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Methodological guidelines for a mitigation potential study in the transport sector in Colombia

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Abstract

A detailed mitigation potential study is an essential element for setting up strategies to reduce greenhouse gas emissions. This report provides guidelines for conducting a bottom up study for the potential and costs for mitigation options in the transport sector in Colombia. It gives recommendations for setting up the marginal abatement cost curve and shows which choices can be made related to coverage of direct and indirect emissions, cost calculations and data collection, as well as a list of potential Colombian stakeholders.

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Acronyms and symbols

AMS	Approved small-scale methodology
AM	Approved methodology
AC	Abatement cost
BRT	Bus rapid transit
CCAP	Center for Clean Air Policy
CDM	Clean development mechanism
CER	Certified emissions reduction
CEF	CO_2 emission factor
CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon dioxide
EEA	European Environmental Agency
GDP	Gross domestic product
GHG	Greenhouse gas
GWP	Global warming potential
HFC	Hydrofluorocarbon
IPCC	Intergovernmental panel on climate change
IVE	International vehicle emissions model
ISSRC	International sustainable systems research center
JRC	Joint Research Centre
MACC	Marginal abatement cost curve
MAVDT	Ministry of environment, housing, and territorial development
NAMA	Nationally appropriate mitigation actions
Mt	Megaton
NPV	Net present value
N_2O	Nitrous oxide
NO_x	Oxides of nitrogen
O_3	Ozone
PM	Particulate matter
SRES	(IPCC) Special Report on Emission Scenarios
TEMPO	Transport Emissions Model for POlicy evaluation
TTW	Tank-to-wheel
UDLA	Universidad de los Andes
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VKT	Vehicle kilometers traveled
WTW	Well-to-wheel

1. Introduction

The transport sector is a major contributor to global greenhouse gas (GHG) emissions. It is also a sector where emissions have proven difficult to abate - it is the fastest-growing source of CO_2 (IEA, 2008). In both, Annex I and non-Annex I countries emissions have been rising and are projected to increase at an alarming rate in the near future. On a general level, there are three ways of reducing GHG emissions in the transport sector (adapted from Grütter, 2007): 1) Reduce the demand for transport services (e.g., by spatial planning or road taxes); 2) Reduce the emissions per unit transported (e.g., by modal shift, increased occupancy rates, or use of larger units); and 3) Reduce the emissions per kilometer traveled (e.g., by improving driving behavior and vehicle efficiency or by switching to low-carbon fuels).

The only current international policy instrument for reducing GHG emissions in non-Annex I countries is the Clean Development Mechanism (CDM). CDM and other potential international incentives are, however, not the only reasons to reduce emissions from transport. More sustainable transport provides significant co-benefits, such as improved air quality, energy supply security, and reduced congestion. Currently, there are four CDM transport-related projects in Colombia, which according to UNEP/Risø (2009) abate a total of 0.55 $MtCO_2$-eq/yr. Three of the four projects involve bus rapid transit - BRT - systems, and one project involves an aerial cable car). These transport CDM projects represent more than 10% of total GHG emissions reduction by the Colombian CDM portfolio[1] (UNEP/Risø, 2009). These values contrast with the experiences in other non-Annex I countries where, typically, the transport sector represents less than 0.5% of total Certified Emission Reductions (CERs) (UNEP/Risø, 2009). In the future, with international negotiations becoming more mitigation action- and sector-oriented, the transport sector could benefit from dedicated incentive schemes to be agreed in Copenhagen in December 2009 (see UNEP, 2009).

The Colombian Government is currently developing an ambitious national policy regarding climate change. It is highly relevant for Colombia’s Ministry of Environment, Housing, and Territorial Development (MAVDT for its initials in Spanish) to start developing a specific strategy for the transport sector. As part of this effort, it needs to be assessed if voluntary approaches would be effective and how policy objectives can be implemented with participation of relevant stakeholders. This requires an appropriate insight regarding the potential and costs of different mitigation alternatives, especially since earlier mitigation studies (World Bank, 2000; Rodriguez and Gonzales, 2000) have only partially covered the transport sector.

The objective of the present study is to assist the Colombian government in formulating policies for reducing emissions in the transport sector. It does so by providing guidelines for methodological choices to quantify the potential and costs of GHG emissions reduction alternatives for Colombia’s transport sector.

[1] This is based on the CDM projects at validation stage or beyond; if the wider project portfolio as given by the Colombian Ministry of Environment (MAVDT, 2009) is used there are 11 transport project covering 3% of the total (potential) GHG reduction.

2. Review of Previous Studies

Documents describing previous studies related to costs and potentials of climate change mitigation options for Annex I and non-Annex I countries can be found in the public domain as well as in journal articles of peer-reviewed literature. These studies represent a wide range of modeling tools, approaches, and comprehensiveness.

As part of the present study we reviewed transport sector mitigation reports conducted between 1998 and 2006 in Latin American countries (see Appendix A). The available studies regarding mitigation options for the transport sector cannot be regarded as providing a straightforward or comprehensive strategy in order to establish policies or measures aimed at reducing GHG emissions. Only the study by CCAP (2006) is comprehensive in terms of coverage of emissions reduction options and is also the only study (among the reports that were part of our analyses - see Appendix A) that includes detailed bottom-up data and scenarios. The remaining studies are of limited scope and include only a small number of emission reduction alternatives. For example, the option of utilizing electric vehicles is not covered in any study, and most of them do not explicitly show the assumptions and input data on cost of technologies.

One study includes several baseline and mitigation scenarios (CCAP, 2006) which can be understood as a measure the uncertainties. Other studies do not explicitly report uncertainties.

This means that for the case of Non-Annex I countries, especially in Latin America, there is plenty of room for further and more detailed studies regarding mitigation options for the transport sector. The present document was prepared to be helpful for such purposes with an emphasis on the particularities of Colombia.

3. Determining the Scope of a Mitigation Study

To calculate GHG emissions from the transport sector for the purpose of a mitigation study, determining which emission sources will be taken into account and what will be the scope of the study (in terms of system boundaries and time) is required.

3.1 Definitions and Study Context

Direct emissions are those produced by sources such as vehicles, trains, ships and airplanes. The main compound of interest is carbon dioxide (CO_2) and the main sources are those related to fossil fuel combustion. Other compounds of interest include methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (F-gases[2]). In addition to direct GHG emissions, the transport sector contributes to climate change by indirect emissions (or upstream emissions), such as those related to the transport and production of oil. Also, electricity consumed by electric trains and road vehicles is indirectly associated with CO_2 emissions from the power sector.

Direct emissions are also known as ‘tank-to-wheel’ emissions whereas indirect emissions are commonly referred to as ‘well-to-tank’ emissions. Indirect emissions may be released both domestically and in foreign countries, depending on the type of fuel and the underlying transport and production chains.

In addition, when defining the context in which a mitigation study is going to be conducted, it is necessary to determine if such effort will include direct and indirect emissions as well as the geographic boundaries of the analysis. For example, if the emissions inventory for the transport sector is developed for an extended framework (i.e., covering all relevant sectors such as refineries, industry, and power plants), indirect emissions will be implicit in the calculations.

On the other hand, if the emission inventories in which the mitigations study will be based are estimated only for the transport sector, it is essential to make an effort to include indirect emissions related to the various mobility alternatives. Otherwise, there will be the risk of implementing novel transport concepts with low direct emissions but high indirect emissions.

3.2 Direct Emissions

The most important direct GHG emission from transport is CO_2. In addition, however, the transport sector emits CH_4 and N_2O from fuel combustion as well as F-gases that may leak from the vehicle air conditioning system. In contrast to the case of CO_2, the emission factors of these other compounds are more uncertain and require much more data in order to be accurately estimated. Nevertheless, it is important to determine emissions given the higher global warming potential of these gases compared to CO_2.

Carbon Dioxide. Direct emissions are those produced during transportation activities, with CO_2 from fuel combustion being the dominant source. Roughly, one kilogram (kg) of fuel burned produces three kg of CO_2. The specific CO_2 emission factors for most traditional transport fuels are well documented and they are closely related to the fuel carbon content (see textbox below on calculating CO_2 emissions).

[2] Common F-gases include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFC). CFCs and HCFCs are being out by the Montreal Protocol.

Box 1. Calculating fuel CO_2 emissions

CO_2 emissions during fuel combustion are dependent on the carbon content of the fuels. The Intergovernmental Panel on Climate Change (IPCC, 2006) guidelines for calculating emissions inventories require that an oxidation factor be applied to the carbon content to account for the small portion of the fuel that is not oxidized into CO_2. For all oil and oil products, the oxidation factor used is 0.99. To calculate the CO_2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO_2 (44 g/mol) to the molecular weight of carbon (12 g/mol): 44/12. CO_2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams = 8.8 kg/gallon. CO_2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12) = 10,084 grams = 10.1 kg/gallon.

Source: EPA (2005).

Methane. Emissions of CH_4 from the transport sector range between 0.1 and 0.3% of total transport GHG emissions (Ribeiro et. al., 2007). These emissions are related to incomplete fuel combustion and the methane slip effect experienced by natural gas engines. The global warming potential (GW_p) of CH_4 is 23 times higher (IPCC, 2006) than that of CO_2 - i.e., in terms of global warming, one molecule of CH_4 would be equivalent to 23 molecules of CO_2.

Nitrous Oxide. Transport N_2O emissions are a by-product of catalytic NO_x reduction in the exhaust gas system. Although N_2O emissions are expected to decrease with the ongoing introduction of increasingly stringent NO_x control techniques (Behrentz et. al., 2004), N_2O emissions could be considerable for relatively old vehicle fleets. Michaels (1998) reports that estimates of the contribution of N_2O emissions from mobile sources in the US range between 0.5% and 3% (expressed in CO_2-equivalents) relative to the total emission of CO_2-equivalents. However, N_2O emissions may vary up to a factor of 50 and will be higher for vehicles equipped with aged or malfunctioning catalytic converters.

F-gases. F-gases are characterized by their high GW_p[3]. In 2003, worldwide emissions of transport-related F-gases were 0.3 to 0.6 Gt CO_2-eq, about 5 to 10% of total transport GHG emissions (Ribeiro et al., 2007). Even though the leakage of F-gases from air-conditioning systems has decreased substantially over the last few years as a consequence of the global phase-out on these gases , old vehicle fleets such as those typical of small towns in developing countries (including Colombia), may still be a significant source of these emissions.

3.3 Indirect Emissions

In addition to direct GHG emissions from vehicles, aircrafts, and ships, the transport sector contributes to climate change by indirect or upstream emissions. As these emissions relate mainly to the fuel production processes, they are discussed here per type of transport fuel.

Gasoline and Diesel. Indirect emissions of gasoline- and diesel-powered vehicles amount to about 15% of direct emissions (JRC, 2007a, b, c; Kroon, 2009). The contribution is expected to grow in the near future due to greater use of non-conventional oil, which requires more energy for extraction and refining processes. Also, as worldwide oil supplies shrink, the refined fractions that used to be sold as residual oil or bunker fuels are increasingly being upgraded to diesel or petrol quality fuels. Such conversion processes require additional energy.

Natural Gas. Indirect emissions from natural gas include upstream emissions from natural gas production and transportation. In general, indirect energy use and GHG emissions for natural gas-powered vehicles are lower than those for diesel and gasoline. However, this is not the

3 F-gases can persist in the environment for thousands of years and have a global warming potential that exceeds by three to four orders of magnitude that of CO_2.

case if the natural gas is extracted outside the country and imported via extensive pipelines, that could be thousands of kilometers long (JRC 2007a, b, c; Kroon, 2009). Such pipelines could leak significant amounts of methane.

As an example, Figure 3.1 provides Dutch direct and indirect emissions related to gasoline-, diesel- and compressed natural gas-powered vehicles (Kroon, 2009).

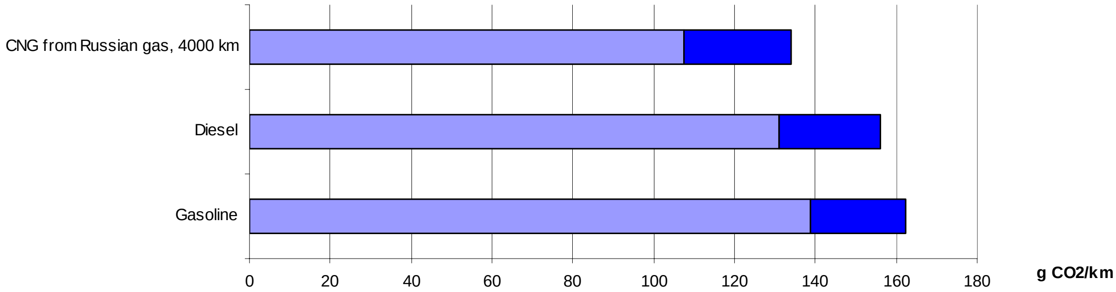

Figure 3.1 *Average direct (light bar) and indirect (dark bar) emissions in the Netherlands for vehicles using different fuels (expressed in gCO_2-eq per vehicle-km)*
Note: Both domestic and foreign indirect emissions are included.

Biofuels. Indirect emissions from biofuels arise from production and transportation activities. These include fossil fuel and electricity consumption, fertilizer use and emissions from land-use changes. For this case, indirect emissions may represent up to 50% of the fossil fuel's direct emissions. Quantification of these indirect emissions is difficult, especially for farming and land-use related emissions (that may be quite significant for N_2O). Direct emissions from biofuels are by definition zero (IPCC, 2006).

Electricity Consumption from Vehicles and Trains. Vehicles with on-board electric engines can be categorized as hybrids, plug-in hybrids, and all-electric vehicles. Hybrid vehicles are powered by an electric motor and a relatively small battery in combination with an internal combustion engine that uses a generator to recharge the battery. Plug-in hybrids are vehicles that can be plugged into an external charging point to extend the electric drive range and require a much greater battery capacity. All-electric vehicles are fully electric and battery-powered machines that can only be charged with electricity. Finally, electric trains and metro systems may be significant sources of indirect emissions, especially if electricity production is heavily dependent on fossil-fuel power plants.

3.4 Other Considerations

Geographic Boundaries. Another key methodological question is related to the extent to which indirect emissions should be estimated for sources located outside of the country's political borders. Such considerations complicate the analyses and require additional resources, but may be relevant depending on the scope of the mitigation study.

Time Horizon. A mitigation study can describe the potentials and costs for GHG emissions reduction alternatives for several time horizons. The decision regarding the time scale of the analysis is not only important for the meaning and usefulness of the results but also for the methodology to be applied. For example, the uncertainty related to the projected country's economic growth increases significantly as the time horizon expands. At the same time, however, longer time horizons allow for a larger number of mitigation alternatives. For these reasons, it is generally recommended to work with different time scales, including short, medium, and long term scenarios.

4. Estimation of Current and Future Emissions

The estimation of future transport emissions and the impact of mitigation options are often conducted in several steps. Typically, several baseline transport scenarios are developed to determine the emission reductions that can be achieved. Subsequently, the impact of policies and measures aimed at reducing emissions can be quantified relatively to the baseline scenarios.

4.1 Conceptual Framework for Transport Emissions

Figure 4.1 shows the overall framework for estimating future emissions from the transport sector[4], including its environmental impact chain. The remainder of this chapter will be used to describe the components of this figure in more detail (see references to the chapter's sections in the figure).

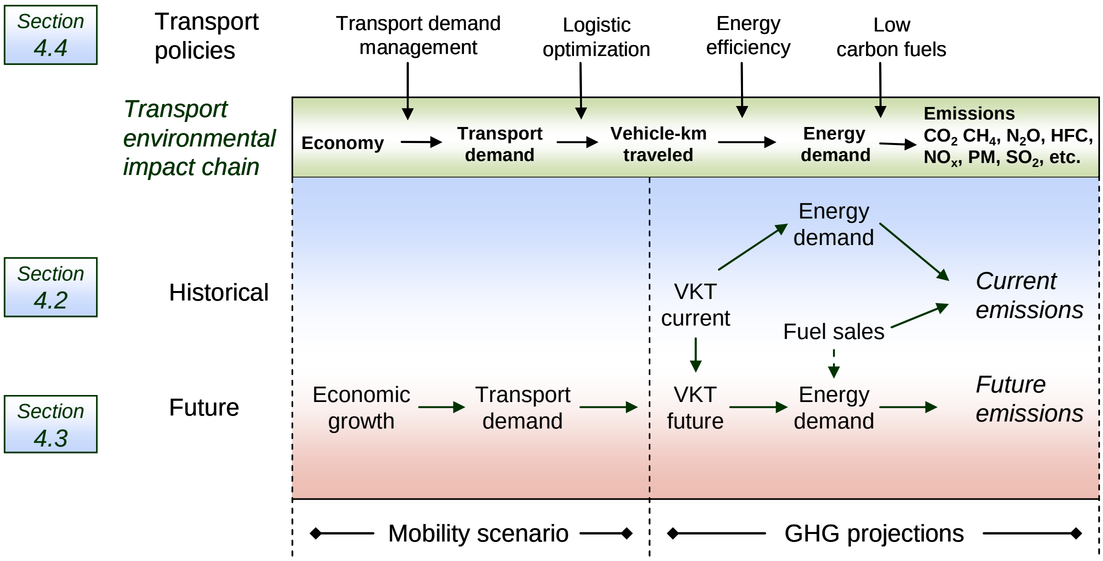

Figure 4.1 *Conceptual framework for estimating future transport emissions*

4.2 Estimation of Current Emissions

4.2.1 Direct CO_2 Emissions

There are two main approaches for estimating current direct CO_2 emissions from the transport sector: 1) top-down IPCC methodologies, based on fuels sales; and 2) bottom-up methodologies, based on vehicle fleet characteristics and vehicle activity data (i.e., number of kilometers traveled).

Typical top-down methodologies, as used by the IPCC (2006) are based on national fuel sales statistics, specified for the different fuel types (i.e., gasoline, diesel, natural gas). Since the carbon content of the different fuels has been well documented, the CO_2 emissions resulting from combustion in the vehicles' internal combustion engines can be estimated.

Data requirements for these type of methodologies include: a) annual fuels sales (for diesel, gasoline, liquefied petroleum gas, compressed natural gas, liquefied natural gas, kerosene, lubricants and biofuels); and b) CO_2 emission factors for each fuel type (expressed in grams of

[4] The figure is tailored to direct CO_2 emissions from road transport but can also be used for other emission sources as well as for other subsectors such as rail, air and water-borne transport.

CO_2 produced per liter (or kg) of fuel used).

Bottom-up methodologies require more and better quality data, including fleet size and distribution (by engine size, service type and fuel used) and total distance driven (vehicle kilometers traveled - VKT) per vehicle category. In these cases, it is also necessary to know the CO_2 emissions per vehicle category (in grams of CO_2 per km). The overall annual CO_2 emissions are estimated from the product of kilometers driven and CO_2 emissions per km for all vehicle categories. A detailed description of a bottom-up methodology can be found in Hoen et al. (2006).

The methodologies to be used are similar for the case of non-road transport (e.g., aircrafts and ships), although a lower level of detail may be required depending on the relative importance of the sub-sector being analyzed.

4.2.2 Non-CO_2 Direct Emissions

The emission factors of CH_4, N_2O, and F-gases largely depend on vehicle type and are highly variable. IPCC (2006) provides several methods for estimating the emissions of CH_4 and N_2O, which could be used depending on data and resource availability (see Figure 4.2). The IPCC Guidelines include emission factor ranges for these substances for a large set of vehicles as well as specific adjustments to be used for developing countries. These guidelines also consider rail, shipping and aviation related emissions. CDM baseline methodology AM 31 (UNFCCC, 2009a) provides default emission factors for CH_4 and N_2O for six different vehicle types and two fuels (diesel and gasoline) in gCO_2-eq/litre.

An important element to consider is future emission regulation. The Euro standards also cover N_2O and CH_4. These standards (see IPCC (2006) for a detailed overview) can also be used as an upper limit for new vehicles, provided they are implemented and enforced. However it should also be noted that for existing vehicles these standards may not be appropriate, depending on the legislation.

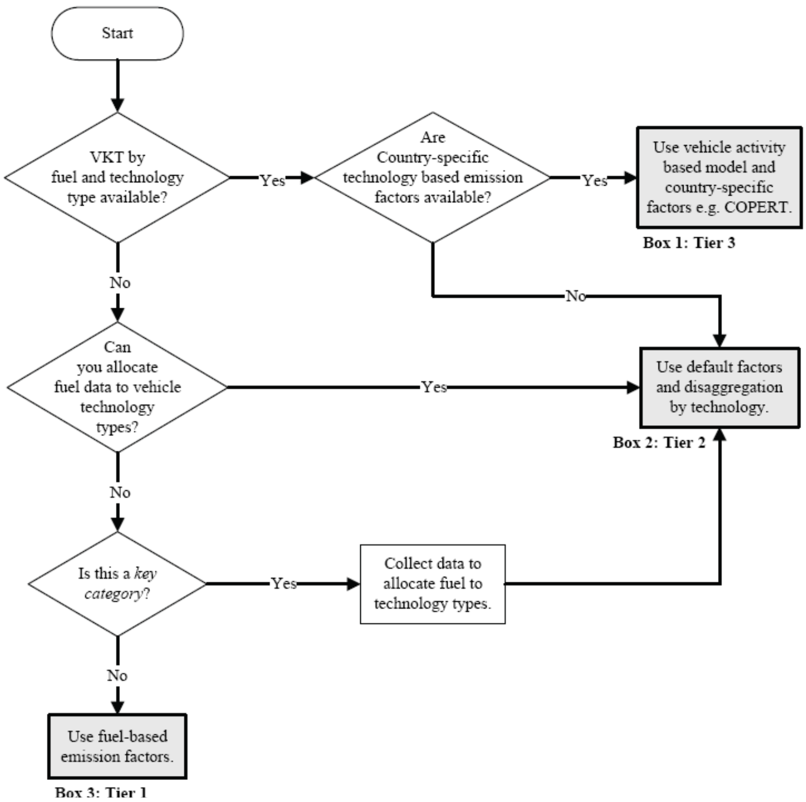

Figure 4.2 *Decision tree for estimating mobile CH_4 and N_2O emissions*
Source: IPCC, 2006.

4.2.3 Indirect Emissions

Well-to-tank emission sources related to biofuels include crop cultivation, land-use change, and energy consumed in the processing and transporting of the biofuels. Details about the protocol to estimate these emissions can be found in AMS.III-T (CDM-approved methodology for plant-based biofuels).

Assessments of benefits for electric vehicles show that the method used for electricity generation is the dominant factor when determining CO_2 emissions[5]. If the electric vehicle operates in a predominantly fossil-fuel power system, the climate benefits are modest. The contrary will be the case for a country (such as Colombia) where hydropower is the predominant source of electricity.

A key question is whether the average grid emission factor should be used to calculate the emissions, or the emission factor of a particular source of electricity, e.g. the marginal plant at a particular time of the day. This will greatly impact the emissions of electric vehicles. CDM baseline methodology AMS.I-D (for small-scale renewable electricity for the grid) gives two options: 1) the average of the operating and build margin (as described in ACM0002 for large scale projects) or 2) the average grid emission factor.

4.2.4 Air Pollutants

The estimation of accurate emission factors for air pollutants such as particulate matter (PM) and ozone precursors (including nitrogen oxides and organic compounds) is usually more difficult than for CO_2. More commonly, these compounds' emissions are estimated using bottom-up methodologies that have high data requirements[6].

The international vehicle emissions (IVE) model, developed by the International Sustainable Systems Research Center (ISSRC[7]), comprises a methodology that was specifically designed for developing countries with vehicle data limitations. The methodology has been widely used in Latin America and several major Colombian cities have used it for estimating their mobile sources emission inventories. The IVE model allows the consideration of variables such as vehicle maintenance, fleet age, use of emission control technologies, fuel type, fuel quality, driving patterns and city's altitude.

As a general principle, all GHG emissions mitigation alternatives should not produce a negative impact on urban pollution. This is particularly relevant for developing countries where ambient air concentrations of several air pollutants not only exceed the air quality standards but also exhibit an upward trend. Examples of such situations can be found in almost all major urban centers in Colombia.

4.3 Development of a Baseline Transport Scenario and Related Emissions

A baseline scenario is a plausible and consistent description of how a system might evolve in the future in the absence of explicit GHG mitigation policies (UNFCCC, 2008). The baseline should reflect national development priorities, including the strategies for climate change mitigation and adaptation (which for the case of Colombia are a top priority for the national environmental authority).

The three more common baseline scenarios (UNEP, 1999) are: 1) the economically efficient case, in which economic resources are allocated optimally and result in exclusively 'no-regret' mitigation options; 2) the business-as-usual scenario, where continuation of current trends is assumed; 3) the most likely case, which is a compromise between the two cases above.

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[5] Electric vehicles use about 1 kWh of electricity to drive 6 kilometers, resulting in approximately 140 grams of CO_2-eq per kilometer if 100% of the electricity is coal-produced (35 g-CO_2-eq/km for 25% coal + 75% hydro).

[6] Several global emission models use top-down methodologies but they usually lack the level of detailed required for a local-scale emissions inventory.

[7] See more details at http://www.issrc.org.

In all cases, any policies regarding GHG emissions reduction that are currently being implemented should be taken into account in the baseline scenario. For example, for the case of Colombia, the promotion of natural gas and biofuels represents a national policy that is likely to continue in the following years and that will have an impact on the emissions of greenhouse gases.

The baseline scenarios for transport emissions are typically developed in two separate stages (VITO, 2008): 1) development of a mobility scenario; and 2) translation of the mobility scenario into GHG emissions projections (see Figure 4.1).

4.3.1 Development of a Mobility Scenario

The development of a mobility scenario comprises two different steps: projecting the transport demand and projecting a detailed VKT.

Projecting Transport Demand. In this step the total demand for mobility (in passenger- and ton-kilometers) is determined. Mobility projections are quite complex as they are affected by different policies including those regarding the environment, infrastructure, taxes, safety, urban congestion, urban parking, and public transportation.

Economic growth, however, is the dominant driver for passenger and freight transport demand. Nearly all data available suggest that personal income and traffic volume grow in tandem, although the correlation differs between countries and time periods. In general, as average income increases, the annual distance traveled by car, bus, train or aircraft rises by roughly the same proportion (Schäfer and Victor, 2000; EEA, 2006). Consequently, economic growth is the basic proxy for estimating future mobility (see Appendix B).

Projecting Detailed VKT. Projecting the detailed VKT, specified for as many vehicle categories as possible, is also a complicated issue. The VKT can be estimated with sophisticated models that account for economic growth, societal structure, fuel price elasticity, and demographic developments. However, when a detailed transport demand model tailored to the local situation is not available, the transport demand may be assumed to grow linearly with economic growth (this is plausible since transport and economic growth are strongly coupled - see Appendix B).

It is of utmost importance that the links between economic growth and transport demand are applied in the local context and using as much local data as possible. For example, in the European Union data from EUROSTAT has been used (VITO, 2008) to determine that vehicle usage elasticity (increase in VKT per unit of economic growth) corresponds to the range between 0.295 and 2.45 (median value = 0.8). However, in developing countries, elasticity between economic growth and transport performance could be significantly higher (APERC, 2007). Figure 4.3 and 4.4 show results of a recent study by the Universidad de los Andes (Bogotá, Colombia) regarding the future of the transport sector in Colombia (UDLA, 2009).

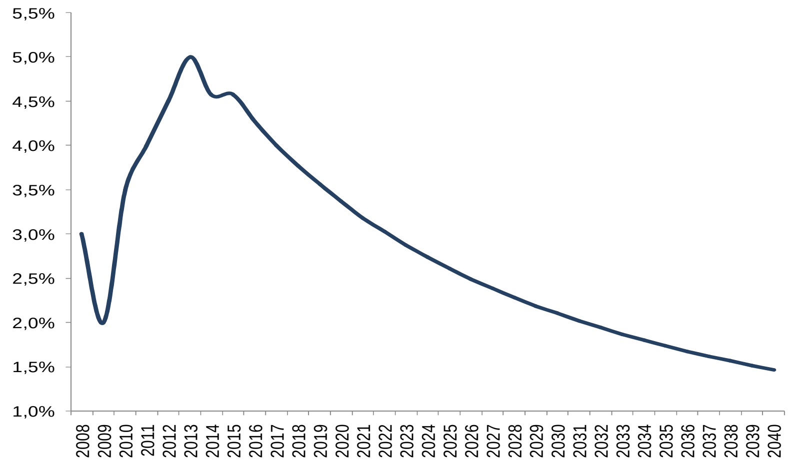

Figure 4.3 *Economic growth projection (GDP) in Colombia*
Source: UDLA, 2009.

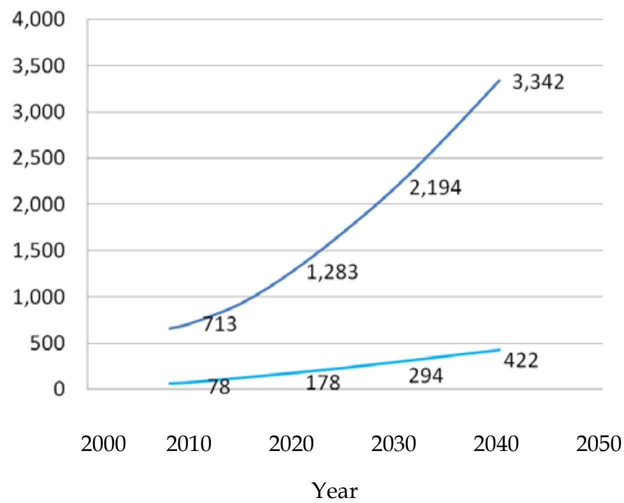

Figure 4.4 *Projected number (thousands) of passenger cars (top line) and motorbikes in Colombia's capital city*
Source: UDLA, 2009.

4.3.2 Translation of the Transport Scenarios into Emissions

After the projection regarding vehicle fleet size and composition, as well as the demand for transportation of people and goods are known, and the way in which these conditions affect the specific VKT for all vehicle categories is characterized, it is possible to estimate the baseline projections for the air pollutants and GHG emissions (using emission factors that apply to the local context). This baseline scenario will be compared (see next section) to the emission scenarios that will be generated for the different emissions reduction alternatives.

4.4 Mitigation Alternatives

A climate change mitigation scenario represents the path of emission reductions compared to a baseline scenario. The starting point for such process could be: 1) an emissions reduction target for a certain year; 2) a maximum marginal abatement cost; 3) bottom-up technology choices (such as a specific biofuel blend or fuel standards); and 4) scenarios based on an overall desirable energy system (such as a sustainable transport system).

Even though these approaches are significantly different, the final results obtained through them could be quite comparable as the most common practice is to use a combination of all approaches. For example, if for certain emissions reduction targets the marginal abatement cost rises to unacceptable levels, the target may be reduced.

4.4.1 Policy Context

The choice of the mitigation scenarios depends on which policy measures are already in place . For example, only Annex I countries face specific emission targets under the Kyoto Protocol and their national mitigation obligation will be shared among different sectors.

Non-Annex I countries (including Colombia) are not required to meet an emissions target and it is unlikely this situation will change after the Copenhagen Agreement[8]. There are, however, several possible international policy instruments that are relevant, such as the project-based CDM[9], which most likely will continue (although it may be subject to some modifications) after 2012 (UNFCCC, 2009b).

At the same time, the project-based CDM could be reformed into sectoral CDM or other sectoral approaches, in which the emissions of an entire sector in a certain region of the world are covered under one common baseline. There is also the concept of Nationally Appropriate Mitigation Actions (NAMAs), which would entail a deviation from business-as-usual emissions by non-Annex I countries, as a contribution to global emission reductions, and may be supported by Annex I in the form of finance, technology and capacity building. Whether NAMAs will be part of the carbon market is unclear as of now. For the transport sector both NAMAs and sectoral approaches may be relevant, considering the limited scope for achieving significant reductions of this sector by the CDM. Finally, other international developments, such as vehicle efficiency improvements or more stringent emission standards, shall be considered.

At a national level, there are significant incentives for strong transport-related policies that are not motivated by GHG emission reductions but have to be taken into account. For example, it is widely documented that the transport sector causes substantial impacts on public health, energy security (supply of oil), urban congestion, road safety and urban planning. Policies related to such issues will likely evolve in Colombia and other developing countries during the time period chosen for the analyses. Such policies shall be considered since their long-term impact on emissions could be more significant than that of mitigation-related policies.

4.4.2 Choice of Mitigation Policies and Measures

In order to reduce emissions below the baseline, a range of technologies and measures can be implemented. These could be directed at different parts of the transport sector's environmental impact chain (see Figure 4.1).

The estimation of the measures' effectiveness in the short term is relatively simple as the baseline developments in the near future are close to the current situation. Short term measures (two to five years from present) are often focused on the implementation of strategies that do not require major changes in the current vehicle fleet (e.g., fuel saving tires, introduction of alternative fuels compatible with existing technology and promotion of energy saving driving behavior) or that are aimed at a more efficient transport-related infrastructure.

Medium term measures (ten years from present) include strategies such as technologically improving vehicle efficiency, modal shift and use of second generation biofuels. When including these type of measures in the analyses, the fuel efficiency of future cars (up to 50% more efficient in 2020 than presently) should be considered. This will be particularly important for motorized 2-wheelers with 4-stroke engines, a vehicle type that is highly relevant in the Colombian context.

Short and medium term measures involve mostly incremental reduction of emissions, enabling an overall GHG emissions reduction of about 50% (Passier et. al., 2008). Consequently, these

[8] Countries like South Korea, South Africa and Mexico have announced their plans to establish domestic targets.
[9] Including programmatic CDM, which can be seen as an expansion of the project-based CDM.

measures are insufficient to meet the long-term global reduction target of about 80% compared to year-2000 levels (Stern, 2007), especially since the transport volume is expected to increase substantially (particularly in the developing world).

This means that long term (30 years from present) measures that allow further emission cuts need to be considered now, especially since such measures typically involve long implementation trajectories. For example, the introduction of electric or hydrogen-powered vehicles have the potential of achieving CO_2 emission reductions of more than 70%, but their massive use depends on a myriad of factors including technology development, international policy, global economy and fuel prices.

4.4.3 Examples of Mitigation Alternatives for Colombia

In this section we provide a list of possible GHG emissions mitigation alternatives that could be implemented in Colombia, pending the elaboration of a full mitigation study for the transportation sector. For these alternatives we also include examples of possible barriers of various types.

Alternatives Related to Demand Reduction: Spatial planning (transit oriented development), promotion of teleworking or flexible working hours, road pricing, tax measures on fuel, and restriction on use of private fleet. <u>Potential barriers</u>: Welfare loss, institutional barriers, general acceptability, and public acceptance.

Alternatives Related to Emissions Reduction per Unit Transported: Promotion of non-motorized transport, promotion of mass transit systems and public transportation, increase of public transport ridership, modal shift of freight transport (e.g., road to rail or water), and carpooling. <u>Potential barriers</u>: Competition for road space, extended construction time and budget, infrastructure limitations, and social preferences.

Alternatives Related to Emissions Reduction per Kilometer Traveled: Driver training, efficiency in engine technology, traffic management, use of hybrid, hydrogen-powered and electric vehicles, use of second generation biofuels and other alternative fuels such as compressed natural gas. <u>Potential barriers</u>: technical limitations; slow fleet replacement, infrastructure requirements, competition for public space, overall sustainability, land availability, and social acceptance.

5. Cost of Mitigation Options

Following the establishment of emissions mitigation scenarios, the next step is to determine the abatement costs of the alternatives that are included in such scenarios.

5.1 Cost Calculations

Incremental cost of mitigation action is an integral part of most mitigation studies. Incremental cost represents the deviation of resources that are aimed at reducing GHG emissions that could have been used for alternative purposes, such as promotion of public health or construction of basic infrastructure. These resources are measured against a ‘no action’ reference in which the economy follows its normal development (UNEP, 1999).

Costs of technologies can be calculated in different ways[10,11]: 1) economic cost, which looks at technologies from a national point of view (i.e., transfers between producers and consumers and between governments are excluded) and in which taxes and subsidies are not taken into account. In this case, the discount rate is set at a ‘social’ level; 2) private cost, or investor/end-user’s point of view, in which the discount rate is set at a level applicable to investment decisions common to the private sector. Taxes and subsidies are included; 3) social cost, where the assumptions of the economic cost approach are used, in addition to the consideration of externalities (costs assumed by society for the negative implications of the investment decisions. This is also called the ‘welfare-economic’ analysis (Davidson et. al., 2007). Policymakers need to choose the leading cost approach for their own policies.

Most abatement cost studies use the first approach (McKinsey, 2009; IPCC, 2007) in which taxes, subsidies and externalities are excluded. For the transport sector these are however very important and may need further consideration (Davidson et. al., 2007; UNEP, 1999) as there is the risk that a narrow perspective shortcuts the decision process by ignoring relevant impacts.

On the other hand, if the perspective of the end-user (e.g., a private car owner) is considered as the main approach, the cost-benefit ratio of the mitigation options (e.g., use of biofuels) may change significantly (e.g., prices are determined to a great extent by taxes). An additional complicating factor in this regard is the uncertainty related to future taxes and subsidies.

In social cost calculations, full accounting for externalities is a complex issue (Egenhofer et al., 2006). External effects from mitigation options may have positive impacts on public health, energy supply security, biodiversity, and traffic congestion (Markandya, 1999) but uncertainties in these cases are typically quite important (e.g., monetization of life’s value).

UNEP (1999) provides a useful reference for social cost calculations, in which they present a basic framework for assessing impacts of mitigation measures that are not easy to express in monetary terms. In this case the following aspects should be considered: a) employment: if a project creates a job there is a benefit to society which is equal to the social cost of unemployment; b) income distribution and poverty: different income groups are affected (positively or negatively) by the mitigation action; c) environmental impacts: including air quality, biodiversity, and sustainability. In most mitigation studies, however, these types of impacts are not considered when determining the mitigation alternatives´ abatement cost. This is due, as previously discussed, to the high uncertainty as well as the general interest in producing results that are comparable to other studies.

Finally, implementation costs are those additional to technology, including labor, land, and capital. These include costs related to awareness-raising campaigns or policies to overcome infor-

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10 See Appendix C for more details.

11 As used in Egenhofer et al. (2006); in Daniels & Farla (2006) the economic cost approach is the national cost whereas the private cost is the end-user cost. Davidson et al. (2007) also distinguishes the government cost perspective.

mation gaps (UNEP, 1999). Implementation costs can be divided into administrative costs (such as costs for planning, training, and monitoring) and barrier removal costs, such as capacity building, enhancing market transactions, and enforcing regulatory policies.

5.2 Discounting of Future Costs and Benefits

The costs and benefits that accrue in the future are computed into net present values (NPV) through the discounting of such values. The discount rate's proper value is a matter of large debate. The discount rate can be understood as 1) An ethical description of how future benefits should be regarded (therefore a political choice of what is desirable); 2) A description of peoples´ behavior in their daily decisions (i.e., equal to the capital's marginal rate of return) (UNEP, 1999).

A discount rate[12] of 3% is generally recommended by Markandya (1999). In the Fourth Assessment Report, the IPCC uses a rate of 4%. Bakker et al. (2009) has used 3 to 5% as the social rate and 8 to 12% for private cost calculations. UNEP (1999) recommends 3% as the central value with sensitivity calculations to be carried out using a range between 1 and 10%. In Colombia's developing economy, capital is scarcer than in Annex I countries. Thus, the market discount rates should be higher than in developed countries.

5.3 Incremental Cost Calculation

As previously discussed, any action taken to mitigate climate change may cause economic resources to be diverted away from alternative uses. Mitigation assessments should therefore attempt to estimate the value of such resources using cost-benefit analysis techniques.

Incremental costs are normally measured relative to a 'no-action' or 'what would have happened otherwise' counterfactual baseline. In these cases, it may not be necessary to specify all costs for non-technical actions involving alternatives at the social level (e.g., campaigns to encourage the public to waste less energy) (UNFCCC, 2008).

Cost of technology generally consists of an investment and periodically recurring maintenance and operational costs that can be calculated back to a net present value (NPV). If two technologies with different annual emissions are compared, the incremental cost of the GHG emissions reduction (see equation below) can be established by dividing the differences in the overall cost of the technologies (for example in terms of \$/km traveled) by the difference in the observed emission factors (for example in terms of gCO_2/km-travelled).

$$AC_M = \frac{Cost_T - Cost_R}{CEF_R - CEF_T}$$

With:
AC_{M1} Abatement cost of Mitigation option (M)
Cost Cost of technology (T) or reference (R)
CEF CO_2 emission factor

For example, in Hanschke et al. (2009), abatement costs for electric vehicles for a long-term scenario were calculated based on a scenario that was developed using the TEMPO model (see Appendix D). This model describes the replacement of conventional internal combustion engine vehicles with electric vehicles. This scenario results in total GHG emission reductions (direct and indirect emissions) in the Netherlands of 2.0 Mt/yr by 2030. The additional vehicle costs to achieve this goal were estimated at 800 M€ while the benefits were estimated to be 200 M€, in terms of reduced energy costs (based on a 4% discount rate and 10 years economic lifetime). The abatement costs thereby are calculated as being 600 M€ / 2.0 $MtCO_2$-eq = 300 €/tCO_2-eq. In this study, the infrastructure costs for providing electricity on a large scale (charg-

[12] In all cases this refers to a real rate (i.e. corrected for inflation).

ing points) were not considered, based on the assumption that such costs would be quite small (on a per vehicle basis) compared to battery costs.

Another relevant example is provided by Bakker et al. (2009), in which the abatement costs for biofuels for the year 2020 were determined using an additional vehicle cost of € 200, discounted at a rate of 4% and 13 years of economic lifetime. For such assumptions, the additional fuel costs were determined to be 9 €/GJ. The differences in the life-cycle GHG emissions were computed as 63 gCO_2-eq/MJ. Dividing the additional cost by the difference in emissions yields an abatement cost of 163 €/tCO_2-eq.

5.3.1 Marginal Abatement Cost Curve

The marginal abatement cost curve (MACC) is the main outcome of a mitigation study. This graphic representation expresses the relationship between the minimum costs to society for achieving additional GHG emission reductions (compared to a baseline). It also indicates the level of emission reductions that can be accomplished.

There are several methods to generate MACC (UNEP, 1999): 1) partial (option-by-option); 2) retrospective systems approach; and 3) integrated systems approach. An example of a MACC is provided in Figure 5.1.

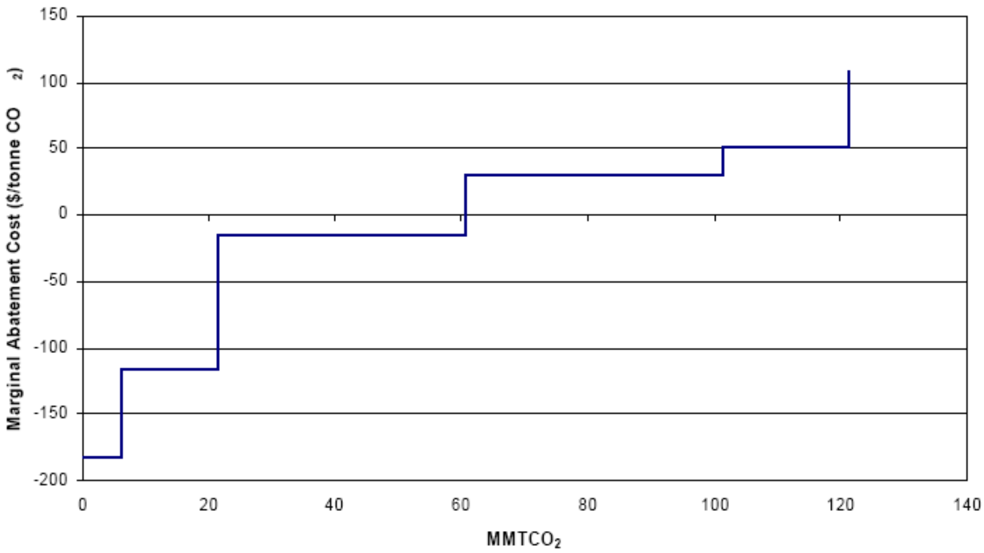

Figure 5.1 *Example of a MACC*
Source: CCAP, 2006.

6. Data Requirements and Uncertainty

Data requirements for any mitigation study depend on the selected approach and the methodologies. In this section, we provide an overview of such requirements when determining the GHG emission reductions and the costs related to different mitigation scenarios. Although intensive in some cases, data requirements for mitigation studies are, in general, less demanding than for CDM projects as the latter requires a high level of certainty in order to quantify actual GHG reductions.

6.1 Data Required for Mitigation Alternatives

- For mitigation alternatives related to demand reduction (see Section 4.4.3), typical data requirements include travel demand statistics, price elasticity, quantification of the impact of the measures on people's behavior, emission reductions and data regarding rebound effects.
- For mitigation alternatives related to emissions reduction per unit transported (see Section 4.4.3), typical data requirements include statistics regarding the potential of modal shifts, baseline emissions, emissions per passenger, emissions per vehicles, and data on people's behavior.
- For mitigation alternatives related to emissions reduction per kilometer traveled (see Section 4.4.3), data requirements include baseline emissions, emission factors for the different fuel types, VKT statistics, indirect emissions data, quantification of the impacts on emissions of variables such as average speed, fuel consumption data, and detailed characteristics of the vehicle fleet.

6.2 Data Required for Abatement Costs

In most cases, to calculate abatement costs for a particular mitigation alternative, the costs for the reference situation (i.e., baseline scenario) are also required. Here the abatement costs refer to the savings achieved by applying a specific strategy and may be estimated using different methodologies (see Section 5.3).
For different types of mitigation alternatives (i.e., transport demand reduction and emissions reduction - see Section 4.3.3), data requirements typically include: a) Investment costs; b) operation and maintenance cost; c) implementation costs; d) fuel costs; and e) cost of baseline options. Additionally, in some cases, there could be negative impacts on fuel economy, indirect costs for the economy, and society welfare loss.

6.3 Dealing with uncertainties

In addition to low data availability, the GHG reduction potential of transport sector strategies is difficult to determine due to the uncertainties related to such strategies. For example, the success of the different policies and measures may depend on behavioral and lifestyle aspects, such as driving patterns and consumer preferences for electric cars. Forecasting and quantifying such dimensions are a major challenge.

In addition, estimating the impact of the technical measures aimed at reducing GHG emissions carries its own uncertainties related to, for instance 'autonomous' improvements in technologies and their associated costs

For abatement costs, the level of uncertainty is related to variables such as energy prices, economic growth, and tax forecasts, all of which are complex to determine for long-term scenarios (see Bakker et al., 2009). Therefore any calculation involves uncertainty that must be made explicit quantitatively (e.g., using ranges of values or a statistical measure of variability) or qualitatively. By carrying out a sensitivity analysis for insight can be gained as to which as the most important variables. These can then be looked at in more detail in order to reduce uncertainty.

7. Stakeholders and Relevant Actors

Early involvement of key actors is essential to guarantee the success of any policy, including mitigation policy. Such involvement serves several purposes, including: a) Minimizing the probability of facing opposition to the designed measures; b) Inclusion of all relevant components; and c) Optimization of society's knowledge regarding the impacts and mitigation options for GHG emissions.

In this section we provide a list of key actors and stakeholders relevant for the transport sector in Colombia. Such actors should be involved, according to their specific expertise, in all stages of the mitigation study; including the development of the baseline scenario, the data gathering efforts and the final review process.

7.1 Public Sector

Government agencies and ministries other than MAVDT are essential for data gathering, for providing input on the main conclusions of the mitigation study, and during the implementation of any mitigation policy. For example, it will be a major challenge for a Ministry of the Environment to implement a transportation policy without the consent and collaboration of the Ministry of Transport. Relevant public sector entities include:

- Environmental, health and weather authorities: Ministry of Environment, Housing, and Territorial Development; Institute for Hydrology, Meteorology and Environmental Studies; and Ministry of Social Protection.
- Transportation, energy and commerce authorities: Ministry of Mining and Energy; Ministry of Transportation; Civil Aeronautics Board; Superintendence of Transport and Ports; National Oil Company (ECOPETROL); representatives of the planning agencies of the existing BRT systems; and Ministry of Commerce, Industry and Tourism.
- Planning and finance authorities: Ministry of Finance and Public Credit and National Department of Planning.
- Infrastructure related authorities: National Institute of Roads and National Institute of Road Concessions.
- National Congress: House of Representatives' Fifth Commission (component of the legislative branch that is in charge of environmental issues).
- Colombian Institute of Certification and Technical Guidelines (ICONTEC).
- Colombian Council on Competitiveness.

In addition, the Ministry of Environment, Housing, and Territorial Development could be used to allocate the discussion among local and regional authorities. For similar purposes, the National Association of Municipalities should be involved in the process.

7.2 Private Sector

Private associations also play a role during policy design. In the case of mitigation alternatives, they will be the ones applying and being affected by the measures and policies implemented to reduce GHG emissions. These associations should be part of the baseline scenario development and need to be considered as reviewers of the main conclusions of the mitigation study. The level of engagement depends strongly on the type of mitigation measure – for electric vehicles, for instance, the power sector is important but for vehicle efficiency less so. The private-sector actors may include:

- Commerce and industry associations: National Business Association (ANDI) and National Chamber of Commerce (FENALCO).
- Utilities and fuel-related associations: National Association of Public Utility Companies (ANDESCO); National Federation of Palm Oil Growers (FEDEPALMA); National Association of Natural Gas (Naturgas).
- Vehicle manufactures and importers: Association of Motor Vehicles (ANDEMOS); Colombian

Federation of Interurban Transporters (COLFECAR); National Federation of Urban Transporters (CONALTUR).
- National Chamber of Infrastructure.
- CDM specialists and consultants.

7.3 Academia and NGOs

For better policy quality and public engagement, it is recommended to consider the technical and independent advice of universities and non-government organizations dedicated to work on climate change mitigation and adaptation. Such institutions will be helpful through the entire process as they will be a source of quality data and baseline scenario considerations. Also, experts affiliated to these types of organizations would aid during the review of the final conclusions of the mitigation study. The Academia and NGO sector actors may include:

- Private and public universities that have worked on GHG emissions abatement from the transport sector[13]: Universidad Nacional de Colombia, Universidad de Antioquia, Universidad del Valle, Pontificia Universidad Bolivariana, Universidad del Norte, Universidad Industrial de Santander, Universidad de los Andes, Pontificia Universidad Javeriana, Universidad Externado de Colombia.
- NGOs[14]: Clinton Foundation in Colombia, Humane City Foundation, ECOFONDOrivate and public universities: Universidad Nacional de Colombia, Universidad de los Andes, Universidad Javeriana, Universidad Externado de Colombia.

[13] This is not a comprehensive list of all Colombian universities that will be useful in this process.
[14] This is not a comprehensive list of all NGOs based in Colombia that will be useful in this process.

8. Guidelines for Methodological Choices

In this chapter we summarize the main recommendations regarding the methodologies that should be used for a mitigation potential study related to the Colombian transport sector. It must be noted that the following recommendations depend on the local context and could lose part of their applicability after a few years. Also, the choice of approaches and methodologies to be utilized will depend on the study's scope as well as on data and resource availability.

8.1 Estimation of Emissions

Top-down vs Bottom-up.

The bottom-up approach is, in general, more helpful and more appropriate for the purpose of generating GHG emission scenarios. This is mainly due to the effect that variables such as vehicle type, fuel quality, and fleet's maintenance may have on the vehicles' emission factors (especially for the case of urban air pollutants). Such components are implicit in all bottom-up methodologies and are complex to determine using top-down approaches. Bottom-up methodologies are more demanding on data requirements but in most Colombian cities (where the majority of GHG emissions are produced) such information is likely to be available.

An alternative is using a hybrid method in which the historical and baseline emissions are estimated based on fuel sales (i.e. top-down approach) and the emission reductions for the mitigation scenarios are calculated using detailed projections on VKT and fleet composition (i.e. bottom-up approach).

Non-Vehicle Emissions

We recommend the consideration of both passenger and freight transport in as many subsectors as possible (e.g., road, rail, water-borne and air transport) in order to provide a complete and comprehensive perspective. Such an approach is consistent with IPCC guidelines.

Direct GHG Emissions

Consistent with IPCC guidelines, we recommend that mitigation potential studies include methane, nitrous oxide and F-gases when baseline scenarios indicate that GHG could be relevant due to their high GW_p. For the Colombian context, the consideration of CH_4 and N_2O emissions may be particularly important given the extensive and growing use of natural gas powered vehicles and the relatively old vehicle fleet (equipped with aging catalytic converters).

Indirect Emissions - GHG

Certain indirect emissions must be considered when developing a mitigation study. This is particularly important for the case of fuel switching strategies (e.g., promotion of alternative and clean fuels). Methodologies for such calculations have been discussed elsewhere in this document (e.g., AMS.I-D methodology - UNFCCC, 2009).

In general, for the case of baseline emissions, most indirect sources may be ignored (the exclusion of such emissions will result in smaller emission reductions potential, i.e. conservative estimates). As a general rule, indirect emissions need to be included in those cases in which their magnitude is significant or when a mitigation alternative that is being evaluated may produce additional indirect emissions.

Direct Emissions - Urban Pollutants

Given the importance of the co-benefits that could be achieved by many mitigation alternatives aimed at reducing GHG emissions and considering that urban pollution remains a major challenge for local authorities in Colombia, all mitigation studies should include analyses related to particulate matter and ozone precursors (the main air quality problems in Colombian cities). In addition GHG mitigation options included in a national policy should not have a negative impact on urban air pollution.

Geographical Scope
In most mitigation studies, indirect emissions produced in foreign countries may be ignored. An exception to this rule would apply when conducting an international study or when the country is heavily dependent on energy produced in neighbor states. This, however, does not seem to be the case for Colombia.

Time Horizon
To obtain a comprehensive perspective and to provide an integrated set of measures, we recommend that emission scenarios be estimated and analyzed for the short (5 year), medium (10 year) and long (50 year) term.

Baseline Scenarios
When computing baseline scenarios, the following components must be taken into account (see Figure 4.1): economic growth, current and future emissions, future mobility scenarios and transportation demand (in terms of fleet's size and usage), price and GDP elasticity, fleet replacement, and energy prices.

Mitigation Scenarios
To establish the mitigation scenarios and the set of possible mitigation strategies it is essential to carefully consider the local context (see sections 4.4.1 and 4.4.2). Also, as a starting point of scenarios for a mitigation study for the transport sector in Colombia, the list of alternatives described in Section 4.4.3 shall be used.

8.2 Estimation of Abatement Costs

Economic Approach
In general, when determining the cost of mitigation alternatives, the economic cost (government's point of view) approach is more convenient. However, calculations based on real investment behavior from consumer and companies may provide useful information. External effects are rarely taken into account when generating a marginal abatement cost curve but need to be included as non-monetary benefits. Benefits of avoided climate change impacts may be disregarded, as these are quite uncertain and will equally affect cost estimates for all options and thereby do not provide better information. In this sense, the benefits are for the global community and not for the country in which the actions are taken.

Discount Rate
As discussed elsewhere, typical discount rates are in the range of 3 to 5% for social rates and between 8 to 12% for private cost calculations. It is difficult to establish a standard value for this rate. Therefore, the main recommendation in this regard is to consider the decision about the discount rate to be used to be a major priority within the mitigation study.

Marginal Abatement Cost Curve
Given that the MACC is the main outcome of a mitigation study, its should be considered a priority during the development of the project. The MACC shall include all sectors considered in the study and should be able to provide a comprehensive perspective of the main results.

8.3 Other Recommendations

- Refer to and follow international guidelines and standardized methodologies as much as possible, but make and effort to use locally generated data in all possible cases.
- Be upfront and candid regarding assumptions, limitations and uncertainties. All these components should be estimated and made explicit.
- Develop a bottom-up simulation tailored to the Colombian context that also allows comparison with other countries.
- Running sensitivity analyses is always recommended as these tools make the quantification of the impact of different variables' impact possible.
- Establish panels of experts and discussion tables with stakeholders and key actors. This will help for the data gathering process as well as for identifying relevant mitigation scenarios.

Also, public involvement is an essential strategy to avoid rejection of the policies that will be implemented.

- Develop fact sheets for the cost and potential of each mitigation alternative.

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Appendix A Overview of existing mitigation studies in Latin America

Country	Transport sector included?	Baseline scenario included	Bottom-up data	Assumptions	Mitigation scenario (s) included	Mitigation options assessed	Year(s) of projection	Reference	Remarks
Colombia	yes	no, but some info on electricity sector	no	10% discount rate; cost based on NPV calculation; option by option approach	yes, by including options	switch to gas for trucks, taxis and buses	2010	Rodriguez & Gonzales (2000)	Methodology developed by UNEP for the Abatement Costing Studies was followed
Colombia	no							World Bank (2000)	
Brazil	yes	yes, several based on SRES A2 and B2	vehicles, fuels, efficiency	unclear	yes, by assuming different policy scenarios	flex-fuel vehicles, efficiency gains and biodiesel for private vehicles and heavy duty	2010, 2015, 2020	CCAP (2006)	Unclear how abatement costs are calculated Sensitivity for oil prices is discussed
Argentina	yes	yes	only fuel mix	unclear	yes	increased use of CNG in public passenger and cargo transport; modal shift; hydrogen	2015 (not completely clear)	World Bank (1999)	LEAP model is used, all GHGs;
Peru	yes	overall emission baseline	not reported	unclear	no	ethanol blend, BRT	2008-2012	CONAM (2003)	This the summary of the Nation Strategy Study, full report not found. RICE-99 model used.
Bolivia	yes	yes for fuel mix	only fuel mix	unclear	yes	fuel switch to CNG	2008-12, 2020, 2030	Hanna et al (2000)	LEAP used

Note: 'Bottom-up data' refers to whether the study reported (detailed) data on fuel mixes and vehicles composition, historically and projected

Appendix B Economic growth, transport demand , transport performance

Nearly all data available suggest that personal income and traffic volume grow in tandem (see Figure B.1 and B.2). As average income increases, the annual distance traveled by car, bus, train or aircraft rises by roughly the same proportion. The average North American earned $ 9600 and traveled 12,000 km in 1960. By 1990 both per capita income and traffic had approximately doubled (Schäfer and Victor, 2000). In the EU, passenger transport volumes have grown in most Member States, largely following GDP. Relative decoupling, i.e. a transport growth income growth ratio lower than 1, has been achieved in only some of the new EU Member States (EU-10). It is however likely that with time the development in the EU-10 will show the same trends as the older member states (EEA, 2006). As a result of the strong increase in private car use and aviation, public transport generally shows a decoupling with increasing GDP over the past decades (Figure B.1). In developing countries the decoupling between increasing income and passenger transport is less tight, partly because of the shift from non-motorized to motorized transport. This is visible for some regions in Figure B.2. Most explicitly some African regions do not fit in the trend.

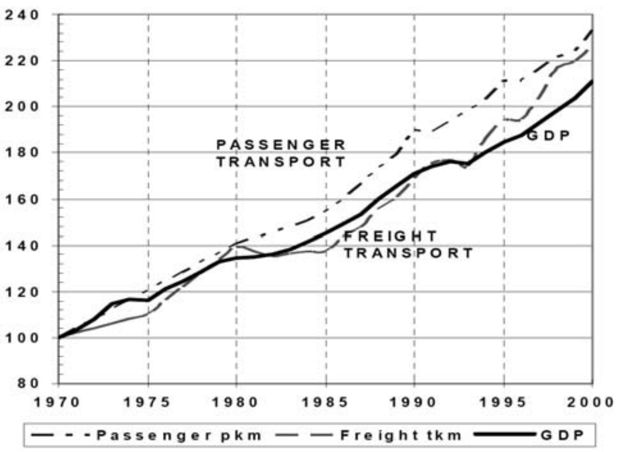

Figure B.1 *Trends of GDP and Transport Activity in the EU, 1970-2000*

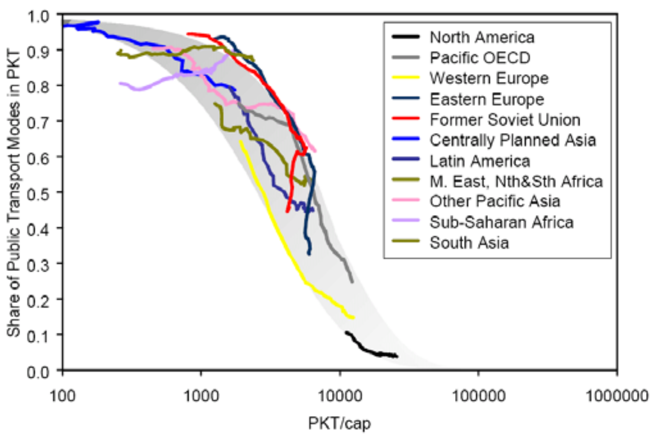

Figure B.2 *Global public transport trends as a function of income*
Source: Schäfer, 2005.

Appendix C Valuation of costs and benefits methodology[15]

In valuing costs and benefits of different CO_2 abatement options a distinction between three different concepts of costs can be made:
a) National economic perspective
b) Private end user perspective
c) Social perspective

Brief descriptions of different perspectives, their main assumptions and differences between their cost calculations are discussed below.

Economic Perspective
Calculation of costs and benefits from a national economic perspective refers to costs and benefits that an option involves for a country as a whole. The costs of energy and the benefits of energy savings are calculated based on international trading prices of the energy sources involved. Taxes, subsidies and levies are not included in the calculations as they are perceived as money flows within the country and not costs or benefits. Implementation costs of certain policies are governmental costs and thus they are considered as a part of the national costs. Costs of CO_2 emissions (i.e. damage cost due to climate change) are highly uncertain and not taken into account as these are common to all options and thus do not provide additional information. In addition the CO_2 costs reflect global environmental costs and thus they are out of the spatial boundaries of the study and consequently cannot be taken into account from a national and social point of view. The discount rate usually assumed for national investments is about 3-5%.

Private Perspective
Financial costs and benefits refer to the costs (and benefits) that individuals, investors and sectors consider during the investment decision making process. To estimate the private costs, there are some assumptions that differ from the assumptions made for the calculation of national costs. Normally the discount rate that is assumed from an investor's financial perspective is higher and depends on the average cost of capital in different sectors. A value in the range of 6-10% discount rate is often assumed for private investments. Another main difference in comparison of the assumptions taken from a national point of view is the fact that all fiscal incentives (e.g. subsidies, tax reductions, soft loans, taxes, feed in tariffs) are taken into consideration as they have direct impact on the end user prices.

Social Perspective
The impact of a project to the society as a whole should be considered when calculations of costs and benefits of a project are estimated from a social point of view. The main difference between calculation of social costs and economic costs are the so called 'external' costs. External costs (and benefits) or 'externalities' - which can be positive or negative - are the impacts that arise from an activity or project and affect members of society but are not accounted for in the economic or private analysis (mainly because those costs caused are not adequately internalised into market prices). While performing social costs assessment of GHG abatement technologies, external costs should be included in the calculations. Important relevant externalities are health damage due to air pollution and energy supply security (Egenhofer et al., 2006).Regarding carbon costs, as was mentioned before, they express global environmental external costs and as the geographical scale of the analysis is at the EU level, global externalities and thus climate change external costs will not taken into account. The social discount rate used can be similar to those applied in the economic analysis (3-5 %).

[15] This appendix is an adapted version of the cost concept discussion in Bakker et al. (2009).

Appendix D TEMPO Transport model

ECN's transport model TEMPO (Transport Emissions Model for POlicy evaluation; Uyterlinde et al, 2009) determines the energy use and CO_2 emissions of the road transport sector based on several data inputs, including (anticipated) amount of kilometers driven (so-called transport performance). By comparing scenarios with different staring points, it is possible to determine the impact of certain measures on the emissions and energy use of the sector. In the model, road transport is divided into a number of categories, including passenger cars, delivery vans, buses, trucks and lorries. Per category a further subdivision is made according to the primary fuel (gasoline, diesel or LPG). To enable calculations of future scenarios, advanced drive-train technologies or alternative fuels have been added to the model, including hydrogen fuel cell cars, electric vehicles, and (plug-in) hybrid versions for gasoline and diesel. Figure D.1 provides a schematic overview of the model.

Development of the car fleet
Starting with the historical fleet composition, the model determines the future composition of the future car fleet via 5 year cycles. To this end, the most recent car fleet composition, per category (e.g. passenger cars on petrol), will be aged five years older, which will also lead to the omission of part of these cars. In the next step, the number of new cars required is determined, which, combined with the original dated fleet, are needed to achieve the desired future transport performance. The market shares per scenario then determine the distribution of new cars over new technologies. This way, a technology can be introduced in a realistic manner, indicating from which segment of the market it must be extracted.

Determining energy use and emissions
Every year, the standard energy use per type of vehicle is determined for a technology/fuel. This consumption is then adjusted. The first adjustment is related to a number of scenario-specific exogenously defined efficiency improvements, which will be required, for example, to meet the current EU standards (e.g. passenger cars: 130 gCO_2/km in 2015). This could also include expected efficiency improvements resulting from more efficient driving. Secondly, consumption is also corrected for the present share of the three above-mentioned saving technologies based on the assumed saving percentages. The emissions are derived directly from fuel consumption.

Cost calculations
Per scenario the annual costs are determined. Currently, this has only been done for the (additional) costs of the car fleet and the total fuel costs.

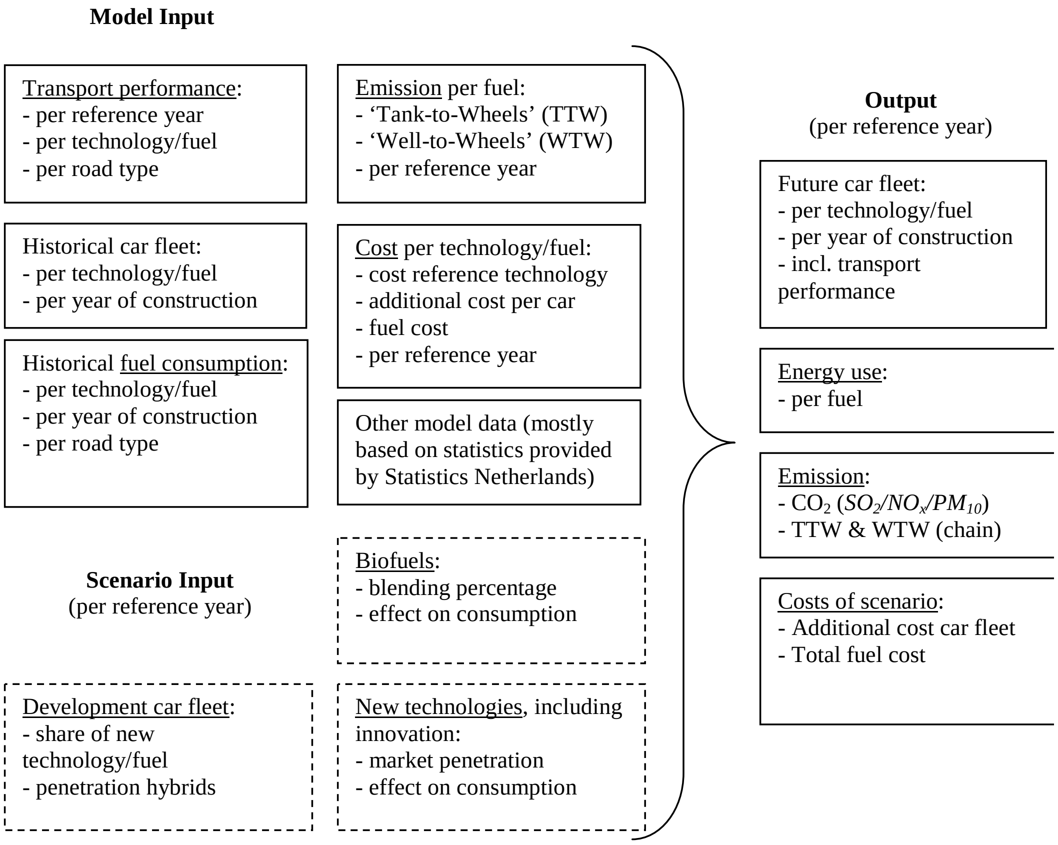

Figure D.1 *Schematic overview ECN's transport model TEMPO*

Appendix E Collection of figures

This appendix includes figures and examples of how data input for a mitigation study could be derived.

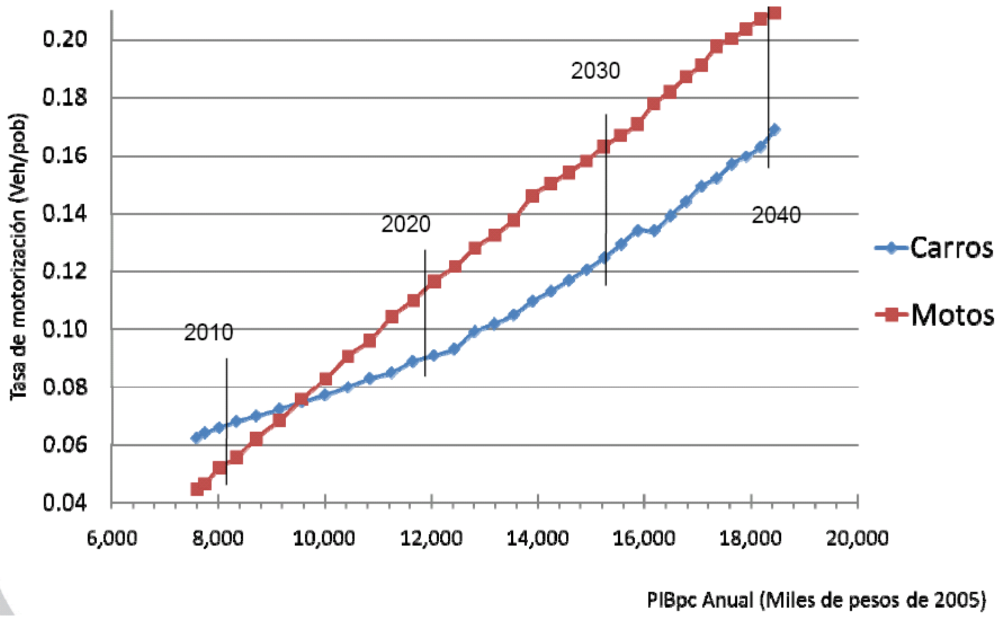

Figure E.1 *Ownership of passenger cars and motorised 2-wheelers as a function of income*
Source: UDLA, 2008.

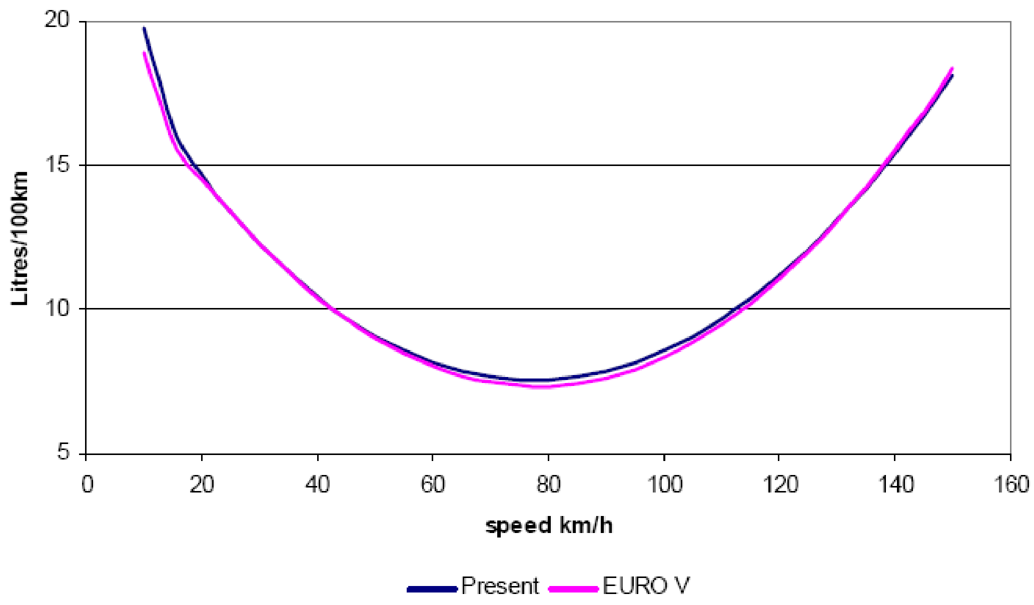

Figure E.2 *Average fuel consumption curve for the European car park at present and assuming a full implementation of the EURO V directive*
Source: Petersen et al, 2009.