses of product i above the minimum level that the household requires and thus depends on disposable income after consuming the necessary minimum of the other products, weighted by a desirability factor, β_i, and the price of product i. The measures analyzed in this section may be implemented by adequately adjusting the minimum consumption (the θ_i parameter) of several of the goods in order to obtain the estimated changes in consumption demand calculated with the cost-benefit methodology. This procedure was chosen because: (a) the relation between the minimum consumption parameter and the demand for consumption goods is straightforward and direct, so it is easy to calculate the changes in the minimum consumption parameter that guarantee a given change in the demand for the product (assuming everything else is constant) and (b) it is not necessary to resort to variations of behavioral parameters like elasticities.

93 For this exercise, it was assumed that the baseline scenario was that of reference 1 (REF 1), while the with-mitigation scenario was the most aggressive of the four presented, LCEC 4. See Figure 53.

94 Proportionality factors were calculated using the baseline scenario from the CGE and the data from the cost-benefit analysis. The first step was to associate the goods from the cost-benefit analysis with a particular product in the CGE. Second, with the data from the without intervention scenario (cost-benefit analysis) and the household consumption demand from the baseline scenario of the CGE, a proportionality factor was calculated that represents the weight of the mitigation measure goods in the CGE goods. Given this and the data from the "with intervention" scenario, the change in the consumption of the CGE sector was calculated by multiplying the proportionality factor with the estimated change in the mitigation measure product. The following example can help to understand the methodology: In 2020, the expenditure on lighting amounts to about 17 percent of household expenditures in electricity and gas. For this year, it was estimated that the electricity consumption related to lighting would differ from the baseline scenario by about 7 percent, due to substituting efficient bulbs for incandescent ones. That is equivalent to saying that the consumption of the CGE electricity and gas product should differ from the baseline scenario by 1.19 percent (7 percent of 17). This methodology was used because of the lack of data regarding the household consumption of goods such as light bulbs, refrigerators and vehicles, and where only data for the more aggregated sectors in which these products are embedded is contained in the CGE. The possibility to compare the data from the cost-benefit analysis and the CGE stems from the joint use of common macroeconomic projections (mainly GDP growth).

Figure 51 | Percent change in sectoral GDP

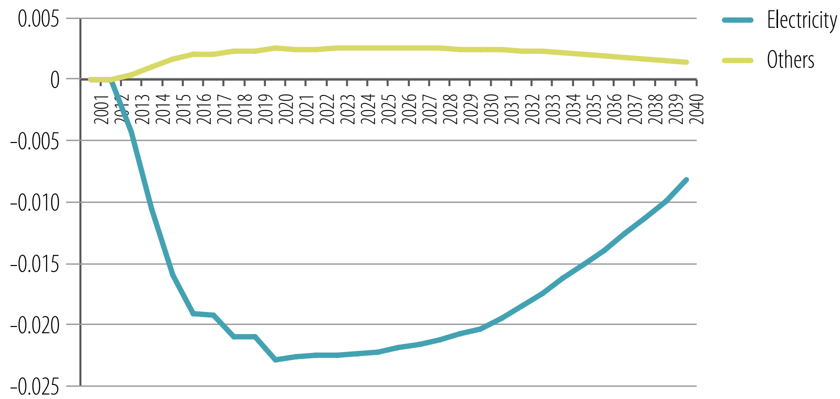
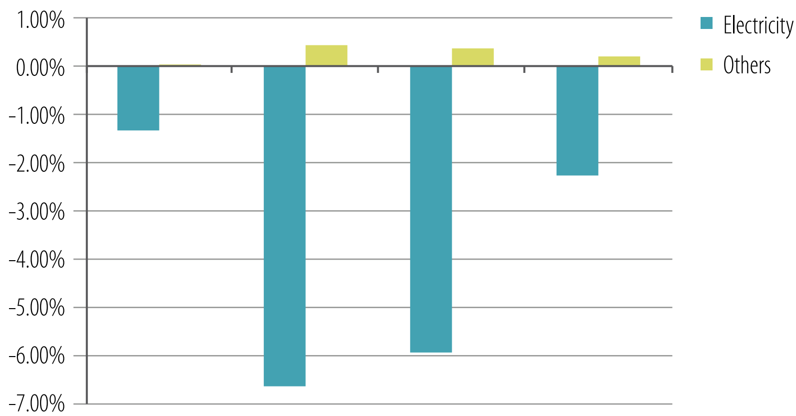
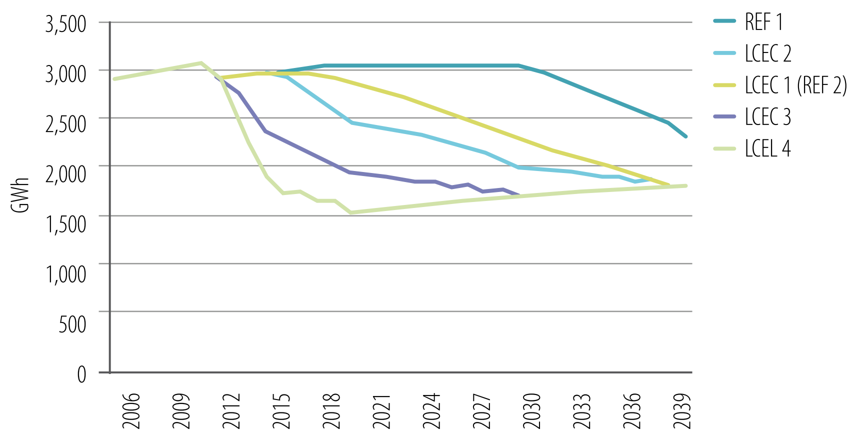


Figure 52 | Percent of household consumption



In analyzing the dynamics of national GDP, two elements stand out: (a) the strong initial increase, followed by a decrease in the next years; and (b) the small scale of this impact, which is less than 0.15 percent. The explanation for the first result relates to the dynamics of the proposed scenario (LCEC 4). Figure 53 reproduces the paths of electricity consumption for lighting in both the baseline and mitigation scenarios. One can see that the difference between the reference scenario 1 (REF1) and the more ambitious mitigation scenario (LCEC4) increases sharply in the first years but then begins to decrease, with the sharpest reduction at the end of the study period. The impact is small because the proposed measure is minor in terms of changes in household demands.

Figure 53 | Consumption of electricity for lighting



The CO_2 emissions presented in Table 14 follow a pattern similar to that of the macroeconomic indicators. Despite the increase in GDP stemming from the measure, national emissions are lower for the entire period of analysis due to the reduction in emissions associated with the fall in GDP from the electricity sector (the row corresponding to "National Emissions" in Table 14). However, in the early years, the reduction is slight, which shows that the growth in emissions from GDP caused by the efficient lighting measure, is not strong enough to counteract the CO_2 reductions due to lower demand for electricity. A final emission reduction measure was considered, assuming that only those emissions from household electricity consumption changed (in Table 14, the row corresponding to "National emissions–electricity consumption only"), while emissions associated with other elements of the economy remained constant. In that case, the reduction in national emissions, although rather small, was higher (in absolute value) than that obtained when the change in the entire sector's emissions is included (the row "National emissions" in Table 14), with a maximum decrease of 0.11 percent. Thus, it is possible to see the importance of the effects of general equilibrium when determining the effectiveness of a mitigation measure.

Table 14 | Percent changes in CO_2 emissions[95]

	2013	2020	2030	2040
National emissions	-0.01%	-0.009%	-0.038%	-0.013%
National emissions–electricity consumption only	-0.02%	-0.11%	-0.11%	-0.05%
Emissions–household electricity consumption	-1.33%	-6.64%	-5.95%	-2.25%
Emissions–electricity sector	-0.43%	-2.28%	-2.04%	-0.82%
Emissions–remaining sectors	0.04%	0.26%	0.25%	0.14%

95 The last three rows refer to the emission reductions of one part of the system, eg., the row "Electricity sector emissions" refers to the percentage of emission reductions of the electricity sector.

b. Refrigerator replacement and removal

This measure reduces household electricity consumption as a result of replacing old refrigerators with new, more efficient ones. As with efficient bulbs, refrigerators are associated with the CGE model's manufacturing sector.

Figure 54 | Percent change in national GDP with refrigerator replacement and removal

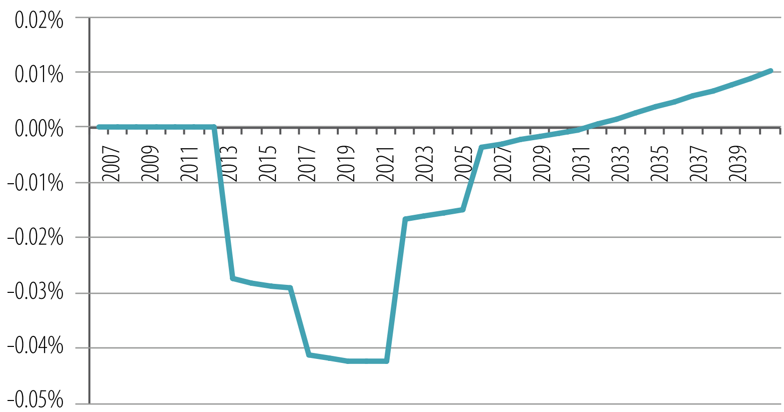


Figure 54 shows the percent change in national GDP by introducing the measure. There is a negative impact on GDP in the early years, but by the end of the period, there is practically no change in GDP with respect to the baseline scenario. Table 15 shows the percent changes of several macroeconomic variables and CO_2 emissions at three periods in time. As in the previous exercise, the GDP of the electricity sector is the most affected, although it is much smaller than in the case of efficient light bulbs. The state of GDP in the remaining sectors is ambiguous: some grow and others decrease. On average, the overall change is close to zero. Over time, there are increasingly fewer sectors showing losses.

When the changes in emissions are compared between the different residential programs (Tables 14 and 15), replacing refrigerators generates greater reductions than replacing light bulbs. This result is counterintuitive, since it is entirely due to the fact that refrigerator activities generate a decrease in the GDP of other sectors which causes a decrease in emissions. With a partial analysis in terms of emissions, one finds that if only a change in emissions due to electricity consumption is considered (row "National emissions–electricity consumption only" in Table 15), the maximum reduction is 0.032 percent, compared to 0.11 percent in the light bulb measure (see row "National emissions–electricity consumption only" in Table 14).

Table 15 | Percent change for several variables

	2019	2030	2040
GDP–electricity	-0.34%	-0.5%	-0.58%
GDP–remaining sectors	-0.003%	0.025%	0.01%
Unemployment	0.038%	0.005%	-0.005%
Electricity consumption	-1.15%	-1.37%	-1.56%
Consumption–remaining sectors	-0.13%	0.05%	0.07%
National emissions	-0.085%	-0.018%	0.055%
National emissions–electricity consumption only	-0.018%	-0.025%	-0.032%
Emissions–electricity consumption	-1.15%	-1.37%	-1.56%
Emissions–electricity sector	-0.34%	-0.5%	-0.58%
Emissions–remaining sectors	-0.129%	-0.081%	-0.095%

As in the previous case, the effect of replacing refrigerators tends to decrease over time, both in terms of the macroeconomic variables and CO_2 emissions.

c. Electric vehicles

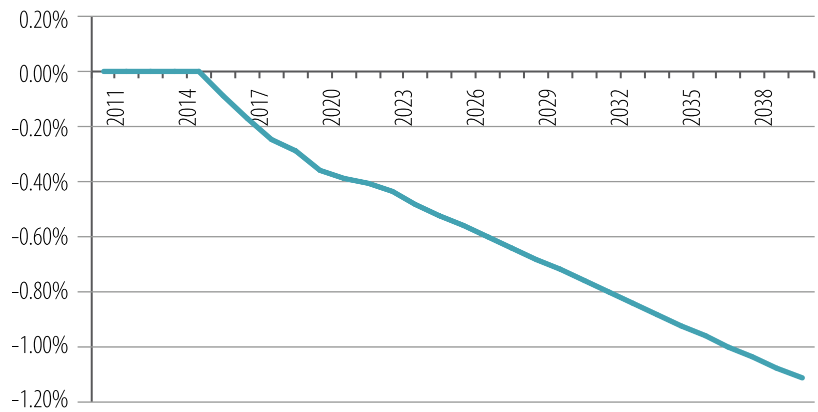
The larger scale and complexity of the electric vehicle measure brings with it larger, more varied changes in the structure of household demand. Households spend more on vehicles, electricity, and charging infrastructure, but at the same time reduce their automobile O&M costs[96] and gasoline consumption. For the calculation of proportionality factors, it was assumed that all household expenses for goods from petroleum are for automobile fuel, the proportion of expenses for transport equipment is found in expenses for machinery, and the proportion for automobile repair services is found in commercial expenses.[97] For electricity, data from the cost-benefit methodology was used.

Figure 55 shows the percent change in national GDP from the BEV measure. The scale of the electric car measure is substantially greater than that of lighting and refrigerators, as is reflected in the change of national GDP, which in its worst year loses nearly one percent relative to the baseline scenario. There is a steady decrease in GDP over time, reflecting the assumption that the proportion of electric vehicles in the Colombian vehicle fleet steadily increases.

96 O&M costs for electric vehicles are generally lower than internal combustion vehicles due to less moving parts and lower operating temperatures of BEVs.

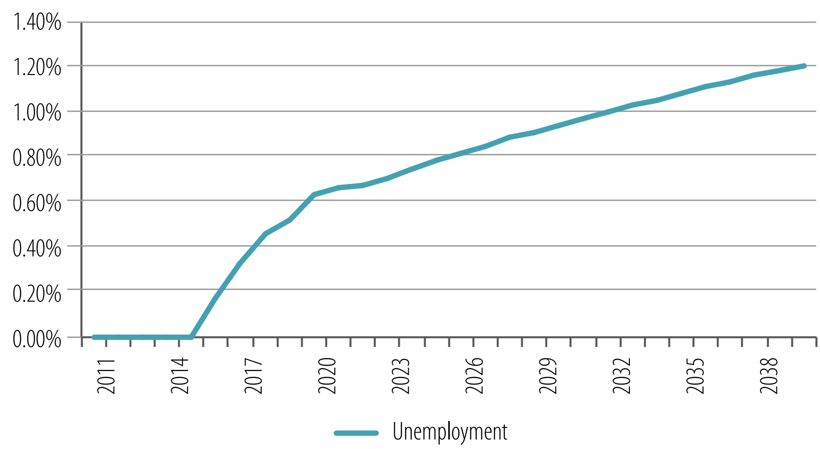
97 Both the expenditures for machinery and auto repair services are obtained from National Accounts.

Figure 55 | Percent change in national GDP with electric vehicles



The evolution of unemployment associated with the electric vehicle measure is shown in Figure 56 and, as in the previous cases, it moves similarly to that of national GDP—although in the opposite direction, ie., the unemployment rate increases when compared to the baseline scenario.

Figure 56 | Percent change in the unemployment rate due to the electric vehicle measure

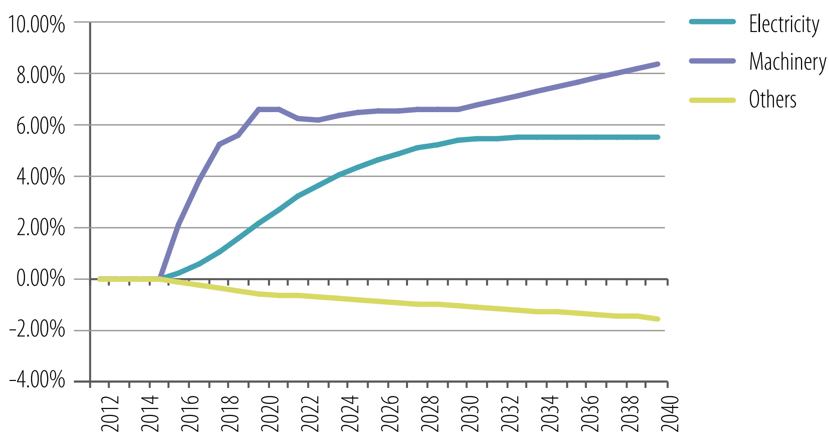


Given the measure's assumptions, the GDP movements in other sectors adjust to the changes in the parameters: Household demand for machinery (including electric vehicles and charging supplies) and electricity demand increase, which explains the growth of the sectors that produce these goods (Figure 57). The shift in the allocation of resources towards the machinery and electricity sectors has an overall negative impact on national GDP. This is related to the large share of imports for the machinery sector. The increase in disposable income (through salaries and capital yields) stemming from the growth of the machinery sector does not compensate for the loss of disposable income in other sectors;[98] –since it is assumed that all electric vehicles are imported,[99] causing a significant number of jobs to be lost due to reduced demand for domestically-produced conventional automobiles.

98 Data from the social accounting matrix (SAM) supports this argument. By calculating the ratio between wage expenditures and total sales of the CGE's different sectors in the 2005 SAM, one can see that on average, this proportion tends to be approximately 32 percent, while for the machinery sector it does not reach 3 percent. This means that increases in this sector's product generates comparatively less income for households.

99 It is important to note that the proportion of imported goods in the baseline scenario was not changed for any of the three exercises. This means that if the proportion of imported goods in the machinery sector was approximately 50 percent in the baseline scenario, it was the same for the electric vehicle measure.

Figure 57 | Percent change in sectoral GDP



For CO_2 emissions, a sharp drop is observed at the national level, accompanied by a reduction in most productive sectors, which is explained by the drop in sectoral GDP and by the reduced household demand for fossil fuels. The emission reductions due to these two factors are offset by an increase in CO_2 emissions as a result of an increase in household electricity consumption and the growth of the electricity generation sector, although this increase in emissions is not very high given that the majority of Colombia's power is from hydroelectricity. As in previous cases, besides the direct effects of the proposed measures, the decrease in national GDP is a key determinant of the reduced emissions (Table 16).

Table 16[100] | Percent change in CO_2 emissions

	2019	2030	2040
National emissions	-0.47%	-0.72%	-1.16%
National emissions–mining and energy consumption	-0.126%	-0.555%	-0.762%
Emissions–mining and energy consumption	-17.7%	-66.8%	-82.6%

(2) Forest plantations

For the macroeconomic analysis, the aim of the exercise was to understand the approximate effects on the Colombian economy as the forestry sector output increases. From a modeling perspective, this measure requires exogenous increases in investment. However, the nature of the sector makes it possible to link it with the CGE in an alternative manner, as shown below.

The low-carbon measures in the transport and electricity sectors are aimed at changing production and organizational methods (as in the case of BRTs, SETP), and by allocating

100 The first row refers to the national emissions reductions taking into account the emission changes in all sectors, while the second row considers only the changes in emissions due to reduced household fossil fuel consumption. The third row presents the emission reductions in just one part of the economy--those related to household fossil fuel consumption.

more resources to procure capital goods with new technologies that reduce fossil fuel consumption (gasoline, diesel, gas, coal). These changes do not assume a change in the quantity of goods or services produced; for example, an improved mass transport system seeks to meet the same demand for services, but with a different and more efficient production structure. Likewise, when introducing new technologies in the electricity generation sector, the aim is to produce the same amount of electricity but with different, less carbon-intensive technologies (eg., wind or geothermal).

By contrast, in the forestry sector, reductions in GHG emissions (through carbon sequestration in trees and soils[101]) are due to an increase in forest plantations: Thus, forestry experiences major growth, with sectoral GDP about four times higher than in the baseline scenario.

As mentioned earlier, the *MEGC4* model does not include land as a factor of production. This limits the possibility of assessing some important aspects of the forestry measure, such as finding new land to increase the plantations. However, the livestock sector occupies about 40 million ha of land and is very unproductive. Thus, it is assumed it is possible to reallocate land for forests without reducing the output of livestock significantly, if the productivity of that sector was increased in terms of cattle production per ha.

To increase production in the forestry sector, it is necessary to increase the demand for forest products. Currently, much of the new demand for these plantations in Colombia is from international companies. From a modeling perspective, the increase in demand for forestry products is therefore assumed to come from the external sector. Through an exogenous increase in the demand for exports of forest products, the model generates an increase in the forestry sector's GDP.

To determine the growth of the forestry sector's GDP in relation to the baseline scenario, a time series was constructed for the sector's GDP in the baseline scenario, using National Accounts data (for 2009) and the baseline GDP growth rates for the overall study.[102] Next, a ratio was found between the increase in the forestry sector's GDP due to the mitigation measure and in the baseline scenario. With these data, it was possible to calculate the increase in export demand, which, in turn, increases the forestry sector GDP.

The calculation of GHG emissions for this measure was different from the first three in the chapter. As mentioned in Box 6, the way the CGE simulates emissions is through an emission factor that relates the product or the demand for energy assets from sector *i* with the emissions of the same sector. However, this method does not work for the measure analyzed in this section, because tree plantations, aside from being a source of wood products, also play an environmental role by sequestering carbon in the soil and woody biomass. Therefore, unlike the typical correlation in which production growth generates increases in GHG emissions, an increase in the GDP of the forest sector does not increase emissions but instead reduces them. Again, the lack of a land factor in the model limits the possibility of describing the state of emissions from the expansion of forest plantations. To resolve this problem, data on the forest plantation measure (from the cost-benefit analysis) were used to calculate a factor that determines how much emissions decrease for each percentage point that the forestry sector's GDP is above the GDP of the baseline scenario.[103] Accordingly, the emissions from all other sectors were calculated in the model, while emissions from forestry were taken from the estimates in the forestry chapter.

101 Forests are important sources of carbon capture, and help generate negative GHG emissions.

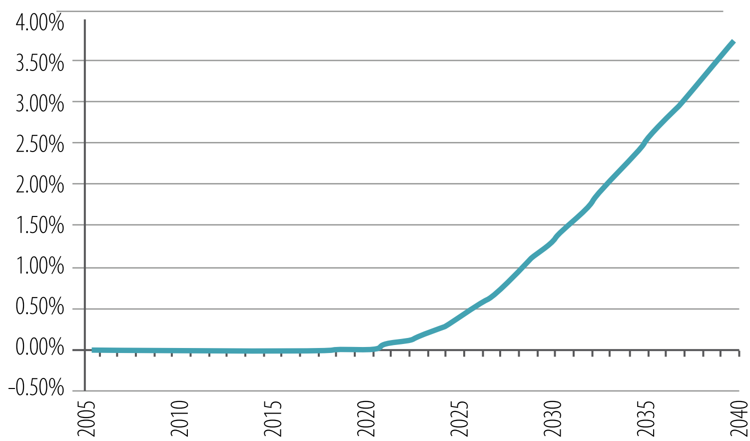
102 For example, the GDP of the forestry sector in the baseline scenario in 2020 would be provided by equation 2, where g_i is the growth rate of the national GDP for year i.

$$PIB_{forestal,2020} = PIB_{forestal,2009} - (1 + g_{2009}) \cdots (1 + g_{2019}) \quad (2)$$

103 The reduction in carbon from the periodic harvesting of wood is considered in the calculation of emission reductions from forest plantations (AFOLU chapter).

Figure 58 shows the percentage difference between national GDP with the forest plantation measure and the baseline.[104] National GDP experiences an acceleration in growth, resulting in a 3.73 percent increase above the baseline in 2040. This result should be interpreted carefully, since the aggregated nature of the GDP variable represented in Figure 58 does not distinguish between the direct and indirect effects of the mitigation measure. The direct effects are related to the increase in national GDP as a result of the forestry sector's GDP (assuming that all other sectors do not alter their production), while the indirect effects consider the growth in other sectors due to the greater circulation of resources experienced by the economy.[105] Figures 59 and 60 present the proportion of GDP growth and new jobs[106] that can be attributed to the growth of the forestry sector as well as the rest of the economy.

Figure 58 | Percent change in national GDP through forest plantations



In the first years of implementing the measure, the forestry sector contributes approximately 50 percent of GDP growth and the generation of new jobs. This proportion decreases over time. By increasing production in the sector, this increases demand for productive inputs and a greater flow of resources to workers, due to the increase in forestry jobs. The first element is not very significant due to the small size of the forestry sector. Thus, even after it grows substantially, it does not represent a significant source of demand for other sectors. As such, growth in the GDP of the other sectors should result in the greater flow of resources to workers. This factor is even more important when it is recognized that over half the forestry sector's expenditures are wages. Thus, it may be argued that as workers' incomes increase, they increase their consumption and thus encourage the growth of all sectors.

104 Although investments in forest plantations begin in 2012, it is only by 2020 that growth can be seen in nationwide sales of forest products. The long-term investment feature means that it takes several years until investments show a profit. This delayed investment performance cannot be captured by the CGE. Thus, it was assumed that, in the years in which forestry sales did not grow, the economy did not experience any change. Therefore, it is only after 2020 that the values of the variables in the baseline scenario begin to differ.

105 This division (direct–indirect effects) is artificial; the multiple inter-relationships that characterize the economy do not allow the forestry sector to grow without affecting the others.

106 As in the mitigation measures analyzed in the previous sections, the behavior of unemployment moves in parallel to GDP; unemployment falls throughout the entire period of analysis and ends 3.14 percent below the baseline scenario in 2040.

Figure 59 | Proportional contribution to GDP growth

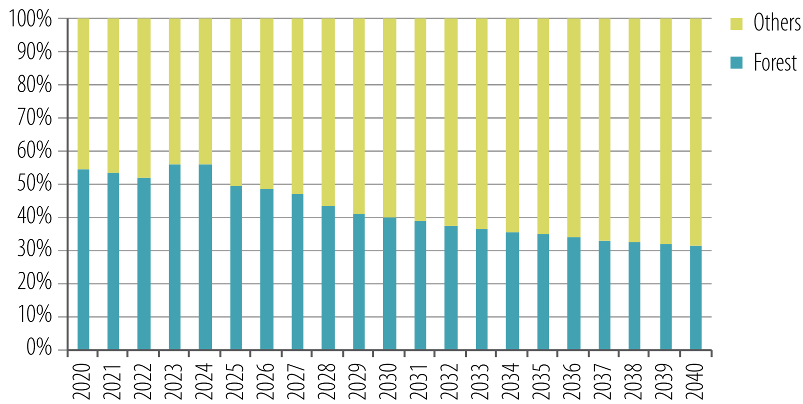
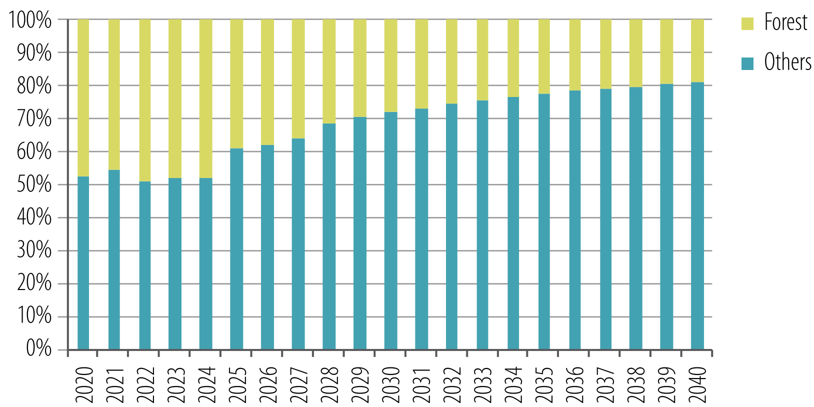


Figure 60 | Proportional contribution to new job growth

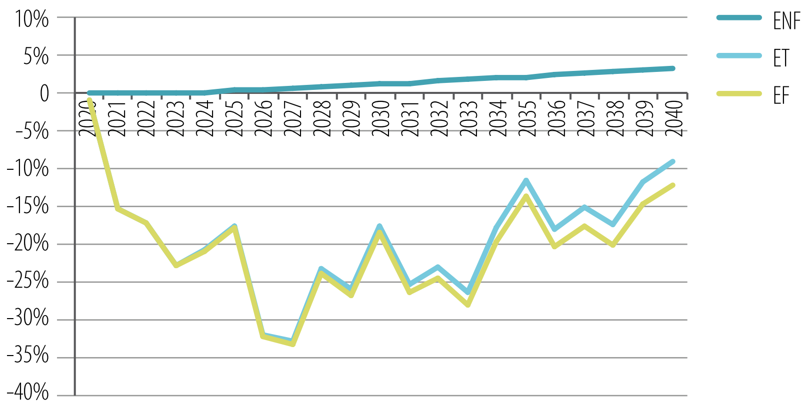


GHG emissions[107] are presented in Figure 61.[108] The change in the total is divided between the change generated by carbon sequestration (forestry sector) and that generated by movement in the other sectors. Because the measure generates growth for all sectors, emissions increase (ENF in Figure 61) and replicate the movement of GDP (reaching 3.14 percent above the baseline scenario in 2040). However, the carbon emissions sequestered by forest plantations more than compensate for this growth in CO_2 emissions, so total emissions decrease considerably. The greatest amount of reductions occur in the intermediate years (2026-2034), when most of growth in the forestry sector's GDP occurs.

107 According to the cost-benefit analysis, forest plantations sequester carbon from the first year of the measure (2012). However, for the reasons cited in Footnote 89, the CGE model does not allow delayed investments to be represented; thus, changes in emissions in the CGE are only seen starting in 2020. In the first years, there is thus an over assessment of the emissions captured by forest plantations stemming from the CGE, but the GDP of the forestry sector does not increase, although more emissions reductions are from sequestration. The aim is to make a proper correlation between the cost-benefit analysis and that of the CGE.

108 The conventions of Figure 61 are as follows: ENF is the change in emissions without considering the forestry sector, EF is the change considered only in the forestry sector; and ET is the change in total emissions, considering both effects.

Figure 61 | Percent change in CO_2 emissions



(3) Green taxes[109]

This section evaluates the macroeconomic effects of introducing environmental or green taxes, and analyzes the effects of implementing fiscal policies for climate mitigation. As discussed in the literature,[110] taxes can be an effective way to reduce pollution by giving economic agents an incentive to reduce economic activities that create pollution externalities. Taxes can also provide an incentive for innovating and increasing efficiency, and can generate revenue that can be used to finance education, health and infrastructure, and reduce poverty.

Unlike changes in structural parameters, the introduction of green taxes reflects an external change, where agents change their production and consumption decisions based on their usual demand response functions. These changes spread to the rest of the economy, leading to appreciable macroeconomic effects.

Four independent exercises were conducted:[111] (a) emission reductions due to lower household electricity consumption (using efficient bulbs, replacing refrigerators); (b) emission reductions due to lower household consumption of petroleum products (electric vehicles); (c) emission reductions in transport;[112] and (d) emission reductions in electricity generation.[113]

Based on cost-benefit methodology data, the percentage of emission reductions was calculated for each of the exercises using the respective proportionality factors. For example, transport measures show the percentage of emission reductions for land transport; thus, in determining reductions for the entire transport sector, these values must be multiplied by the ratio between land transport and the sector as a whole (which also includes air and river transport, as well as complementary transport services). Figure 62 shows the percentages of emission reductions for the respective exercises.[114]

109 This section is based on the EIECC working document (Villalba Pardo F. D., 2011), that provides more details on the methodology for introducing green taxes.

110 See (OECD, 2011).

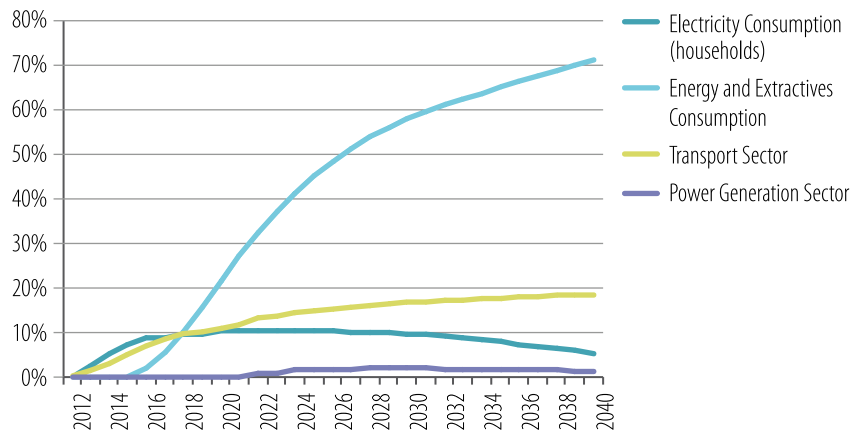
111 The tax rate is calculated in each case, making it possible to reproduce emissions' changes in the sector of interest.

112 The electric vehicle measure is excluded from the transport sector because it is related to household consumption. This is analyzed in exercise (ii).

113 The following measures were analyzed in the transport sector: (a) removal of trucks, (b) SETP, (c) BRT and (d) SITP. The measures analyzed in electricity generation were the substitution of a coal and gas plant by a wind park and geothermal plants.

114 For each exercise, the percentage of emission reductions is calculated with respect to each sector of the exercises, ie., for exercise (ii) the percentage of emission reductions from household consumption of mining and energy goods is represented.

Figure 62 | Percent of emission reductions



The methodology to reproduce emissions in the CGE consists of two interrelated elements: (a) levying a tax on CO_2 emissions to promote their reduction; and (b) recycling the tax to encourage other desired behaviors. The second item (b) is called the Revenue Recycling Mechanism because it uses the revenue generated by the tax on emissions to subsidize certain desirable behaviors by agents, and encourage more changes in consumption and production decisions. For example, tax revenues could be used to subsidize energy efficiency equipment. Once the recycling mechanism has been determined, the next step is to find the tax in each year that ensures the desired reduction in emissions.

The determination of the CO_2 taxes was carried out independently for each of the four exercises, eg., for the emissions reductions in transport, the tax was calculated with the sole objective of obtaining them from the transport measures (green line in Figure 62). At the same time, and due to the importance of the revenue recycling mechanism,[115] different scenarios were analyzed (summarized in Table 17). For measures in the productive sectors (transport and electricity generation), three scenarios were considered: (a) nothing explicitly is done with the CO_2 tax revenue,[116] (b) the revenue is used to subsidize the consumption of capital goods, and (c) the revenue is used to reduce labor taxes. For the other two sets of measures (Table 16), two scenarios were considered: (a) nothing explicitly is done with the CO_2 tax, and (b) the revenue is used to subsidize the consumption of certain goods.[117]

115 See (Timilsina, 2007).

116 In this case, nothing is done with tax revenue. Rather, it is introduced with the intention of having a better criterion when differentiating between the effect of the tax and that of the recycling mechanism.

117 The goods chosen to be subsidized were taken from the cost-benefit analysis. For example, in the case of machinery goods, bulbs and refrigerators were subsidized.

Table 17 | Scenarios of green taxes analyzed

Scenario	Green tax	Recycling Mechanism
Transport and electricity generation		
Scenario 1	Tax on energy package	None explicit
Scenario 2	Tax on energy package	Capital subsidy
Scenario 3	Tax on energy package	Reducing labor taxes
Consumer goods (efficient light bulbs and refrigerators)		
Scenario 1	Tax on electricity consumption	None explicit
Scenario 2	Tax on energy consumption	Reducing taxes on consumption of manufactured goods
Consumer goods (electric vehicles)		
Scenario 1	Tax on electricity consumption	None explicit
Scenario 2	Tax on energy consumption	Reducing electricity and machinery goods consumption

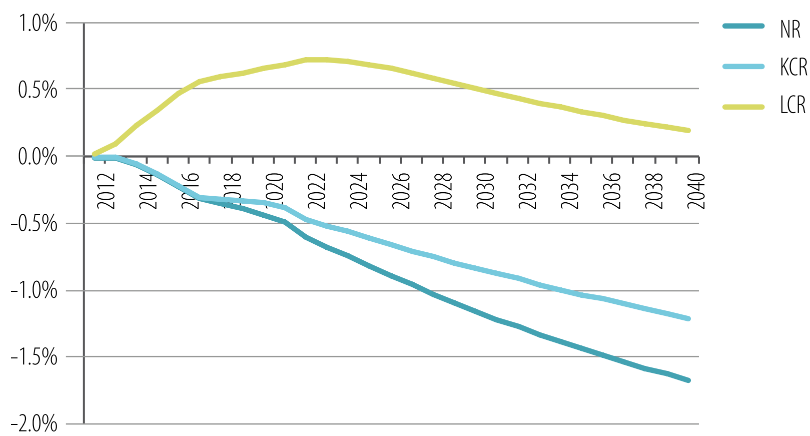
This section presents three aggregate exercises, each related to a different revenue recycling scheme: (a) no recycling or consumption subsidies (NR), (b) capital recycling and consumption subsidies (KCR), and (c) labor recycling and consumption subsidies (LCR). Each one was constructed using the estimated taxes obtained from the various exercises (Table 17), ie. the tax rate is the same as the one calculated for each exercise. For the analysis of the results, four main variables are presented: National GDP, sectoral GDP, CO_2 taxes, and CO_2 emission reductions.

It is useful to discuss how the implementation of a tax works in the model. For example, a tax on the consumption of an energy product (a productive input or consumer good) makes it more costly and therefore generates an incentive to reduce its consumption. Because there is a direct link between its consumption and CO_2 emissions, these are correspondingly reduced. The recycling mechanism enters in a subsequent stage: The subsidy of certain productive inputs (or consumer goods) encourages their consumption and may change the production levels that alter the demand for the pollution-generating input (or good) and thus in CO_2 emissions. This is why the effect of taxation depends on the recycling mechanism.

Figure 63 presents the changes in real national GDP due to the introduction of taxes. The most important observation is that various types of behavior can be promoted if the taxes are or are not recycled (capital, labor, consumption). As the figure shows, from a welfare perspective, the best scenario is the one that reduces labor taxes and subsidizes the consumption of some goods: This is explained by the increased demand for labor that is promoted by the reduced labor taxes. Since labor is now cheaper, the sectors (transport and electricity, because these are the ones that are being taxed and subsidized) will demand more labor and foster an increase in household income, which, in turn, promotes a further increase in production due to a rising consumption/ demand. The hump-shaped path of the changes in real GDP stem from the temporal behavior of the taxes introduced (Figure 63), since they grow in the first years and then steadily decrease.

For the capital recycling and consumption subsidies (KCR) scenario, while real GDP is better than in the NR scenario, it still is reduced when compared to the baseline during the entire period of analysis. The capital subsidy reduces the cost of acquiring capital for the specific sectors (transport and energy), and encourages its demand: At the end of the period, the transport sector had increased its demand for capital by about 50 percent. Although this benefits the sectoral GDP of the sectors being analyzed, it is not enough to overcome the negative impacts on real GDP. The conclusion is that the positive change in real GDP in the LCR scenario stems mainly from the increase in labor income.

Figure 63 | Percent change in real GDP



The state of GDP has a clear counterpart in that of the tax rate for each scenario (Figure 64 shows the tax rate for the transport sector in three scenarios).[118] The rates needed to reduce emissions are higher in the scenarios that include recycling mechanisms because of their effect on real GDP. For example, in the LCR scenario, real GDP increases, reflecting an increase in sectoral outputs. Accordingly, transport will increase its production (in relation to the NR scenario), which results in a greater demand for energy goods. If the intent is to reduce transport emissions by a given quantity, the tax must be higher.

118 A similar behavior can be observed in the other exercises.

Figure 64 | Green tax rates (transport measure)

To better understand the dynamics of the GDP in the three scenarios, it is necessary to analyze the results at a higher level of disaggregation. Figure 65 presents graphs on sectoral behavior for the three scenarios. Although the different measures (Table 17) promote quite different sectoral behaviors, which are all combined in the aggregated exercises, it is possible to highlight some common and important results. First, it is interesting to analyze the behavior of the transport sector in the three scenarios. As expected, in the NR scenario, transport is strongly hurt by the taxes—mainly because the CO_2 tax causes an increase in transport prices, which reduces the demand for transport services and decreases transport's GDP. When a recycling mechanism is introduced, the state of the transport sector improves substantially, even experiencing positive changes in the LCR scenario. The subsidies help reduce the tax-induced increase in transport prices, so the demand and GDP do not fall (and even increase) as much as in the NR scenario. As with the national GDP, the difference between the two recycling scenarios is the extra labor income that the LCR scenario can produce, which increases household income and expenditures on different consumption goods.

The situation in the fossil fuels sector is quite different, since the recycling mechanism produces a more negative effect on its GDP. Unlike the transport or electricity sectors, the reduction of GDP in fossil fuels is not due directly to price changes as a result of the CO_2 taxes, but from the effects of taxes on the demand for energy goods: Transport experiences a hugely reduced demand, as do households, for fossil fuel goods. This reduction increases when the recycling schemes are introduced because the subsidy on the other production factors (capital and labor) further fosters the reduction in consumption of fossil fuels. The better results in the LCR scenario are due solely to the increase in GDP that promotes an increase in the demand for all goods, partly counteracting the reduced demand in the transport sector and from households. It should be noted that the decrease in GDP in fossil fuels is mainly due to the reduction in domestic demand. Given the importance of the global fossil fuel market, it is likely that all the production not consumed domestically would be exported. In this case, national economic variables would be better and Colombia would be exporting CO_2 emissions.

The reduction in the GDP of the electricity sector is due to decreased household demand for electricity and the increased price of the electricity product, directly caused by the CO_2 tax. This last effect is offset when the recycling scheme is considered, since the electricity price does not increase as much as in the NR scenario.

Figure 65 | Percent change in sectoral outputs

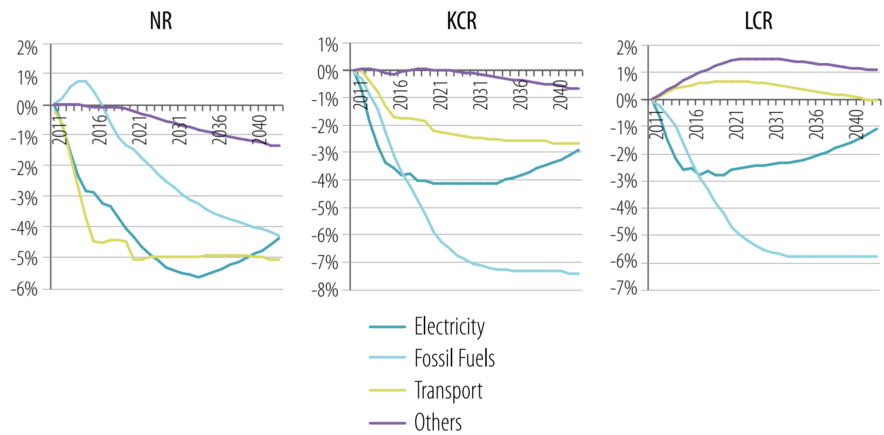
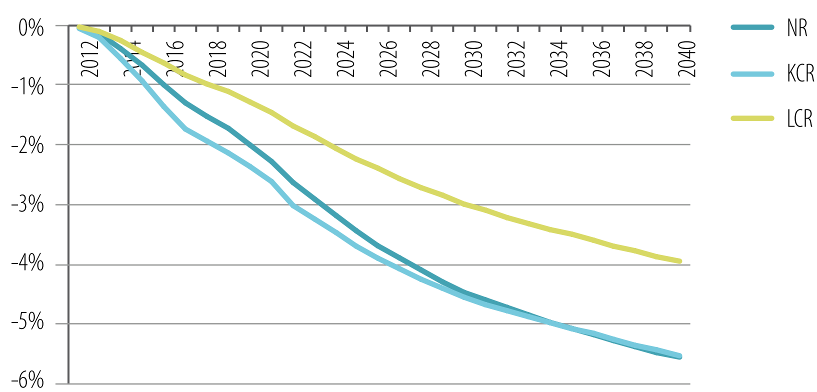


Figure 66 presents the overall emission reduction results. As expected, they are lower in the LCR scenario, reflecting the positive changes in real GDP, which promotes an increase in CO_2 emissions. With regard to the other two scenarios, their emissions reductions are fairly similar at the end of the period, while in the early years, they differ by almost 0.5 percent. Since the impact on GDP was more negative in the NR scenario, it may seem surprising that the emissions reductions in the KCR scenario are larger than in the NR scenario for almost all the period analyzed. The explanation is that first, the difference in GDP is quite small, and second (and most important), the reduction in GDP in the mining-energy sector in the KCR scenario is almost twice that of the NR scenario. In analyzing the sources of emissions, in every source except the mining-energy sector, the KCR scenario experiences smaller reductions than the NR scenario. The obvious conclusion is that the behavior of the mining-energy sector explains the larger reductions of CO_2 in the KCR scenario.

Figure 66 | Percentage change in CO_2 emission reductions



C. Conclusions

This macroeconomic analysis contributes to a better understanding of the effects that the implementation of climate mitigation measures could have on Colombia's overall economy. The methodology used to prepare these analyses involved two views of the problem. In the first, structural changes were made in the model to generate changes in the behavior of economic agents. The second introduced green taxes to provide incentives that reduce GHG emissions. In reality, Colombia is undertaking some of the low-carbon measures evaluated (such as efficient lights), and is now considering carbon taxes, both of which would have broad macroeconomic impacts.

In general terms, the macroeconomic assessment finds that forest plantations would provide positive benefits to the economy with regard to GDP growth and a reduced unemployment rate. It should be emphasized that the measure positively affects the economy because of the greater flow of income from the increased forestry jobs, which, in turn, generates a significant increase in households' disposable income and thus promotes the growth of other sectors.

Another important conclusion is the importance of considering the effects of general equilibrium, ie. the interrelationships between sectors, to determine the GHG reduction potential of mitigation measures. In general, what is found is that when behavior changes in order to reduce activities that generate GHG emissions, those from other economic activities may increase. It is therefore important to look at the overall impacts of all impacted sectors.

With regard to the analysis of green taxes, it is possible to intervene through fiscal policy in a way that the economy is not necessarily affected by them. Thus, a tax whose revenue is used to generate jobs (by reducing labor taxes) can stimulate the economy and even reduce GHG emissions. It should also be noted that the green tax does not necessarily have a major effect on the sector in which it is applied. Generally, what happens is that the energy sectors, which in turn supply the sectors where the tax is levied, are most affected.

CHAPTER 6
Contributions to Colombia's Low-Carbon Strategy

1. Background

This study is intended to contribute to Colombia's evolving low-carbon development strategy. While not intended to be comprehensive, the sectoral chapters provide examples of measures to reduce GHG emissions that are economic and could be implemented today. Using the results of the low-carbon measures, the macroeconomic analysis shows the importance of looking beyond the direct project impacts to the indirect effects on other sectors in terms of income, employment, and emissions reduction: The analysis found that low-carbon development would not result in economic losses, but in fact, could produce significant benefits.

The report has not yet addressed several important issues that are crucial for Colombia's low-carbon development strategy. They include:

- **Quantifying the potential size and cost of reducing emissions.** Much as policymakers need to know the resource potential for hydropower or wind, they also want to know the potential for reducing emissions and how much such actions would cost. Because the sectoral assessments used a common methodology, it is possible to aggregate the potential for GHG mitigation for the energy, transport, and AFOLU sectors. It is also possible to compare the net costs of different GHG mitigation measures, which is important when allocating domestic or international resources to these ends.

- **A framework for low-carbon development**. Building on Colombia's intention to mainstream low-carbon projects in its development plan, the study proposes such a framework. Using the sectoral and macroeconomic results, low-carbon measures are identified for their contributions to income growth, competitiveness, sustainability, resilience, and social inclusion.

- **Key development trends that will drive CO_2 emissions**. Drawing on the study's findings, this chapter describes several key development trends that will affect carbon emissions in the next decades. For each trend, policies and actions are identified to achieve domestic development goals that are also consistent with low-carbon growth.

- A final section summarizes the contributions of the study and describes some of the challenges for introducing low-carbon actions.

2. Integrated Assessment

The common methodology used in the energy, transport, and AFOLU sectors allows the results on GHG potential to be aggregated and net costs compared. The first section provides an estimate of the potential to reduce emissions from now to 2040. The estimates are based mainly on an aggregation of the low-carbon measures by sector, plus some adjustments to account for gaps in the sectoral analysis. The result is a series of "wedge" diagrams of the emission reduction potential by sector. The second section evaluates the relative costs of the different low-carbon measures, presented in the form of the familiar marginal abatement cost curve.

A. Potential to reduce emissions

By undertaking the low-carbon measures in the energy, transport and AFOLU sectors, Colombia could maintain and actually lower its GHG emissions over the next three decades. The lowering of total emissions would depend largely on the degree to which AFOLU activities are carried out that could result in significant carbon sequestration. A simple baseline emissions trajectory to the year 2040 was prepared using a combination of projections of GDP, population, and energy use. Under the baseline, emissions would increase around 1.3 percent a year, reaching around 250 $mtCO_2$ in 2040.

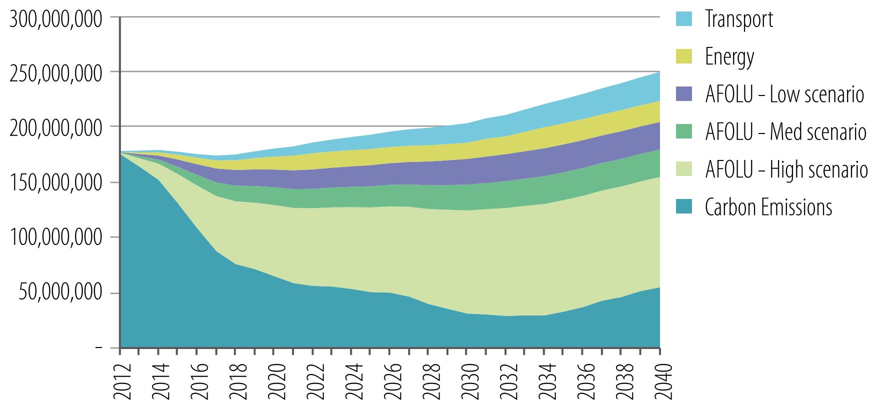
Compared to Colombia's annual emissions of 170 million tons of CO_2 in 2010, undertaking the sectoral measures could reduce as much as 200 $mtCO_2$ in 2040. For example, transport sector actions alone could reduce about 50 $mtCO_2$ by 2040. By assuming that a large share of the future transport fleet could be replaced by electric vehicles, emissions from the consumption of gasoline and diesel fuel could be reduced significantly. Smaller emissions reductions, but by no means insignificant, would be achieved sooner through the continuation and expansion of bus rapid transit (BRT) schemes and related integrated urban transport systems.

In terms of sheer technical potential, AFOLU measures provide the largest source for reducing emissions, mainly through afforestation (plantations), silvopastoral systems, and avoided deforestation. Given the large tracts of land in Orinoco that are currently being planned for agricultural and forestry expansion, this area alone provides the single largest potential for future reduced emissions. However, it is unclear to what extent such a large expansion would be feasible and economically attractive given the many factors affecting such development, including the security of land-tenure, the lack of infrastructure, and potential social and environmental sustainability issues. Given these large uncertainties, which in turn would affect the amount of land ultimately developed, several scenarios of AFOLU are presented in Figure 67, representing low, medium and high reduction potential.

The potential in the energy sector includes the energy efficiency and renewable energy measures from Chapter 2, plus estimates of CDM potential for the energy and industrial sectors.[119] The relatively small energy sector wedge reflects the current dominance of hydropower for generating electricity and also the fact that industrial activity is limited when compared to other countries with similar levels of GDP. The energy sector wedge does not reflect what would happen if hydropower does not remain the dominant supply source in the future, which could result from various scenarios in which it does not expand as planned (environmental and social constraints, the growth of domestic fossil fuel supplies, or climate change).

119 For the energy sector, only a small fraction of potential low-carbon projects were evaluated. This was due to the lack of adequate data for analysis in some cases. Overall, there are many low-carbon energy projects, with each measure accounting for a small percent of the country's total energy efficiency or fuel-switching potential.

Figure 67 | Potential to reduce Colombia's GHG emissions, 2012-2040 (tons)



B. Net costs of reduction

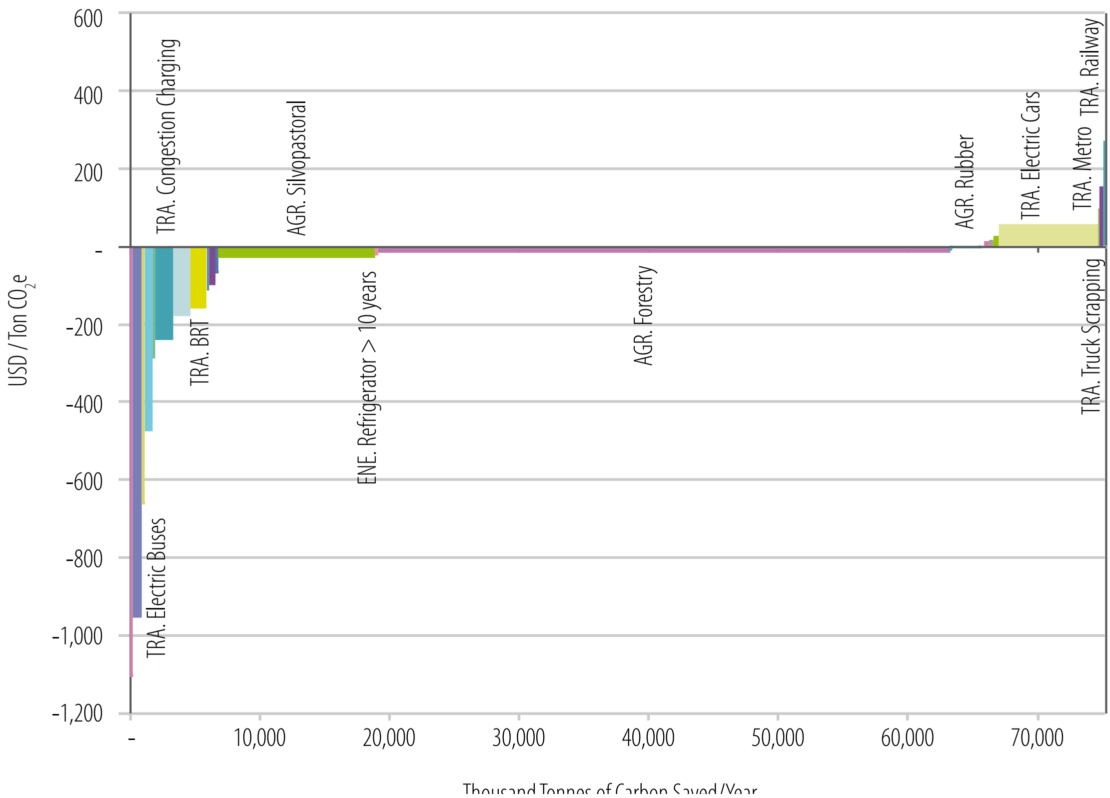
The sector chapters identify some low-carbon measures that have positive economic benefits for Colombia. Also, many of the measures are part of the current economic development plan. The cost-benefit analysis has been designed to highlight the economic and financial returns of low-carbon projects. Based on the assumptions of the cost-benefit analysis, measures on the left side of the marginal abatement cost (MAC) curve have positive net economic rates of return of at least 10 percent.

Energy efficiency projects tend to lie on the left side of the curve, implying that they have good economic rates of return. Ultimately, such projects have limited potential for reducing emissions in Colombia due to the dominance of hydropower. However, they often make sense for economic and competiveness reasons and should be promoted where they have good economic rates of return. Two of Colombia's readily available renewable energy technologies – geothermal and wind – are close to being economic when substituting for coal plants, but are not as competitive when they replace natural gas plants. Though not quantified, both geothermal and wind would contribute to increasing the security of Colombia's power sector, and in the process, reduce the risks associated with variable fuel costs for fossil fuel plants and seasonal and climate risks associated with hydropower plants.

In the transport sector, BRT and other urban transport measures can have good economic rates of return if designed and managed well. The analysis of electric vehicles found that electric buses are economic at current costs, but that electric passenger cars are still too expensive to make it to the left side of the MAC curve. Still, it is expected that as global manufacturing of electric vehicles expands, technology costs will continue to fall as has been true for other emerging low-carbon technologies such as wind-turbines or solar PV panels. It should be noted that environmental and health benefits associated with reducing local air pollution can provide significant benefits to public transport projects, as well as for cleaner fuels and vehicles. In fact, the high economic returns (ie. low net cost of reducing CO_2) of many of the public transport measures are in large part due to including other benefits which are (a) lowering local air pollution and associated health impacts, (b) time savings from reducing congestion, and (c) fewer traffic accidents.

In the AFOLU sector, forestry projects could reduce emissions as they expand, and those with commercial potential could do it at negative cost. Improved pastures and silvopastoral systems help reduce methane emissions from livestock, while improving the overall productivity of the landscape. Such projects improve the efficiency of production, producing lower emissions per unit of milk or meat, and also typically produce revenue from related activities (lower feed costs and more timber sales). Projects without direct revenue flows or other quantifiable benefits—such as sustainable forest management, ecological restoration, or other REDD activities—will have higher costs for reducing CO_2 emissions. However, unlike commercial activities, which generally have good financial returns, these others often have large ecosystem benefits related to water and land conservation. For this reason, it is important to identify all the projects' benefits, even if they cannot be well quantified.

Figure 68 | Integrated marginal abatement cost (MAC) curve



3. Framework for Low-Carbon Development

An important principle of Colombia's climate change strategy has been aligning low-carbon development with the broader economic goals, which this study explores. Connecting global environmental benefits with national economic goals was a key criterion for selecting the mitigation measures that were evaluated in the sectoral chapters. By applying cost-benefit techniques to assess direct project costs and benefits as well as externalities, it was shown that many of the low-carbon projects have good economic and social rates of return. While previous chapters using cost-benefit and macroeconomic analysis have shown that projects with good economic returns would not have negative impacts on other sectors through their spillover effects, this next chapter focuses in a qualitative[120] way on how low-carbon measures can contribute to economic development (national income growth, competitiveness, sustainability, resilience, and social inclusion).

While international financing (such as the CDM, GEF, climate investment funds, or voluntary carbon markets) can promote mitigation measures, it is inherently unsustainable if it does not overcome the incremental capital cost requirements of the projects it supports. Further, this financing is often biased towards certain sub-sectors (such as land-fill gas projects), while other sectors are usually under-represented (agriculture, transport). Also, and perversely, the eligibility requirements for such funds sometimes lead to marginally economic projects.[121] Many of the activities the study evaluated could certainly qualify for international climate funding. However, rather than focus on projects that have good potential for such funding, the study looked for projects that had (a) a high priority for national development, (b) good economic rates of return, and (c) significant climate mitigation potential. Ultimately, global goals must be aligned with national development goals, since projects with marginal economic or social returns will be hard to expand and replicate, and thus not reduce emissions over the longer term.

Applying the principle that low-carbon measures should be prioritized based on their contribution to Colombia's economic development, the study has categorized several of those it evaluated (Table 18).

Table 18 | Low-carbon measures and domestic development objectives

Objectives	Energy	Transport	AFOLU
Economic growth	Renewable energy	Bus rapid transit (BRT); electric vehicles	Commercial plantations, fruit and vegetable production
Competitiveness	Energy efficiency	BRT; SETP; SITP; freight efficiency	Improved pastures; productivity gains in livestock
Sustainability/ resilience	Renewable energy	BRT, SETP, SITP, non-motorized transport; electric vehicles	REDD, silvopastoral systems;
Inclusion	Renewable energy for access	SITP, BRT, SETP, non-motorized transport	Fruit and vegetable production

120 While contributions to national income are fairly straightforward, subsequent work is needed to quantify the development benefits that low-carbon measures have for other national objectives.

121 For example, by pursuing "additionality" or "incremental cost" criteria of the CDM or the GEF, low-carbon project developers often bypass projects with good financial and economic rates of return, and instead choose those that need added resources to buy down the capital costs. But, by focusing on policy, regulatory, and institutional constraints that inhibit low-carbon projects, it is possible to select economically attractive projects and still meet the additionality criteria.

A. Economic growth

Economic growth, measured by increases in national income, is the most common indicator of domestic development.[122] Such increases have been associated with increased energy consumption, and the global production and consumption of fossil fuels, which are the largest source of GHG emissions. However, this is not always the case. Low-carbon energy technologies, such as wind, geothermal, hydro, biomass, and solar, can reduce emissions as they are increasingly adopted. Colombia has significant resource potential for these technologies, and developing them could contribute well to economic growth. Another example specific to Colombia is an electric vehicle program, including the growth of a domestic industry, which could have positive impacts on economic growth while reducing GHG emissions.[123]

A second example of how growth in economic production can be correlated with reduced carbon emissions, and is especially relevant for Colombia, is expanding forests and perennial crops. As was noted earlier, commercial forest plantations could reduce GHG significantly by sequestering carbon in above- and below-ground biomass and in soils. Other perennials—fruit trees, palm, and coffee—also sequester carbon to varying degrees as their production increases. The key for many of these measures is that they are profitable and economic, thus generating incentives for investment, and contributing to national income growth.

B. Competitiveness

Improving the efficiency of production is an important way to lower costs in various sectors and thus improve competitiveness. A fine example of how low-carbon projects improve competiveness is in the area of energy efficiency (EE). Many such projects have good financial rates of return and a rapid payback, especially in sectors where technologies are old and energy tariffs are high. Moreover, industries that do not adopt the new, more efficient production processes (which often have a quality element), may not be able to compete or survive. And, as Colombian industries increasingly compete on the international market, they must adopt efficient processes/technologies, whether these are electric motors, boilers and furnaces, or lighting. The cleanliness of production processes is also important in the electronics, textiles, and food and beverage sectors, which not only favor energy efficient production systems, but the use of clean fuels. Macroeconomic analyses of Mexico's EE projects have shown they contribute to GDP growth by improving productivity and freeing up resources for other productive investments (Johnson, 2010).

Expanding coverage and improving the efficiency of passenger and freight transport is important for a country or city's competitiveness. Many low-carbon actions in transport improve EE by lowering the energy use per unit of service (passenger-kilometers, or freight-kilometers). Thus, cities that have modern, efficient transport are more likely to attract domestic and foreign investment. Some major benefits of expanding Colombia's rail and river networks is that they lower freight costs, connect large areas of the country with consumption centers and ports, and improve the transport network and the economy's overall competitiveness.

Various low-carbon agricultural measures improve the efficiency of production and thus competitiveness. Silvopastoral systems improve pastures and soil use, raise the productivity of meat and milk, while using less land. Then, the released pasture land can be used for higher-productivity activities such as annual crops and perennials, while the livestock

122 Given the limitations of national income accounts, including the failure to include the consumption and stock of a country's "natural capital," it is important to expand the definition of national income to account for the depletion of natural resources (eg. minerals, soil fertility, water quality, biodiversity).

123 The macroeconomic analysis found that a large-scale electric vehicle program could have a negative impact on GDP if Colombia relied completely on importing the vehicles. The measure would also likely affect domestic production of conventional motor vehicles.

sector puts less pressure on forests. All these cases help to increase the efficiency and competitiveness of agriculture and forestry, where Colombia has a clear competitive advantage, and which will be increasingly important as the economy develops and international trade expands.

C. Sustainability and resilience

Low-carbon measures can promote sustainability and resilience because the production of goods or services can be maintained and preserved in the future and the production can more easily adapt and survive changing climate conditions. In the energy sector, renewable energy technologies have the advantage of providing long-term energy services while not depending on distant fuel supplies with unknown or variable costs. Moreover, the disadvantages of intermittent distributed renewable energy technologies such as solar PV and wind are at least partly offset by the resilience the RE technologies can provide due to disruptions in fuel supply or following a natural disaster that knocks out central power stations or the transmission and distribution grids. EE can also help sustainability and resilience by reducing the total amount of energy required, while reducing peak demand in the event of a sudden energy shortage.

In the agricultural sector, silvopastoral systems can provide a sustainable landscape for livestock and crops as well as contribute to biodiversity by creating biological corridors (protected and contiguous ecosystems for fauna. Besides shade, trees and certain plant species (such as *leucaena*) also provide nourishment to livestock and nutrients to the soil. Further, multi-crop systems are less vulnerable to the variability of individual product markets and prices, as well as to the impact of pests and diseases.

By preventing deforestation, biodiversity and habitats are preserved, as are important ecosystem functions such as soil and water conservation. Preventing deforestation needs dual measures such as promoting forest plantations to avoid pressure on timber resources in natural forests, ending the incentive for land titling that promotes slash-and-burn techniques, exerting greater police control, and generating conservation incentives.

Many of these resilience attributes can lessen the effects of climate change; however, low-carbon projects must consider the various climate change impacts—such as the effect of droughts and floods on hydropower production and of changed temperatures on crops.

D. Social inclusion

Low-carbon policies can and should be used to promote social inclusion, defined as providing all citizens with equal opportunities and access to services. To this end, community forestry and REDD programs could involve rural households in sustainable forest management programs, which would provide them with resources and jobs.

While rural small-scale renewable energy projects – such as household solar PV systems – typically only reduce GHG emissions to a limited extent, they are often the least-cost way of providing electricity service in remote areas. At the same time, they offer communities the opportunity to obtain new livelihoods, modern health care, educational services, and information. Thus, they reduce the incentives to migrate to urban areas.

Urban transport projects – such as SITP, SETP, and BRT – not only make urban transport more efficient but provide affordable services to poor neighborhoods. They also reduce accident rates and decrease air pollution which, in turn, provides important social, health and financial benefits.

4. Carbon Trends and Policies for Low-Carbon Development

Several key development trends are expected to greatly impact Colombia's GHG emissions over the coming decades. Some are common in other developing countries, such as increasing national income and urbanization, which in turn increase energy use and emissions. However, other trends are more region-specific, such as the high share of hydropower in the energy mix and the large share of GHG emissions produced by forms of land use. Those in Colombia that could affect carbon emissions involve the future of both hydropower and coal. However, trends such as the expanding agricultural frontier and pressure on native forests (both of which are related to the peace process and rural security), may be the most important variables. A final factor—climate change—could significantly affect economic and social development and, in turn, GHG emissions.

A. Urbanization

The growth in Colombia's urbanization over the past 40 years has helped increase income, reduce poverty rates and improve access to basic services such as water and electricity.[124] Now, over three-quarters of the population live in cities, which also produce a sizeable share of the country's GDP. These factors have led to rapid motorization rates, which cause greater consumption of petroleum products and higher GHG emissions, although they have also led to an expanded public transport system, such as Transmilenio and other programs.

While this report has focused on the link between urban transport and energy, cities also consume large amounts to light and air condition buildings, to heat and provide power in industry, and to supply water and sanitation; and, the intensity of the cities' emissions is largely affected by urban design—the location and type of office buildings, schools, and residential neighborhoods, and the layout of roads and other infrastructure.

Policies

Various national and municipal policies could limit the growth of carbon emissions from transport. These include:

- **Efficient, equitable urban transport.** Bogota is a world leader in sustainable transport: Its *TransMilenio* program has been reproduced in many cities worldwide. By continuing to promote efficient, equitable public transport in its urban areas, Colombia can lower carbon emissions and, more important, contribute to the cities' productivity and quality of life.

- **Managing the growth of private vehicles.** Unless cities can limit the growth of private vehicles, public transport systems cannot operate efficiently. Likewise, unless there are viable public transport options, the urban population will continue to increase their use of private cars and motorcycles. However, such options are possible. At present, fuel and vehicle taxes are low by international standards, and have encouraged motoriza-

124 Urbanization in Colombia over the past 20 years has been somewhat unique. While it is a global phenomenon and the "pull" aspects are well known, rural violence was a powerful "push" factor—causing people to leave rural areas and agriculture.

tion and private cars. Thus, Colombia could limit motorization rates by increasing them, which, in turn, could generate revenue for urban transport programs. Another program that could reduce traffic at peak times and locations involves congestion charges, which are now easier to administer through the use of electronic toll technology.

- **Cleaner fuels and vehicles.** The public and private vehicle fleet could become less carbon intensive through various means. The most basic involves inspection and maintenance programs that keep highly polluting, inefficient vehicles off the road; although they may be a small percent of the fleet, they are responsible for most of the pollution. Further, as noted in the transport chapter, there seems to be a large potential to expand the fleet of electric vehicles, which could be particularly attractive for Colombia and other countries with large hydroelectric capacity and potential.[125]

B. Land

Land is one of Colombia's greatest assets and its future use will be a major wildcard for GHG emissions. At present, the government aims to expand agricultural and forestry in Orinoco and other under-developed regions. Given the scale of land potentially available in Orinoco, it will play an important role in terms of income and jobs. Further, since a large part of the planned activities are related to perennial crops (commercial timber, fruit trees, and palm), the region may have large carbon mitigation potential. Several major investors have moved into the region and begun producing palm and other plantation crops. But, such development is new and many obstacles need to be overcome to make agriculture a highly viable sector. Long-term needs include (a) major investments in infrastructure (roads, electricity), (b) improving the soil structure and fertility, and (c) reforming policies regarding land ownership and rural financing.

Current inefficient livestock practices create the potential for converting low-value pasture into areas that could produce higher-value agricultural products. To this end, the free trade agreement with the U.S. will increasingly put pressure on low-productivity agriculture and livestock production. One obstacle is that in the Altillanura region, the labor supply is insufficient to meet the growing demand; but, it is expected this will gradually be satisfied through labor "in-migration" from other parts of the country—if salaries and social services are competitive.

Another problem is that many peasants who still hold property titles are not returning to their farms, partly because they lack the necessary capital to recover their land and make it productive. However, with the decrease in rural violence, some who were displaced (*desplazados)* or in militias that have now been demobilized, may return.

Policies

The policies needed to move ahead include:

- **Maintaining security.** To attract investment into agriculture and forestry, the government must increase security.

- **Pro-agrarian programs.** Displaced farmers could be encouraged to return through projects involving land restitution, seed capital, TA, connections with markets to commercialize production, land titles, incentives for infrastructure investment, agricultural R&D, and extension services.

125 Policies to promote advanced technologies in Colombia and elsewhere include removing high customs duties through measures which recognize the environmental benefits of certain products. In addition, the government could help develop and commercialize clean and low-carbon technologies through R&D programs.

- **Access to credit.** Small farmers need credit that could help them return to agriculture and acquire the equipment for modern production. In Brazil, credit programs require farmers to comply with sustainable land management practices (such as forest reserves) and have helped reduce deforestation in the Amazon.

- **Efficient land markets.** Large-scale development requires a more efficient land market, which could involve increasing the farm tax and returning land that was seized by armed groups. Other schemes could provide concessions on vacant lands or to smallholders and cooperatives.

C. Hydropower

As noted throughout the report, the dominance of hydropower is a major reason for the low carbon-intensity of Colombia's energy sector. Thus, whatever happens to the share of hydropower will significantly affect the country's carbon emissions. By all accounts, there is substantial untapped hydropower potential that could provide low-cost electric power for both domestic use and export. Currently, Colombia's energy experts anticipate that hydropower's role will increase slightly over the next decade, gradually decline by 2030, and its share of installed generation capacity will remain at around two-thirds. But uncertainties exist as to how rapidly the remaining hydropower resources can be developed. Several projects now being developed or planned face obstacles related to social and environmental concerns; and, increased risks for developers and project delays can raise the real cost of developing hydropower and make higher-carbon technologies (such as coal or combined-cycle gas plants) more attractive.

One risk related to depending on hydropower involves meeting electricity demand during dry years. At these times, the country needs more power from other sources, ideally from those not affected by climate variability. Currently, annual power generation from hydro is 45 - 90 percent of the total. Largely, though not entirely due to drought, electricity shortages occurred in the early 1990s, and in Brazil in the early 2000s. However, Colombia is more vulnerable than Brazil and other Latin American countries since it lacks large storage capacity for its hydropower system. Moreover, it is expected that climate change will exacerbate the variability in rainfall and runoff patterns that affect hydropower; and, building run-of-river hydro-electric projects, which have a smaller environmental footprint and thus reduce their social/environmental impacts, can also increase climate and hydrological risks due to the lack of storage capacity. During periods of excess water, more power could be generated if such capacity was enlarged.

Policies

The policies needed to promote hydropower include:

- **Overcome barriers.** Improved management of the social/environmental aspects of developing hydropower can help reduce licensing and construction delays which can render good sites uneconomic. Size can also matter: Thus, developing smaller plants often has the advantage of lower environmental/social impacts, shorter licensing times, greater ease of financing, and shorter construction periods.

- **Multi-purpose water control projects.** One of the limitations of the current hydropower system is a lack of storage capacity to regulate flows during wet and dry seasons. Increasing this capacity through multi-purpose control projects could reduce flooding and facilitate irrigation that could greatly expand the productivity of rice and other crops.

D. Fossil fuels

Oil and gas production in Colombia and other Latin American countries has recently been expanding due to increased investment in exploration and drilling. Coal production has also been increasing (Colombia is the largest producer in South America), and output is expected to double in the next decade. Much of the country's oil and coal has been targeted for export, providing important revenues. However, as the need for domestic power grows, it is unclear to what extent Colombia will use more of its coal and oil at home. While there are growing financial and development pressures to increase domestic consumption of coal for power generation and industrial use, this would raise GHG emissions[126] and increase the power sector's carbon intensity. Over the coming decade, carbon taxes in Europe and elsewhere could affect Colombia's coal industry and exports, as well as other hydrocarbons (petroleum and natural gas) over the medium to long term.

Policies

The policies needed to improve Colombia's energy sector include:

- **Energy diversification.** For various economic and environmental reasons, and the country's resilience after climate events, Colombia should continue to diversify its electricity and energy mix. Fossil fuels, especially natural gas, have been important in its diversification strategy. But the country could also diversify with hydro and non-hydro renewables, including wind, geothermal, biomass, and solar, all of which are increasingly competitive as technology costs fall and the costs of conventional energy sources rise.

- **Domestic coal and natural gas.** If coal was more widely used domestically, this could diversify the energy portfolio; but, it would also increase carbon emissions. With respect to local pollution, it is generally easier and more cost-effective to control coal-related emissions in the power sector than in industry, and power plants can be located away from major population areas. Still, natural gas is preferred to coal, including in the residential and commercial sectors, and for industries such as electronics, food and beverages.

E. Climate change impacts

The DNP and others have demonstrated the risks to Colombia from climate change, including impacts on water availability and economic production in climate-sensitive sectors such as agriculture and forestry. For this reason, low-carbon policies should be designed in a way that considers the risks of climate change, and where possible, reflect actions that contribute to sustainability and resilience. The development path Colombia would pursue under a stable climate regime differs from the one that includes variability.

126 Even if Colombia continues to export most of its coal, international GHG accounting rules may change from the current practice of assigning emissions entirely to consuming countries. Such a change could significantly raise Colombia's carbon emissions.

Policies

The policies regarding climate change include:

- **Assess the climate vulnerability of low-carbon actions.** The vulnerability of agriculture, forestry, and hydropower to climate change must be assessed, along with development plans that are part of Colombia's baseline program (eg. hydropower and forestry plantations). Also, activities that could be expanded under a low-carbon development program should be checked for their vulnerability .

- **Resilience factors.** Sectors and development programs that are vulnerable to climate change should be highlighted and policies taken to reduce the risks. For example, multi-purpose water control projects could help reduce the impacts of drought and floods and also reduce the effects on power production, when compared to run-of-river plants. Updated risk assessments (eg. planning infrastructure for a 100-year flood) should be conducted and used for planning purposes. When "firm energy" is promoted, planners should be aware of climate impacts.

F. Summary and conclusions

Colombia is intensely addressing the threats and opportunities of climate change, and has already passed laws—eg. the Policy Guidelines for Climate Change (CONPES No. 3700)—that reflect the country's broad objectives and assign the roles and responsibilities of different sectors and institutions. With respect to mitigation efforts, the country is working on several fronts with different national and international partners. The next step is to define sector priorities and a plan for low-carbon development.

This study presented tools that could help evaluate climate mitigation actions and programs: A microeconomic tool was used to assess low-carbon projects, while a macroeconomic tool (MEG4C Model) evaluated the impact of low-carbon measures and programs on the broader economy.

The microeconomic tool used standard economic cost-benefit analysis (CBA) of the type the World Bank and other development institutions apply to appraise projects. One of the model's advantages is that it has been tested in various countries globally, from Mexico to China, and modified to incorporate more sectors. The CBA analysis provided templates for a growing set of low-carbon measures, incorporated methodologies for valuing key externalities such as air pollution and time-savings, and relied on local expert teams to estimate costs and benefits. The methodology is most suited to comparing projects in a given sector, or projects of a similar type. However, the common methodology in all sectors allows cross-sectoral comparisons of low-carbon actions in terms of their cost/mitigation potential. Also, mitigation actions can be aggregated by sector and for the economy as a whole, thus estimating national mitigation potential (and total costs). This information could help policymakers determine the relative potential (and cost) of different sectors to mitigate climate-related problems, which is important when allocating funds, from international or domestic sources.[127]

The study also developed a macroeconomic tool to assess low-carbon projects/programs. It applied an earlier version of the CGE model developed by DNP to evaluate the potential im-

127 In Mexico, the World Bank's 2010 low-carbon analysis was used as the basis for the investment plan for the Clean Technology Fund, which provided a low-cost loan of US$50 million for energy efficiency and US$200 million for sustainable transport, and provided the analytical underpinning for a US$400 million development policy loan supporting climate mitigation in several sectors.

pacts of climate change on Colombia's economic development. Then, the CGE model was modified and linked with the cost-benefit analysis so as to assess various climate mitigation measures. The macroeconomic analysis demonstrated (a) the importance of considering not only the direct impacts of low-carbon measures on macroeconomic variables such as GDP and employment, but also the broader economic impacts such as backward linkages to factor markets; (b) that measures which contribute to productivity gains (such as efficiency improvements in energy, transport, or agriculture), would have positive effects on GDP and employment and (c) that large-scale investments in forest plantations could create jobs and income. Also, the analysis explored the impact of green taxes and showed that the use of the revenue from such taxes could have a big effect on macroeconomic variables as well as GHG emissions.

The sectoral analyses in this study can feed into the growing pool of knowledge in Colombia on low-carbon development. While many studies have been conducted on the country's energy and transport systems, those on agriculture and forestry have been limited. The work on AFOLU confirms the significant potential for mitigation, but also explores the many barriers such as rural security, land restitution, infrastructure development, and financing. At a minimum, the sectoral analyses demonstrated that many low-carbon measures can be adopted (in fact, some are already being applied) that are consistent with national development goals.

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